NIKOLA TESLA

1856 – 1943

NIKOLA TESLA

LECTURES ♦ PATENTS ♦ ARTICLES

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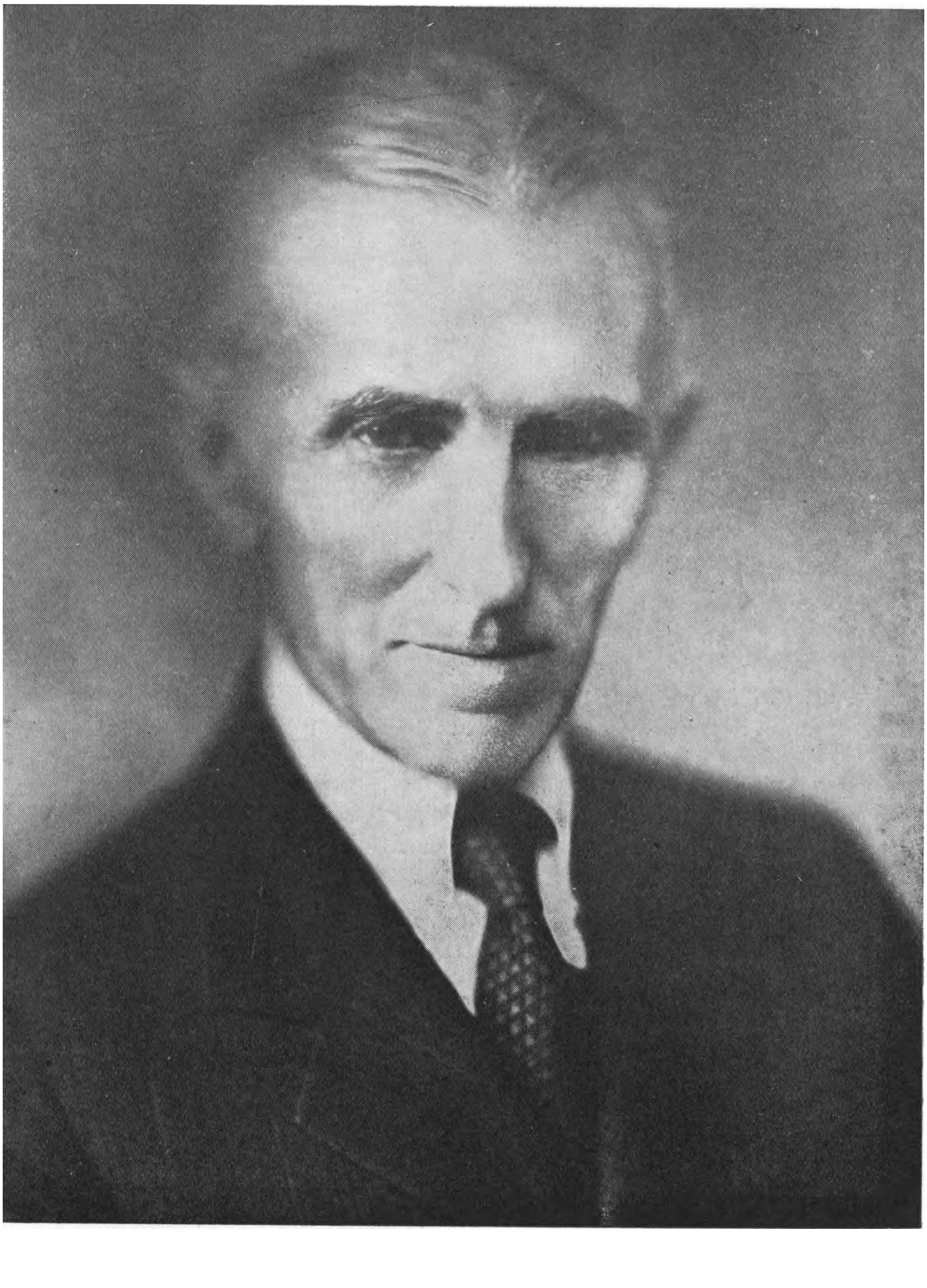
The Yugoslav National Committee for the Celebration of the Centennial Birthday of Nikola Tesla and the Nikola Tesla Museum in Beograd consider the publishing of Nikola Tesla's scientific works to be an honourable obligation to this great scientist and inventor, to science and humanity. The lucky circumstance that, according to Tesla's will, his entire works have been collected in the Nikola Tesla Museum in Beograd, has made the carrying out of this task much easier. Unfortunately, we have not at our disposal one part of Nikola Tesla's documents, the part regarding the first period of his creative activity, which were lost when his laboratory was destroyed by fire. Among the documents at our disposal, a large part could not yet be examined. The documents chosen for this book are published not only as a precious evidence of Tesla's important scientific work, which constitutes one of the bases of contemporary electrical engineering, but they also provide a worthy signpost for the present and future generations of inventors in all fields of science and technics, in which such great results were achieved by Nikola Tesla.

The President
of the Yugoslav National Committee
for the Celebration of the Centennial
Birthday of Nikola Tesla,

Rodoljub Čolaković



Nikola Tesla

INTRODUCTION

Nikola Tesla was born at Smiljan, Province of Lika, in Yugoslavia on July 10, 1856. From 1862 to 1874 he attended elementary and lower secondary school at Smiljan and Gospić, and high secondary one at Karlovac. From 1875 to 1878 he attended the Advanced Technical School at Graz and finished his studies at the University of Prague in 1880.

From the year 1876, when a student in Graz, Tesla was interested in the construction of a motor without commutator. In February 1882, in Budapest, he discovered the principle of the rotating magnetic field. In 1883, at Strasbourg, he made the first models of induction motors. The following year, Tesla left for the United States of America where he worked in Edison Laboratory for a short period of time; later, in 1885, he founded the enterprise "Tesla Arc Light Company" in New York. After founding the enterprise "Tesla Electric Company" in 1887, Tesla was able to obtain the necessary financial and material resources that were needed for the realization of his invention of the polyphase system of the transmission of power and for induction motors of high-grade efficiency.

After taking out the original patents for the asynchronous motor and the polyphase system for the transmission of electric power on October 12, 1887, Tesla took out a further series of 40 patents within the same field from 1887 to 1891. Tesla's polyphase system of power transmission was applied in 1891 at the hydroelectric power station at the Niagara Falls, the first three aggregates of which began to operate in 1896 with a total amount of 15,000 horsepower.

In the second half of 1890, Tesla started to work in the field of high frequency currents by building machine generators with a frequency of up to approximately 30 kc/s. In 1891 he invented a transformer for the production of currents of high frequency and of high tension, which later became known as "The Tesla transformer". Tesla explained the results achieved in the field of high frequency currents in his famous lectures which were held in the period between 1891 and 1893. Work in this field was interrupted temporarily owing to a fire in Tesla's laboratory on March 13, 1895.

After the erection of a new laboratory in 1896, Tesla resumed his work once again, and from 1896 to 1914 he published a series of new inventions which are the fountainhead for contemporary radio technics. The discovery of the four tuned circuits system, which is the basis of radio transmission, is of particular importance here. The construction of a large radio station of 200 kW in Colorado, during 1899, enabled Tesla to apply the principles and ideas set forth in his lectures in 1892 and 1893.

In the spring of 1898, Tesla constructed a radio-guided ship model, and, on July 1, 1898, he took out a patent dealing with the remote control by radio of moving vessels and vehicles. By this invention, he laid the basis for wireless telemechanics. He displayed the results of his work in the article entitled “The Problem of Increasing Human Energy”, published in June 1900.

With these extremely important discoveries and inventions, Tesla occupies one of the outstanding places in the history of modern sciences and technics. For his scientific accomplishments, Nikola Tesla received worthy and esteemed recognition from many distinguished scientific institutions, from reknown fellow scientists throughout the world. He was presented with doctor’s degrees from the following universities:

Sorbonne (Paris), Columbia, Vienna, Prague, Beograd, Zagreb, Yale, Nebraska, Grenoble, Brno, Bucharest, Graz, Poitiers, Sofia, etc.

He died in New York on January 7, 1943, where he had spent the longest period of his life.

*

The purpose of this book is to acquaint the reader with Nikola Tesla’s most important works in the numerous fields of science to which he dedicated himself. Following Tesla’s example, who published his inventions in lectures held at various scientific institutions, who took out numerous patents for his inventions during the course of his life, and who wrote articles in various newspapers and magazines, the book contains three parts: lectures, patents and articles.

The first part of the book contains five of the most important lectures of Nikola Tesla in chronological order. Of primary importance is the classical lecture: “A New System of Alternate Current Motors and Transformers”, held at The American Institute of Electrical Engineers, on May 16, 1888, in which Tesla explained the principle of his famous induction motor. Other important lectures herein included are: “Experiments with Alternate Currents of very High-Frequency and their Application to Methods of Artificial Illumination”, read before The American Institute of Electrical Engineers on May 20, 1891; “Experiments with Alternate Currents of High Potential and High Frequency” delivered before The Institute of Electrical Engineers and at The Royal Institute in London, as well as at The International Association of Electricians in Paris, on February 3, 4 and 19, 1892 respectively; “On Light and other High-Frequency Phenomena”, held at The Franklin Institute in Philadelphia on February 24, 1893, and repeated before the American National Electric Light Association at Saint Louis in March of the same year. In these lectures, Tesla explained his achievements in the field of high frequencies and high voltages. This part of the book ends with the lecture; “High-Frequency Oscillators for Electro-therapeutic and other Purposes”, held before The American Electro-Therapeutic Association at Buffalo, on September 13, 1898.

The second part of the book deals with Nikola Tesla’s patents, selected from the numerous patents registered at the Patent Office of the United States of America. These patents are divided into select groups, each of the groups being arranged according to the order of registration. The first group numbers 25 patents for electrical motors and generators, while the second group consists of 9 patents for electric power transmission. Then follows a group of 6 patents for the solving of certain problems of lighting; then 17 patents for controllers and high frequency apparatus and a group of 12 patents from the field of radio-technics. After listing the important patent for radio-control and a group of 5 patents for turbines and similar apparatus, this part of the book ends with a group of 11 patents for the solution of various problems in which Tesla was interested.

The third part of the book, which contains a cross section of Nikola Tesla's scientific and technical articles, is also divided into select groups. Tesla's articles are given in the order of their publication. The first group consists of 17 articles dealing with Tesla's work on X-ray, Tesla's oscillator, high frequency currents, electric machines, electric discharge in tubes, and ends with an article on telephotography. The second group of this part deals with 8 articles concerning Tesla's views about the world, his opinions about the future of electricity, wherein he discussed technical as well as general problems, which are of interest for humanity. This part ends with Tesla's own biographical sketch.

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LECTURES

1

A NEW SYSTEM OF ALTERNATE CURRENT MOTORS AND TRANSFORMERS *

I desire to express my thanks to Professor Anthony for the help he has given me in this matter. I would also like to express my thanks to Mr. Pope and Mr. Martin for their aid. The notice was rather short, and I have not been able to treat the subject so extensively as I could have desired, my health not being in the best condition at present. I ask your kind indulgence, and I shall be very much gratified if the little I have done meets your approval.

In the presence of the existing diversity of opinion regarding the relative merits of the alternate and continuous current systems, great importance is attached to the question whether alternate currents can be successfully utilized in the operation of motors. The transformers, with their numerous advantages, have afforded us a relatively perfect system of distribution, and although, as in all branches of the art, many improvements are desirable, comparatively little remains to be done in this direction. The transmission of power, on the contrary, has been almost entirely confined to the use of continuous currents, and notwithstanding that many efforts have been made to utilize alternate currents for this purpose, they have, up to the present, at least as far as known, failed to give the result desired. Of the various motors adapted to be used , on alternate current circuits the following have been mentioned: 1. A series motor with subdivided field. 2. An alternate current generator having its field excited by continuous currents. 3. Elihu Thomson's motor. 4. A combined alternate and continuous current motor. Two more motors of this kind have suggested themselves to me. 1. A motor with one of its circuits in series with a transformer and the other in the secondary of the transformer. 2. A motor having its armature circuit connected to the generator and the field coils closed upon themselves. These, however, I mention only incidentally.

The subject which I now have the pleasure of bringing to your notice is a novel system of electric distribution and transmission of power by means of alternate currents, affording peculiar advantages, particularly in the way of motors, which I am confident will at once establish the superior adaptability of these currents to the transmission of power and will show that many results heretofore unattainable can be reached by their use; results which are very much desired in the practical operation of such systems and which cannot be accomplished by means of continuous currents.

Before going into a detailed description of this system, I think it necessary to make a few remarks with reference to certain conditions existing in continuous current generators and motors, which, although generally known, are frequently disregarded.

In our dynamo machines, it is well known, we generate alternate currents which we direct by means of a commutator, a complicated device and, it may be justly said, the source of most of the troubles experienced in the operation of the machines. Now,

* Read before the American Institute of Electrical Engineers, May 16, 1888.

the currents so directed cannot be utilized in the motor, but they must — again by means of a similar unreliable device — be reconverted into their original state of alternate currents. The function of the commutator is entirely external, and in no way does it affect the internal working of the machines. In reality, therefore, all machines are alternate current machines, the currents appearing as continuous only in the external circuit during their transit from generator to motor. In view simply of this fact, alternate currents would commend themselves as a more direct application of electrical energy, and the employment of continuous currents would only be justified if we had dynamos which would primarily generate, and motors which would be directly actuated by such currents.

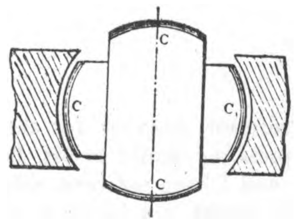

Fig. 1.

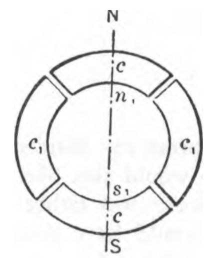

Fig. la.

But the operation of the commutator on a motor is twofold; firstly, it reverses the currents through the motor, and secondly, it effects, automatically, a progressive shifting of the poles of one of its magnetic constituents. Assuming, therefore, that both of the useless operations in the system, that is to say, the directing of the alternate currents on the generator and reversing the direct currents on the motor, be eliminated, it would still be necessary, in order to cause a rotation of the motor, to produce a progressive shifting of the poles of one of its elements, and the question presented itself, — How to perform this operation by the direct action of alternate currents? I will now proceed to show how this result was accomplished.

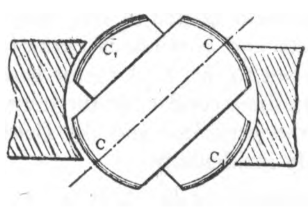

Fig. 2.

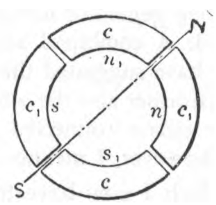

Fig. 2a.

In the first experiment a drum-armature was provided with two coils at right angles to each other, and the ends of these coils were connected to two pairs of insulated contact-rings as usual. A ring was then made of thin insulated plates of sheet-iron and wound with four coils, each two opposite coils being connected together so as to produce free poles on diametrically opposite sides of the ring. The remaining free ends of the coils were then connected to the contact-rings of the generator armature so as to form two independent circuits, as indicated in figure 9. It may now be seen what results were secured in this combination, and with this view I would refer to the diagrams, figures 1 to 8*a.* The field of the generator being independently excited, the rotation of the armature sets up currents in the coils C C, varying in strength and direction in the well-known manner. In the position shown in figure 1 the current in coil C is nil while coil C_1 is traversed by its maximum current, and the connections my be such that the ring is magnetized by the coils c_1 c_1 as indicated by the letters N S in figure *1a,* the magnetizing effect of the coils *c c* being nil, since these coils are included in the circuit of coil C.

In figure 2 the armature coils are shown in a more advanced position, one-eighth of one revolution being completed. Figure 2*a* illustrates the corresponding magnetic condition of the ring. At this moment the coil c_1 generates a current of the same direction as previously, but weaker, producing the poles n_1 s_1 upon the ring; the coil c also generates a current of the same direction, and the connections may be such that the coils *c c* produce the poles *n s,* as shown in figure *2a.* The resulting polarity is indicated by the letters N S, and it will be observed that the poles of the ring have been shifted one-eighth of the periphery of the same.

In figure 3 the armature has completed one-quarter of one revolution. In this phase the current in coil C is maximum, and of such direction as to produce the poles N S in

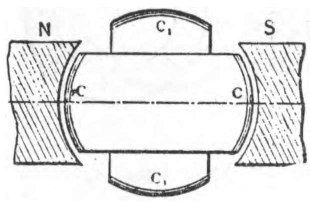

Fig. 3.

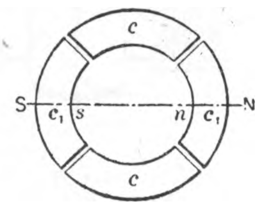

Fig. 3a.

figure 3*a,* whereas the current in coil C_1 is nil, this coil being at its neutral position. The poles N S in figure 3*a* are thus shifted one-quarter of the circumference of the ring.

Figure 4 shows the coils C C in a still more advanced position, the armature having completed three-eighths of one revolution. At that moment the coil C still generates a current of the same direction as before, but of less strength, producing the comparatively weaker poles *n s* in figure *4a*. The current in the coil C_1 is of the same strength, but of opposite direction. Its effect is, therefore, to produce upon the ring the poles n_1 and as indicated, and a polarity, N S, results, the poles now being shifted three-eighths of the periphery of the ring.

In figure 5 one-half of one revolution of the armature is completed, and the resulting magnetic condition of the ring is indicated in figure 5*a*. Now, the current in coil C is nil, while the coil C_1 yields its maximum current, which is of the same direction as

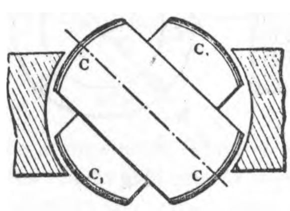

Fig. 4.

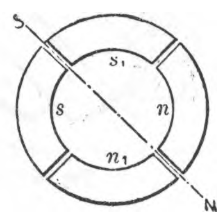

Fig. 4a.

previously; the magnetizing effect is, therefore, due to the coils c_1 c_1 alone, and, referring to figure 5*a,* it will be observed that the poles N S are shifted one-half of the circumference of the ring. During the next half revolution the operations are repeated, as represented in the figures 6 to 8*a.*

A reference to the diagrams will make it clear that during one revolution of the armature the poles of the ring are shifted once around its periphery, and each revolution producing like effects, a rapid whirling of the poles in harmony with the rotation of the armature is the result. If the connections of either one of the circuits in the ring are reversed, the shifting of the poles is made to progress in the opposite direction, but the operation is identically the same. Instead of using four wires, with like result, three wires may be used, one forming a common return for both circuits.

This rotation or whirling of the poles manifests itself in a series of curious phenomena. If a delicately pivoted disc of steel or other magnetic metal is approached to the ring it is set in rapid rotation, the direction of rotation varying with the position of the disc. For instance, noting the direction outside of the ring it will be found that inside the ring it turns in an opposite direction, while it is unaffected if placed in a

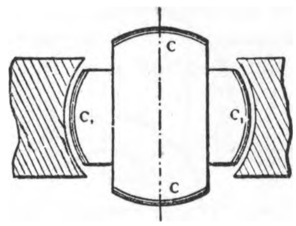

Fig. 5.

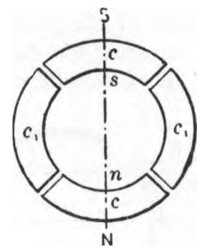

Fig. 5a.

position symmetrical to the ring. This is easily explained. Each time that a pole approaches it induces an opposite pole in the nearest point on the disc, and an attraction is produced upon that point; owing to this, as the pole is shifted further away from the disc a tangential pull is exerted upon the same, and the action being constantly repeated, a more or less rapid rotation of the disc is the result. As the pull is exerted mainly upon that part which is nearest to the ring, the rotation outside and inside, or right and left, respectively, is in opposite directions, figure 9. When placed symmetrically to the ring, the pull on opposite sides of the disc being equal, no rotation results. The action is based on the magnetic inertia of the iron; for this reason a disc of hard steel is much more affected than a disc of soft iron, the latter being capable of very rapid variations of magnetism. Such a disc has proved to be a very useful instrument in all these investi-

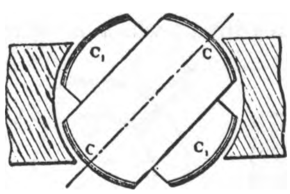

Fig. 6.

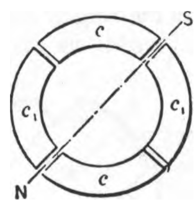

Fig.6a.

gations, as it has enabled me to detect any irregularity in the action. A curious effect is also produced upon iron filings. By placing some upon a paper and holding them externally quite close to the ring they are set in a vibrating motion, remaining in the same place, although the paper may be moved back and forth; but in lifting the paper to a certain height which seems to be dependent on the intensity of the poles and the speed of rotation, they are thrown away in a direction always opposite to the supposed movement of the poles. If a paper with filings is put flat upon the ring and the current turned on suddenly, the existence of a magnetic whirl may be easily observed.

To demonstrate the complete analogy between the ring and a revolving magnet, a strongly energized electro-magnet was rotated by mechanical power, and phenomena identical in every particular to those mentioned above were observed.

Obviously, the rotation of the poles produces corresponding inductive effects and may be utilized to generate currents in a closed conductor placed within the influence of the poles. For this purpose it is convenient to wind a ring with two sets of superimposed coils forming respectively the primary and secondary circuits, as shown in figure 10. In order to secure the most economical results the magnetic circuit should be completely closed, and with this object in view the construction may be modified at will.

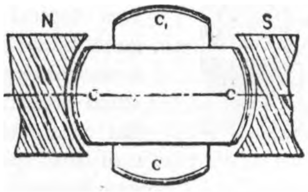

Fig. 7.

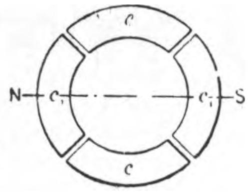

Fig. 7a.

The inductive effect exerted upon the secondary coils will be mainly due to the shifting or movement of the magnetic action; but there may also be currents set up in the circuits in consequence of the variations in the intensity of the poles. However, by properly designing the generator and determining the magnetizing effect of the primary coils the latter element may be made to disappear. The intensity of the poles being maintained constant, the action of the apparatus will be perfect, and the same result will be secured as though the shifting were effected by means of a commutator with an infinite number of bars. In such case the theoretical relation between the energizing effect of each set of primary coils and their resultant magnetizing effect may be expressed by the equation of a circle having its centre coinciding with that of an orthogonal system of axes, and in which the radius represents the resultant and the

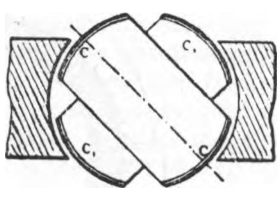

Fig. 8.

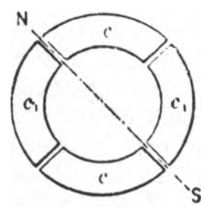

Fig. 8a.

co-ordinates both of its components. These are then respectively the sine and cosine of the angle α between the radius and one of the axes *(O X)*. Referring to figure 1, we have $r^2 = x^2 + y^2$; where $x = r \cos \alpha$, and $y = r \sin \alpha$.

Assuming the magnetizing effect of each set of coils in the transformer to be proportional to the current — which may be admitted for weak degrees of magnetization — then $x = Kc$ and $y = Kc^1$, where K is a constant and c and c^1 the current in both sets of coils respectively. Supposing, further, the field of the generator to be uniform, we have for constant speed $c^1 = K^1 \sin \alpha$ and $c = K^1 \sin (90^\circ + \alpha) = K^1 \cos \alpha$, where K^1 is a constant. See figure 12.

Therefore, $x = Kc = K K^1 \cos \alpha$;

$y = Kc^1 = K K^1 \sin \alpha$, and

$K K^1 = r$.

That is, for a uniform field the disposition of the two coils at right angles will secure the theoretical result, and the intensity of the shifting poles will be constant. But from $r^2 = x^2 + y^2$ it follows that for y = 0, r = x; it follows that the joint magnetizing effect of both sets of coils should be equal to the effect of one set when at its maximum action. In transformers and in a certain class of motors the fluctuation of the poles is not of great importance, but in another class of these motors it is desirable to obtain the theoretical result.

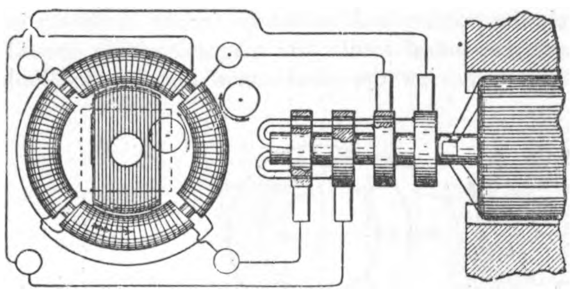

Fig. 9.

In applying this principle to the construction of motors, two typical forms of motor have been developed. First, a form having a comparatively small rotary effort at the start, but maintaining a perfectly uniform speed at all loads, which motor has been termed synchronous. Second, a form possessing a great rotary effort at the start, the speed being dependent on the load.

These motors may be operated in three different ways: 1. By the alternate currents of the source only. 2. By a combined action of these and of induced currents. 3. By the joint action of alternate and continuous currents.

The simplest form of a synchronous motor is obtained by winding a laminated ring provided with pole projections with four coils, and connecting the same in the manner before indicated. An iron disc having a segment cut away on each side may be used as an armature. Such a motor is shown in figure 9. The disc being arranged to rotate freely within the ring in close proximity to the projections, it is evident that as the poles are shifted it will, owing to its tendency to place itself in such a position as to embrace the greatest number of the lines of force, closely follow the movement of the poles, and its motion will be synchronous with that of the armature of the generator; that is, in the peculiar disposition shown in figure 9, in which the armature produces by one revolution two current impulses in each of the circuits. It is evident that if, by one revolution of the armature, a greater number of impulses is produced, the speed of the motor will be correspondingly increased. Considering that the attraction exerted upon the disc is greatest when the same is in close proximity to the poles, it follows that such a motor will maintain exactly the same speed at all loads within the limits of its capacity.

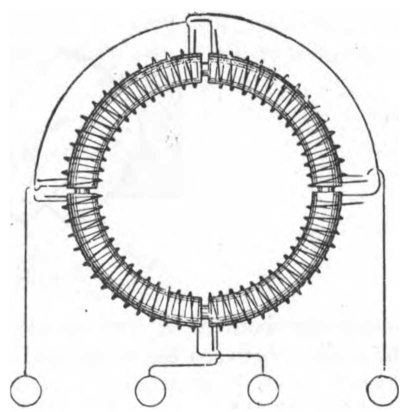

Fig. 10.

To facilitate the starting, the disc may be provided with a coil closed upon itself. The advantage secured by such a coil is evident. On the start the currents set up in the coil strongly energize the disc and increase the attraction exerted upon the same by the ring, and currents being generated in the coil as long as the speed of the armature is inferior to that of the poles, considerable work may be performed by such a motor even if the speed be below normal. The intensity of the poles being constant, no currents will be generated in the coil when the motor is turning at its normal speed.

Instead of closing the coil upon itself, its ends may be connected to two insulated sliding rings, and a continuous current supplied to these from a suitable generator. The proper way to start such a motor is to close the coil upon itself until the normal speed is reached, or nearly so, and then turn on the continuous current. If the disc be very strongly energized by a continuous current the motor may not be able to start, but if it be weakly energized, or generally so that the magnetizing effect of the ring is preponderating it will start and reach the normal speed. Such a motor will maintain absolutely the same speed at all loads. It has also been found that if the motive power of the generator is not excessive, by checking the motor the speed of the generator is diminished in synchronism with that of the motor. It is characteristic of this form of motor that it cannot be reversed by reversing the continuous current through the coil.

The synchronism of these motors may be demonstrated experimentally in a variety of ways. For this purpose it is best to employ a motor consisting of a stationary field magnet and an armature arranged to rotate within the same, as indicated in figure 13. In this case the shifting of the poles of the armature produces a rotation of the latter in the opposite direction. It results therefrom that when the normal speed is reached, the poles of the armature assume fixed positions relatively to the field magnet and the

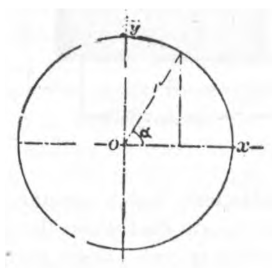

Fig. 11.

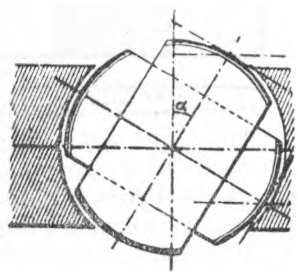

Fig. 12.

same is magnetized by induction, exhibiting a distinct pole on each of the pole-pieces. If a piece of soft iron is approached to the field magnet it will at the start be attracted with a rapid vibrating motion produced by the reversals of polarity of the magnet, but as the speed of the armature increases the vibrations become less and less frequent and finally entirely cease. Then the iron is weakly but permanently attracted, showing that the synchronism is reached and the field magnet energized by induction.

The disc may also be used for the experiment. If held quite close to the armature it will, turn as long as the speed of rotation of the poles exceeds that of the armature; but when the normal speed is reached, or very nearly so, it ceases to rotate and is permanently attracted.

A crude but illustrative experiment is made with an incandescent lamp. Placing the lamp in circuit with the continuous current generator, and in series with the magnet coil, rapid fluctuations are observed in the light in consequence of the induced currents set up in the coil at the start; the speed increasing, the fluctuations occur at longer intervals, until they entirely disappear, showing that the motor has attained its normal speed.

A telephone receiver affords a most sensitive instrument; when connected to any circuit in the motor the synchronism may be easily detected on the disappearance of the induced currents.

In motors of the synchronous type it is desirable to maintain the quantity of the shifting magnetism constant, especially if the magnets are not properly subdivided.

To obtain a rotary effort in these motors was the subject of long thought. In order to secure this result it was necessary to make such a disposition that while the poles of one element of the motor are shifted by the alternate currents of the source, the poles produced upon the other element should always be maintained in the proper relation to the former, irrespective of the speed of the motor. Such a condition exists in a continuous current motor; but in a synchronous motor, such as described, this condition is fulfilled only when the speed is normal.

The object has been attained by placing within the ring a properly subdivided cylindrical iron core wound with several independent coils closed upon themselves. Two

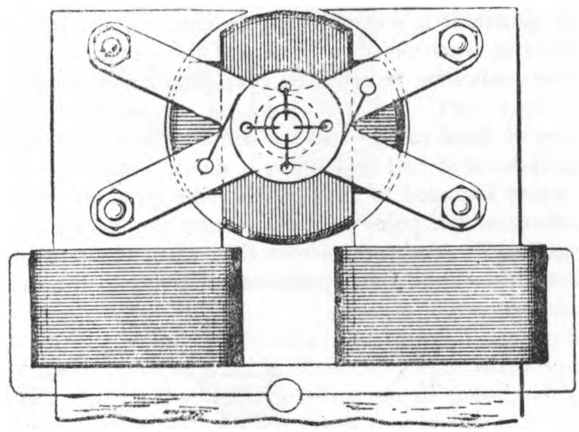

Fig. 13.

coils at right angles as in figure 14, are sufficient, but a greater number may be advantageously employed. It results from this disposition that when the poles of the ring are shifted, currents are generated in the closed armature coils. These currents are the most intense at or near the points of the greatest density of the lines of force, and their effect is to produce poles upon the armature at right angles to those of the ring, at least theoretically so; and since action is entirely independent of the speed — that is, as far as the location of the poles is concerned — a continuous pull is exerted upon the periphery of the armature. In many respects these motors are similar to the continuous current motors. If load is put on, the speed, and also the resistance of the motor, is diminished and more current is made to pass through the energizing coils, thus increasing the effort. Upon the load being taken off, the counter-electromotive force increases and less current passes through the primary or energizing coils. Without any load the speed is very nearly equal to that of the shifting poles of the field magnet.

It will be found that the rotary effort in these motors fully equals that of the continuous current motors. The effort seems to be greatest when both armature and field magnet are without any projections; but as in such dispositions the field cannot be very concentrated, probably the best results will be obtained by leaving pole projections on one of the elements only. Generally, it may be stated that the projections diminish the torque and produce a tendency to synchronism.

A characteristic feature of motors of this kind is their capacity of being very rapidly reversed. This follows from the peculiar action of the motor. Suppose the armature to be rotating and the direction of rotation of the poles to be reversed. The apparatus then represents a dynamo machine, the power to drive this machine being the momentum stored up in the armature and its speed being the sum of the speeds of the armature and the poles. If we now consider that the power to drive such a dynamo would be very nearly proportional to the third power of the speed, for this reason alone the armature should be quickly reversed. But simultaneously with the reversal another element is brought into action, namely, as the movement of the poles with respect to the armature is reversed, the motor acts like a transformer in which the resistance of the secondary circuit would be abnormally diminished by producing in this circuit an additional electromotive force. Owing to these causes the reversal is instantaneous.

If it is desirable to secure a constant speed, and at the same time a certain effort at the start, his result may be easily attained in a variety of ways. For instance, two armatures, one for torque and the other for synchronism, may be fastened on the same shaft, and any desired preponderance may be given to either one, or an armature may be wound for rotary effort, but a more or less pronounced tendency to synchronism may be given to it by properly constructing the iron core; and in many other ways.

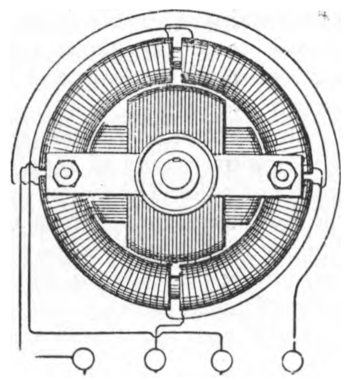

Fig. 14.

As a means of obtaining the required phase of the currents in both the circuits, the disposition of the two coils at right angles is the simplest, securing the most uniform action; but the phase may be obtained in many other ways, varying with the machine employed. Any of the dynamos at present in use may be easily adapted for this purpose by making connections to proper points of the generating coils. In closed circuit armatures, such as used in the continuous current systems, it is best to make four derivations from equi-distant points or bars of the commutator, and to connect the same to four insulated sliding rings on the shaft. In this case each of the motor circuits is connected to two diametrically opposite bars of the commutator. In such a disposition the motor may also be operated at half the potential and on the three-wire plan, by connecting the motor circuits in the proper order to three of the contact rings.

In multipolar dynamo machines, such as used in the converter systems, the phase is conveniently obtained by winding upon the armature two series of coils in such a manner that while the coils of one set or series are at their maximum production of current, the coils of the other will be at their neutral position, or nearly so, whereby both sets of coils may be subjected simultaneously or successively to the inducing action of the field magnets.

Fig. 15. Fig. 16. Fig. 17.

Generally the circuits in the motor will be similarly disposed, and various arrangements may be made to fulfill the requirements; but the simplest and most practicable is to arrange primary circuits on stationary parts of the motor, thereby obviating, at least in certain forms, the employment of sliding contacts. In such a case the magnet coils are connected alternately in both the circuits; that is 1, 3, 5...................... in one, and 2, 4, 6 in the other, and the coils of each set of series may be connected all in the same manner, or alternately in opposition; in the latter case a motor with half the number of poles will result, and its action will be correspondingly modified. The figures 15, 16 and 17, show three different phases, the magnet coils in each circuit being connected alternately in opposition. In this case there will be always four poles, as in figures 15 and 17, four pole projections will be neutral, and in figure 16 two adjacent pole projections will have the same polarity. If the coils are connected in the same manner there will be eight alternating poles, as indicated by the letters n' *s'* in fig. 15.

The employment of multipolar motors secures in this system an advantage much desired and unattainable in the continuous current system, and that is, that a motor may be made to run exactly at a predetermined speed irrespective of imperfections in construction, of the load, and, within certain limits, of electromotive force and current strength.

In a general distribution system of this kind the following plan should be adopted. At the central station of supply a generator should be provided having a considerable number of poles. The motors operated from this generator should be of the synchronous type, but possessing sufficient rotary effort to insure their starting. With the observance of proper rules of construction it may be admitted that the speed of each motor will be in some inverse proportion to its size, and the number of poles should be chosen accordingly. Still exceptional demands may modify this rule. In view of this, it will be advantageous to provide each motor with a greater number of pole projections or coils, the number

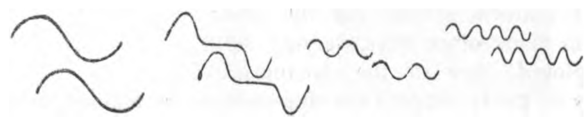

Fig. 18. Fig. 19. Fig. 20. Fig 21.

being preferably a multiple of two and three. By this means, by simply changing the connections of the coils, the motor may be adapted to any probable demands.

If the number of the poles in the motor is even, the action will be harmonious and the proper result will be obtained; if this is not the case the best plan to be followed is to make a motor with a double number of poles and connect the same in the manner before indicated, so that half the number of poles result. Suppose, for instance, that the generator has twelve poles, and it would be desired to obtain a speed equal to $^{12}/_{7}$ of the speed of the generator. This would require a motor with seven pole projections or magnets, and such a motor could not be properly connected in the circuits unless fourteen armature coils would be provided, which would necessitate the employment of sliding contacts. To avoid this the motor should be provided with fourteen magnets and seven connected in each circuit, the magnets in each circuit alternating among themselves. The armature should have fourteen closed coils. The action of the motor will not be quite as perfect as in the case of an even number of poles, but the drawback will not be of a serious nature.

However, the disadvantages resulting from this unsymmetrical form will be reduced in the same proportion as the number of the poles is augmented.

If the generator has, say, n, and the motor n_1 poles, the speed of the motor will be equal to that of the generator multiplied by $\frac{n}{r_1}$.

The speed of the motor will generally be dependent on the number of the poles, but there may be exceptions to this rule. The speed may be modified by the phase of the currents in the circuits or by the character of the current impulses or by intervals between each or between groups of impulses. Some of the possible cases are indicated in the diagrams, figures 18, 19, 20 and 21, which are self-explanatory. Figure 18 represents the condition generally existing, and which secures the best result. In such a case, if the typical form of motor illustrated in figure 9 is employed, one complete wave in each circuit will produce one revolution of the motor. In figure 19 the same result will be effected by one wave in each circuit, the impulses being successive; in figure 20 by four, and in figure 21 by eight waves.

By such means any desired speed may be attained; that is, at least within the limits of practical demands. This system possesses this advantage besides others, resulting from simplicity. At full loads the motors show an efficiency fully equal to that of the continuous current motors. The transformers present an additional advantage in their capability of operating motors. They are capable of similar modifications in construction, and will facilitate the introduction of motors and their adaptation to practical demands. Their efficiency should be higher than that of the present transformers, and I base my assertion on the following:

In a transformer as constructed at present we produce the currents in the secondary circuit by varying the strength of the primary or exciting currents. If we admit proportionality with respect to the iron core the inductive effect exerted upon the secondary coil will be proportional to the numerical sum of the variations in the strength of the exciting current per unit of time; whence it follows that for a given variation any prolongation of the primary current will result in a proportional loss. In order to obtain rapid variations in the strength of the current, essential to efficient induction, a great number of undulations are employed. From this practice various disadvantages result. These are, increased cost and diminished efficiency of the generator, more waste of energy in heating the cores, and also diminished output of the transformer, since the core is not properly utilized, the reversals being too rapid. The inductive effect is also very small in certain phases, as will be apparent from a graphic representation, and there may be periods of inaction, if there are intervals between the succeeding current impulses or waves. In producing a shifting of the poles in the transformer, and thereby inducing currents, the induction is of the ideal character, being always maintained at its maximum action. It is also reasonable to assume that by a shifting of the poles less energy will be wasted than by reversals.

DISCUSSION

Mr. Martin — Professor Anthony, I believe, is here, and as he has given this subject some attention, I think he might very properly supplement Mr. Tesla's paper by some remarks.

Mr. Tesla — I want to express once more my best thanks to Professor Anthony for aiding me in many respects, and I hope he will be able to explain many of the features in this system that I was unable to explain at present.

Professor Anthony — Mr. President and Gentlemen: I have been referred to as having had something to do with these forms of motors. I am very glad to be able to add my testimony to what Mr. Tesla has already given you in regard to their action, and I confess that on first seeing the motors the action seemed to me an exceedingly remarkable one. After my first visit to Mr. Tesla's works, some of the motors, I think these very two that you see here on the table, were brought to me to make some tests of their efficiency, and probably you will be more interested in those than in anything else that I might say. I am sorry I have not brought with me the exact figures that we obtained, but I can give you from memory something of the result. This little motor that you see here gave us about half a horse-power, and gave an efficiency of something above fifty per cent., which I considered a very fair efficiency for a motor of this size, as we cannot expect on such small motors to get as high efficiency as we can on larger ones. This, I believe, is the armature that Mr. Tesla calls the armature for high rotary effort. This little pulley, which is only about three inches in diameter, gave a pull of something like fifty pounds, as I remember it on turning on the current, so that you see the rotary effort is very considerable, and that is also shown in the quickness with which the armature will reverse its motion on reversing the relation of the two currents which pass through the two opposite coils. That could be done by shifting two of the wires, or simply shifting a reversing key in one of the circuits, and the armature would stop and reverse its motion so quickly that it was almost impossible to tell when the change took place. That shows also the very considerable rotary effort that the armature presents. This motor (referring to the second specimen) gave us, I think, about 1¼ h.p., and showed a somewhat higher efficiency than the other — a little over sixty per cent. This would run, with the armature as here constructed, almost at the speed of the generator even under a Very heavy load. When the load was brought up to the maximum load, where the efficiency began to fall off somewhat, the speed of rotation was reduced. As I remember now, it was reduced to about twenty-eight hundred, and the speed, you see, kept up very nearly to that of the generator under heavy load.

I can add very little to what Mr. Tesla has already given you in regard to these motors. I have no question but that all of you would be as much interested as I was in seeing them work. That is really the best way in which to determine what the motors will do.

Mr. Tesla — Mr. President and Gentlemen: Professor Anthony just made the remark that the speed of this motor fell off when the load was increased. That was due to the fact that this armature was designed to secure a strong effort from the start. But if we make an armature which is only designed for synchronism, the speed will always be the same no matter what the load; only there is a disadvantage that at the start the rotary force is so small that it is apt not to start. It would generally start if put in a proper position, but if not put in a proper position it might not start. If we employ an armature consisting of a cut-away block of steel with a coil, it will maintain its speed at all loads. The importance of maintaining the intensity of the pole constant is that if this can be produced we can utilize, instead of the subdivided armature, an ordinary steel block with the same result. It is only desired to close the magnetic field. You can readily see, if the poles are fixed, that it is not necessary to subdivide the armature, if the intensity of the force is constantly maintained the same. But, if the intensity is not maintained the same, then it is necessary to subdivide, and generally in the results that I have obtained I have found that it is necessary to subdivide. I have also observed that in the tests of Professor Anthony the results obtained were superior. I attribute that to the fact that the dynamo has got a powerful field and a small armature and the field is very concentrated, and for that reason probably, the result is nearer a theoretical result.

Professor Thomson — I have been very much interested in the description given by Mr. Tesla of his new and admirable little motor. I have, as probably you may be aware, worked in somewhat similar directions, and towards the attainment of similar ends. The trials which I have made have been by the use of a single alternating current circuit — not a double alternating circuit — a single circuit supplying a motor constructed to utilize the alternation and produce rotation. I have carried on since the last annual meeting of the Institute the development and perfecting, as far as my time allowed, of a closed circuited armature — if we may so term it — related to the alternating field. That is, the plan which I used and which I brought to the notice of the Institute last year, was to make a laminated field and an that field to place an armature also laminated, winding upon the armature a coil which periodically is close circuited during the revolution by a suitable commutator or circuit-closing device. I have made several such motors on different designs and they uniformly start from a state of rest and develop power, and some of them show, at speeds close to the rate of alternations of the dynamo, a tendency to synchronize. Their rotary effort in most cases is a little greater nearer that point than at other points. I hope sometime before a great while to bring most of these results before the notice of the Institute, and I would therefore prefer delaying further remarks on motors of this description. I certainly think there is a field for alternating motors, and there is undoubtedly an opportunity for obtaining motors which possess even some advantages over the continuous current motors.

Mr. Tesla — Gentlemen, I wish to say that the testimony of such a man as Professor Thomson, as being foremost in his profession, flatters me very much. I might say that I have worked in the same line with Professor Thomson at a period when the invention of Professor Thomson was not known to me. I had a motor identically the same as that of Professor Thomson but I was anticipated by him. I believe that although that peculiar form of motor represents the disadvantage that a pair of brushes must be employed to short circuit the armature coil, that such a form of motor may be made practicable for the simple reason that a motor represents a transformer, and such a transformer we well know we can bring to a very high efficiency. On the other hand, the armature may be provided with conductors that are of comparatively low resistance, and it is a mere matter of making a perfect arrangement for short circuiting. You will see the advantage of this disposition of the closed circuit coil — that this action is always maintained at the maximum and it is indeed more perfect than if the polarities were shifted by means of a commutator.

TESLA REPLIES TO DR. LOUIS DUNCAN, EXPLAINING HIS ALTERNATING CURRENT MOTOR

To the Editor of Electrical Review:

I find in your issue of last week a note of Mr. Duncan referring to my system of alternate current motors.

As I see that Dr. Duncan has not as yet been made acquainted with the real character of my invention, I cannot consider his article in the light of a serious criticism and would think it unnecessary to respond; but desiring to express my consideration for him and the importance which I attach to his opinion, I will point out here briefly the characteristic features of my invention, inasmuch as they have a direct bearing on the article above referred to.

The principle of action of my motor will be well understood from the following:

By passing alternate currents in proper manner through independent energizing circuits in the motor, a progressive shifting or rotation of the poles of the same is effected. This shifting is more or less continuous according to the construction of the motor and the character and relative phase of the currents employed, and I have indicated the theoretical conditions which should exist in order to secure the most perfect action.

If a laminated ring be wound with four coils, and the same be connected in proper order to two independent circuits of an alternate current generator adapted for this purpose, the passage of the currents through the coils produces theoretically a rotation of the poles of the ring, and in actual practice in a series of experiments, I have demonstrated the complete analogy between such a ring and a revolving magnet. From the application of this principle to the operation of motors, two forms of motor of a character widely differing have resulted, one designed for constant and the other for variable load. The misunderstanding of Dr. Duncan is due to the fact that the prominent features of each of these two forms have not been specifically stated. In illustration of a representative of the second class, I refer to Fig. 1, on page 1 of ELECTRICAL REVIEW of May 12th. In this instance, the armature of the motor is provided with two coils at right angles. As it may be believed that a symmetrical arrangement of the coils with respect to the poles is required. I will assume that the armature is provided with a great number of diametrically wound coils or conductors closed upon themselves, and forming as many independent circuits. Let it now be supposed that the ring is permanently magnetized so as to show two poles (N and S) at two points diametrically opposite, and that it is rotated by mechanical power. The armature being stationary, the rotation of the ring magnet will set up currents in the closed armature coils. These currents will be most intense at or near the points of the greatest density of the force, and they will produce poles upon the armature core at right angles to those of the ring. Of course there will be other elements entering into action which will tend to modify this, but for the present they may be left unconsidered. As far as the location of the poles upon the armature core is concerned, the currents generated in the armature coils will always act in the same manner, and will maintain continuously the poles of the core in the same position, with respect to those of the ring in any position of the latter and independently of the speed. From the attraction between the core and the ring, a continuous rotary effort, constant in all positions, will result, the same as in a continuous current motor with a great number of armature coils. If the armature be allowed to turn, it will revolve in the direction of rotation of the ring magnet, the induced current diminishing as the speed increases, until upon the armature reaching very nearly the speed of the magnet, just enough current will flow through the coils to keep up the rotation. If, instead of rotating the ring by mechanical power the poles of the same are shifted by the action of the alternate currents in the two circuits, the same results are obtained.

Now compare this system with a continuous current system. In the latter we have alternate currents in the generator and motor coils, and intervening devices for commutating the currents, which on the motor besides effect automatically a progressive shifting or rotation of the poles of the armature; here we have the same elements and identically the same operation, but without the commutating devices. In view of the fact that these devices are entirely unessential to the operation, such alternate current system will — at least in many respects — show a complete similarity with a continuous current system, and the motor will act precisely like a continuous current motor. If the load is augmented the speed is diminished and the rotary effort correspondingly increased, as more current is made to pass through energizing circuits; load being taken off the speed increases and the current, and consequently the effort, is lessened. The effort, of course, is greatest when the armature is in the state of rest.

But since the analogy is complete, how about the maximum efficiency and current passing through the circuits when the motor is running without any load, one will naturally inquire? It must be remembered that we have to deal with alternate currents. In this form the motor simply represents a transformer in which currents are induced by a dynamic action instead of by reversals, and as it might be expected the efficiency will be maximum at full load. As regards the current, there will be — at least under proper conditions — as wide a variation in its strength as in a transformer, and by observing proper rules, it may be reduced to any desired quantity. Moreover, the current passing through the motor when running free, is no measure for the energy absorbed since the instruments indicate only the numerical sum of the direct and induced electro-motive forces and currents instead of showing their difference.

Regarding the other class of these motors, designed for constant speed, the objections of Dr. Duncan are, in a measure, applicable to certain constructions, but it should be considered that such motors are not expected to run without any, or with a very light load, and, if so, they do not, when properly constructed, present in this respect any more disadvantage than transformers under similar conditions. Besides, both features, rotary effort and tendency to constant speed, may be combined in a motor, and any desired preponderance may be given to either one, and in this manner a motor may be obtained possessing any desired character and capable of satisfying all possible demand in practice.

In conclusion, I will remark, with all respect to Dr. Duncan, that the advantages claimed for my system are not mere assumptions, but results actually obtained, and that for this purpose experiments have been conducted through a long period, and with an assiduity such as only a deep interest in the invention could inspire; nevertheless, although my motor is the fruit of long labor and careful investigation, I do not wish to claim any other merit beyond that of having invented, and I leave it to men more competent than myself to determine the true laws of the principle and the best mode of its application. What the result of these investigations will be the future will tell; but whatever they may be and to whatever this principle may lead, I shall be sufficiently recompensed if later it will be admitted that I have contributed a share, however small, to the advancement of science.

NIKOLA TESLA

New York, May 26, 1888.

2

EXPERIMENTS WITH ALTERNATE CURRENTS OF VERY HIGH FREQUENCY AND THEIR APPLICATION TO METHODS OF ARTIFICIAL ILLUMINATION*

There is no subject more captivating, more worthy of study, than nature. To understand this great mechanism, to discover the forces which are active, and the laws which govern them, is the highest aim of the intellect of man.

Nature has stored up in the universe infinite energy. The eternal recipient and transmitter of this infinite energy is the ether. The recognition of the existence of ether, and of the functions it performs, is one of the most important results of modern scientific research. The mere abandoning of the idea of action at a distance, the assumption of a medium pervading all space and connecting all gross matter, has freed the minds of thinkers of an ever present doubt, and, by opening a new horizon — new and unforeseen possibilities — has given fresh interest to phenomena with which we are familiar of old. It has been a great step towards the understanding of the forces of nature and their multifold manifestations to our senses. It has been for the enlightened student of physics what the understanding of the mechanism of the firearm or of the steam engine is for the barbarian. Phenomena upon which we used to look as wonders baffling explanation, we now see in a different light. The spark of an induction coil, the glow of an incandescent lamp, the manifestations of the mechanical forces of currents and magnets are no longer beyond our grasp; instead of the incomprehensible, as before, their observation suggests now in our minds a simple mechanism, and although as to its precise nature all is still conjecture, yet we know that the truth cannot be much longer hidden, and instinctively we feel that the understanding is dawning upon us. We still admire these beautiful phenomena, these strange forces, but we are helpless no longer; we can in a certain measure explain them, account for them, and we are hopeful of finally succeeding in unraveling the mystery which surrounds them.

In how far we can understand the world around us is the ultimate thought of every student of nature. The coarseness of our senses prevents us from recognizing the ulterior construction of matter, and astronomy, this grandest and most positive of natural sciences, can only teach us something that happens, as it were, in our immediate neighborhood; of the remoter portions of the boundless universe, with its numberless stars and suns, we know nothing. But far beyond the limit of perception of our senses the spirit still can guide us, and so we may hope that even these unknown worlds — infinitely small and great — may in a measure become known to us. Still, even if this knowledge should reach us, the searching mind will find a barrier, perhaps forever unsurpassable, to the *true* recognition of that which *seems* to be, the mere *appearance* of which is the only and slender basis of all our philosophy.

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* A lecture delivered before the American Institute of Electrical Engineers, at Columbia College, N. Y., May 20, 1891.

Of all the forms of nature's immeasurable, all-pervading energy, which ever and ever changing and moving, like a soul animates the inert universe, electricity and magnetism are perhaps the most fascinating. The effects of gravitation, of heat and light we observe daily, and soon we get accustomed to them, and soon they lose for us the character of the marvelous and wonderful; but electricity and magnetism, with their singular relationship, with their seemingly dual character, unique among the forces in nature, with their phenomena of attractions, repulsions and rotations, strange manifestations of mysterious agents, stimulate and excite the mind to thought and research. What is electricity, and what is magnetism? These questions have been asked again and again. The most able intellects have ceaselessly wrestled with the problem; still the question has not as yet been fully answered. But while we cannot even to-day state what these singular forces are, we have made good headway towards the solution of the problem. We are now confident that electric and magnetic phenomena are attributable to ether, and we are perhaps justified in saying that the effects of static electricity are effects of ether under strain, and those of dynamic electricity and electro-magnetism effects of ether in motion. But this still leaves the question, as to what electricity and magnetism are, unanswered.

First, we naturally inquire, What is electricity, and is there such a thing as electricity? In interpreting electric phenomena, we may speak of electricity or of an electric condition, state or effect. If we speak of electric effects we must distinguish two such effects, opposite in character and neutralizing each other, as observation shows that two such opposite effects exist. This is unavoidable, for in a medium of the properties of ether, we cannot possibly exert a strain, or produce a displacement or motion of any kind, without causing in the surrounding medium an equivalent and opposite effect. But if we speak of electricity, meaning a *thing,* we must, I think, abandon the idea of two electricities, as the existence of two such things is highly improbable. For how can we imagine that there should be two things, equivalent in amount, alike in their properties, but of opposite character, both clinging to matter, both attracting and completely neutralizing each other? Such an assumption, though suggested by many phenomena, though most convenient for explaining them, has little to commend it. If there *is* such a thing as electricity, there can be only *one* such thing, and, excess and want of that one thing, possibly; but more probably its condition determines the positive and negative character. The old theory of Franklin, though falling short in some respects, is, from a certain point of view, after all, the most plausible one. Still, in spite of this, the theory of the two electricities is generally accepted, as it apparently explains electric phenomena in a more satisfactory manner. But a theory which better explains the facts is not necessarily true. Ingenious minds will invent theories to suit observation, and almost every independent thinker has his own views on the subject.

It is not with the object of advancing an opinion, but with the desire of acquainting you better with some of the results, which I will describe, to show you the reasoning I have followed, the departures I have made — that I venture to express, in a few words, the views and convictions which have led me to these results.

I adhere to the idea that there is a thing which we have been in the habit of calling electricity. The question is, What is that thing? or, What, of all things, the existence of which we know, have we the best reason to call electricity? We know that it acts like an incompressible fluid; that there must be a constant quantity of it in nature; that it can be neither produced nor destroyed; and, what is more important, the electro-magnetic theory of light and all facts observed teach us that electric and ether phenomena are identical. The idea at once suggests itself, therefore, that electricity might be called ether. In fact, this view has in a certain sense been advanced by Dr. Lodge. His interesting work has been read by everyone and many have been convinced by his arguments. His great ability and the interesting nature of the subject, keep the reader spellbound; but when the impressions fade, one realizes that he has to deal only with ingenious explanations. I must confess, that I cannot believe in two electricities, much less in a doubly-constituted ether. The puzzling behavior of the ether as a solid to waves of light and heat, and as a fluid to the motion of bodies through it, is certainly explained in the most natural and satisfactory manner by assuming it to be in motion, as Sir William Thomson has suggested; but regardless of this, there is nothing which would enable us to conclude with certainty that, while a fluid is not capable of transmitting transverse vibrations of a few hundred or thousand per second, it might not be capable of transmitting such vibrations when they range into hundreds of million millions per second. Nor can anyone prove that there are transverse ether waves emitted from an alternate current machine, giving a small number of alternations per second; to such slow disturbances, the ether, if at rest, may behave as a true fluid.

Returning to the subject, and bearing in mind that the existence of two electricities is, to say the least, highly improbable, we must remember, that we have no evidence of electricity, nor can we hope to get it, unless gross matter is present. Electricity, therefore, cannot be called ether in the broad sense of the term; but nothing would seem to stand in the way of calling electricity ether associated with matter, or bound ether; or, in other words, that the so-called static charge of the molecule is ether associated in some way with the molecule. Looking at it in that light, we would be justified in saying, that electricity is concerned in all molecular actions.

Now, precisely what the ether surrounding the molecules is, wherein it differs from ether in general, can only be conjectured. It cannot differ in density, ether being incompressible; it must, therefore, be under some strain or in motion, and the latter is the most probable. To understand its functions, it would be necessary to have an exact idea of the physical construction of matter, of which, of course, we can only form a mental picture.

But of all the views on nature, the one which assumes one matter and one force, and a perfect uniformity throughout, is the most scientific and most likely to be true. An infinitesimal world, with the molecules and their atoms spinning and moving in orbits, in much the same manner as celestial bodies, carrying with them and probably spinning with them ether, or in other words, carrying with them static charges, seems to my mind the most probable view, and one which, in a plausible manner, accounts for most of the phenomena observed. The spinning of the molecules and their ether sets up the ether tensions or electrostatic strains; the equalization of ether tensions sets up ether motions or electric currents, and the orbital movements produce the effects of electro and permanent magnetism.

About fifteen years ago, Prof. Rowland demonstrated a most interesting and important fact, namely, that a static charge carried around produces the effects of an electric current. Leaving out of consideration the precise nature of the mechanism, which produces the attraction and repulsion of currents, and conceiving the electrostatically charged molecules in motion, this experimental fact gives us a fair idea of magnetism. We can conceive lines or tubes of force which physically exist, being formed of rows of directed moving molecules; we can see that these lines must be closed, that they must tend to shorten and expand, etc. It likewise explains in a reasonable way, the most puzzling phenomenon of all, permanent magnetism, and, in general, has all the beauties of the Ampere theory without possessing the vital defect of the same, namely, the assumption of molecular currents. Without enlarging further upon the subject, I would say, that I look upon all electrostatic, current and magnetic phenomena as being due to electrostatic molecular forces.

The preceding remarks I have deemed necessary to a full understanding of the subject as it presents itself to my mind.

Of all these phenomena the most important to study are the current phenomena, on account of the already extensive and evergrowing use of currents for industrial purposes. It is now a century since the first practical source of current was produced, and, ever since, the phenomena which accompany the flow of currents have been diligently studied, and through the untiring efforts of scientific men the simple laws which govern them have been discovered. But these laws are found to hold good only when the currents are of a steady character. When the currents are rapidly varying in strength, quite different phenomena, often unexpected, present themselves, and quite different laws hold good, which even now have not been determined as fully as is desirable, though through the work, principally, of English scientists, enough knowledge has been gained on the subject to enable us to treat simple cases which now present themselves in daily practice.

The phenomena which are peculiar to the changing character of the currents are greatly exalted when the rate of change is increased, hence the study of these currents is considerably facilitated by the employment of properly constructed apparatus. It was with this and other objects in view that I constructed alternate current machines capable of giving more than two million reversals of current per minute, and to this circumstance it is principally due, that I am able to bring to your attention some of the results thus far reached, which I hope will prove to be a step in advance on account of their direct bearing upon one of the most important problems, namely, the production of a practical and efficient source of light.

The study of such rapidly alternating currents is very interesting. Nearly every experiment discloses something new. Many results may, of course, be predicted, but many more are unforeseen. The experimenter makes many interesting observations. For instance, we take a piece of iron and hold it against a magnet. Starting from low alternations and running up higher and higher we feel the impulses succeed each other faster and faster, get weaker and weaker, and finally disappear. We then observe a continuous pull; the pull, of course, is not continuous; it only appears so to us; our sense of touch is imperfect.

We may next establish an arc between the electrodes and observe, as the alternations rise, that the note which accompanies alternating arcs gets shriller and shriller, gradually weakens, and finally ceases. The air vibrations, of course, continue, but they are too weak to be perceived; our sense of hearing fails us.

We observe the small physiological effects, the rapid heating of the iron cores and conductors, curious inductive effects, interesting condenser phenomena, and still more interesting light phenomena with a high tension induction coil. All these experiments and observations would be of the greatest interest to the student, but their description would lead me too far from the principal subject. Partly for this reason, and partly on account of their vastly greater importance, I will confine myself to the description of the light effects produced by these currents.

In the experiments to this end a high tension induction coil or equivalent apparatus for converting currents of comparatively low into currents of high tension is used.

If you will be sufficiently interested in the results I shall describe as to enter into an experimental study of this subject; if you will be convinced of the truth of the arguments I shall advance — your aim will be to produce high frequencies and high potentials; in other words, powerful electrostatic effects. You will then encounter many difficulties, which, if completely overcome, would allow us to produce truly wonderful results.

First will be met the difficulty of obtaining the required frequencies by means of mechanical apparatus, and, if they be obtained otherwise, obstacles of a different nature will present themselves. Next it will be found difficult to provide the requisite insulation without considerably increasing the size of the apparatus, for the potentials required are high, and, owing to the rapidity of the alternations, the insulation presents peculiar difficulties. So, for instance, when a gas is present, the discharge may work, by the molecular bombardment of the gas and consequent heating, through as much as an inch of the best solid insulating material, such as glass, hard rubber, porcelain, sealing wax, etc.; in fact, through any known insulating substance. The chief requisite in the insulation of the apparatus is, therefore, the exclusion of any gaseous matter.

In general my experience tends to show that bodies which possess the highest specific inductive capacity, such as glass, afford a rather inferior insulation to others, which, while they are good insulators, have a much smaller specific inductive capacity, such as oils, for instance, the dielectric losses being no doubt greater in the former. The difficulty of insulating, of course, only exists when the potentials are excessively high, for with potentials such as a few thousand volts there is no particular difficulty encountered in conveying currents from a machine giving, say, 20,000 alternations per second, to quite a distance. This number of alternations, however, is by far too small for many purposes,

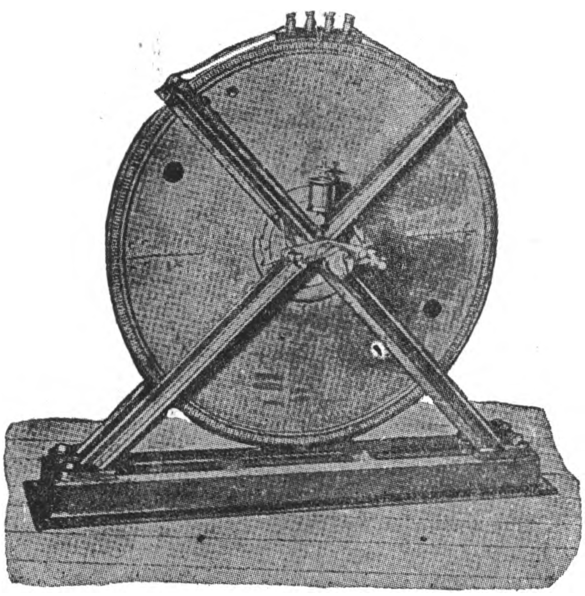


Fig. 1.

though quite sufficient for some practical applications. This difficulty of insulating is fortunately not a vital drawback; it affects mostly the size of the apparatus, for, when excessively high potentials would be used, the light-giving devices would be located not far from the apparatus, and often they would be quite close to it. As the air-bombardment of the insulated wire is dependent on condenser action, the loss may be reduced to a trifle by using excessively thin wires heavily insulated.

Another difficulty will be encountered in the capacity and self-induction necessarily possessed by the coil. If the coil be large, that is, if it contain a great length of wire, it will be generally unsuited for excessively high frequencies; if it be small, it may be well adapted for such frequencies, but the potential might then not be as high as desired. A good insulator, and preferably one possessing a small specific inductive capacity, would afford a two-fold advantage. First, it would enable us to construct a very small coil capable of withstanding enormous differences of potential, and secondly, such a small coil, by reason of its smaller capacity and self-induction, would be capable of a quicker and more vigorous vibration. The problem then of constructing a coil or induction apparatus of any kind possessing the requisite qualities I regard as one of no small importance, and it has occupied me for a considerable time.

The investigator who desires to repeat the experiments which I will describe, with an alternate current machine, capable of supplying currents of the desired frequency, and an induction coil, will do well to take the primary coil out and mount the secondary in such a manner as to be able to look through the tube upon which the secondary is wound. He will then be able to observe the streams which pass from the primary to the insulating tube, and from their intensity he will know how far he can strain the coil. Without this precaution he is sure to injure the insulation. This arrangement permits, however, an easy exchange of the primaries, which is desirable in these experiments.

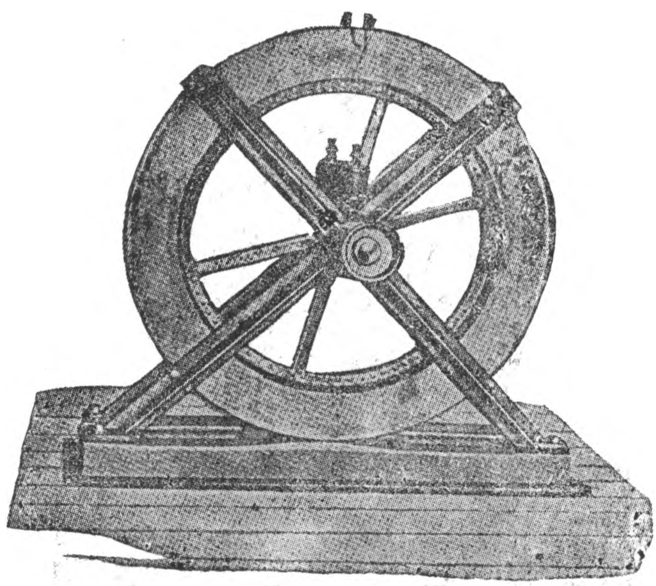


Fig. 2.

The selection of the type of machine best suited for the purpose must be left to the judgment of the experimenter. There are here illustrated three distinct types of machines, which, besides others, I have used in my experiments.

Fig. 1 represents the machine used in my experiments before this Institute. The field magnet consists of a ring of wrought iron with 384, pole projections. The armature comprises a steel disc to which is fastened a thin, carefully welded rim of wrought iron. Upon the rim are wound several layers of fine, well annealed iron wire, which, when wound, is passed through shellac. The armature wires are wound around brass pins, wrapped with silk thread. The diameter of the armature wire in this type of machine should not be more than — of the thickness of the pole projections, else the local action will be considerable.

Fig. 2 represents a larger machine of a different type, The field magnet of this machine consists of two like parts which either enclose an exciting coil, or else are independently wound. Each part has 480 pole projections, the projections of one facing those of the other. The armature consists of a wheel of hard bronze, carrying the conductors which revolve between the projections of the field magnet. To wind the armature conductors, I have found it most convenient to proceed in the following manner. I construct a ring of hard bronze of the required size. This ring and the rim of the wheel are provided with the proper number of pins, and both fastened upon a plate. The armature conductors being wound, the pins are cut off and the ends of the conductors fastened by two rings which screw to the bronze ring and the rim of the wheel, respectively. The whole may then be taken off and forms a solid structure. The conductors in such a type of machine should consist of sheet copper, the thickness of which, of course, depends on the thickness of the pole projections; or else twisted thin wires should be employed.

Fig. 3 is a smaller machine, in many respects similar to the former, only here the armature conductors and the exciting coil are kept stationary, while only a block of wrought iron is revolved.

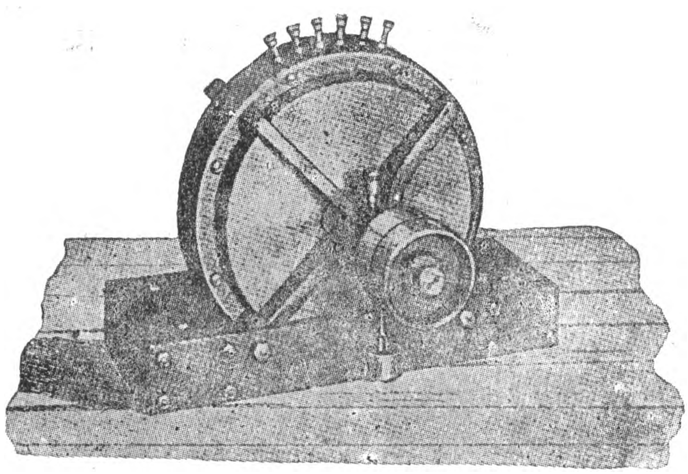


Fig. 3.

It would be uselessly lengthening this description were I to dwell more on the details of construction of these machines. Besides, they have been described somewhat more elaborately in *The Electrical Engineer,* of March 18, 1891. I deem it well, however, to call the attention of the investigator to two things, the importance of which, though self evident, he is nevertheless apt to. underestimate; namely, to the local action in the conductors which must be carefully avoided, and to the clearance, which must be small. I may add, that since it is desirable to use very high peripheral speeds, the armature should be of very large diameter in order to avoid impracticable belt speeds. Of the several types of these machines which have been constructed by me, I have found that the type illustrated in Fig. 1 caused me the least trouble in construction, as well as in maintenance, and on the whole, it has been a good experimental machine.

In operating an induction coil with very rapidly alternating currents, among the first luminous phenomena noticed are naturally those presented by the high-tension discharge. As the number of alternations per second is increased, or as — the number being high — the current through the primary is varied, the discharge gradually changes in appearance. It would be difficult to describe the minor changes which occur, and the conditions which bring them about, but one may note five distinct forms of the discharge.

First, one may observe a weak, sensitive discharge in the form of a thin, feeble-colored thread (Fig. 4a). It always occurs when, the number of alternations per second being high, the current through the primary is very small. In spite of the excessively small current, the rate of change is great, and the difference of potential at the terminals of the secondary is therefore considerable, so that the arc is established at great distances; but the quantity of "electricity" set in motion is insignificant, barely sufficient to maintain a thin, threadlike arc. It is excessively sensitive and may be made so to such a degree that the mere act of breathing near the coil will affect it, and unless it is perfectly well protected from currents of air, it wriggles around constantly. Nevertheless, it is in this

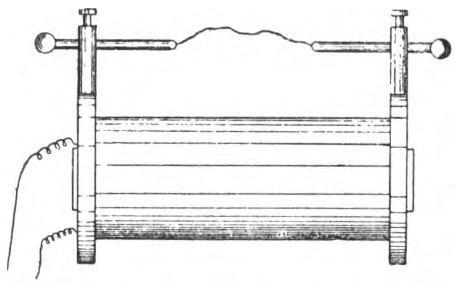


Fig. 4a.

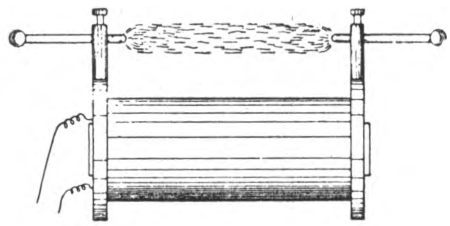


Fig. 4b.

form excessively persistent, and when the terminals are approached to, say, one-third of the striking distance, it can be blown out only with difficulty. This exceptional persistency, when short, is largely due to the arc being excessively thin; presenting, therefore, a very small surface to the blast. Its great sensitiveness, when very long, is probably due to the motion of the particles of dust suspended in the air.

When the current through the primary is increased, the discharge gets broader and stronger, and the effect of the capacity of the coil becomes visible until, finally, under proper conditions, a white flaming arc, Fig. 4b, often as thick as one's finger, and striking across the whole coil, is produced. It develops remarkable heat, and may be further characterized by the absence of the high note which accompanies the less powerful discharges. To take a shock from the coil under these conditions would not be advisable, although under different conditions, the potential being much higher, a shock from the coil may be taken with impunity. To produce this kind of discharge the number of alternations per second must not be too great for the coil used; and, generally speaking, certain relations between capacity, self-induction and frequency must be observed.

The importance of these elements in an alternate current circuit is now well-known, and under ordinary conditions, the general rules are applicable. But in an induction coil exceptional conditions prevail. First, the self-induction is of little importance before the arc is established, when it asserts itself, but perhaps never as prominently as in ordinary alternate current circuits, because the capacity is distributed all along the coil, and by reason of the fact that the coil usually discharges through very great resistances; hence the currents are exceptionally small. Secondly, the capacity goes on increasing continually as the potential rises, in consequence of absorption which takes place to a considerable extent. Owing to this there exists no critical relationship between these quantities, and ordinary rules would not seem to be applicable. As the potential is increased either in consequence of the increased frequency or of the increased current through the primary, the amount of the energy stored becomes greater and greater, and the capacity gains more and more in importance. Up to a certain point the capacity is beneficial, but after that it begins to be an enormous drawback. It follows from this that each coil gives the best result with a given frequency and primary current. A very large coil, when operated with currents of very high frequency, may not give as much as — inch spark. By adding capacity to the terminals, the condition may be improved, but what the coil really wants is a lower frequency.

When the flaming discharge occurs, the conditions are evidently such that the greatest current is made to flow through the circuit. These conditions may be attained by varying the frequency within wide limits, but the highest frequency at which the flaming arc can still be produced, determines, for a given primary current, the maximum striking distance of the coil. In the flaming discharge the *eclat* effect of the capacity is not perceptible; the rate at which the energy is being stored then just equals the rate at which it can be disposed of through the circuit. This kind of discharge is the severest test for a coil; the break, when it occurs, is of the nature of that in an overcharged Leyden jar. To give a rough approximation I would state that, with an ordinary coil of, say, 10,000 ohms resistance, the most powerful arc would be produced with about 12,000 alternations per second.

When the frequency is increased beyond that rate, the potential, of course, rises, but the striking distance may, nevertheless, diminish, paradoxical as it may seem. As the potential rises the coil attains more and more the properties of a static machine until, finally, one may observe the beautiful phenomenon of the streaming discharge, Fig. 5, which may be produced across the whole length of the coil. At that stage streams begin to issue freely from all points and projections. These streams will also be seen to pass in abundance in the space between the primary and the insulating tube. When the potential is excessively high they will always appear, even if the frequency be low, and even if the primary be surrounded by as much as an inch of wax, hard rubber, glass, or any other insulating substance. This limits greatly the output of the coil, but I will later show how I have been able to overcome to a considerable extent this disadvantage in the ordinary coil

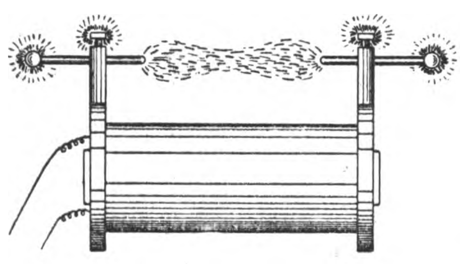


Fig. 5.

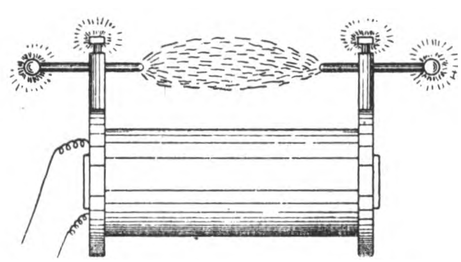


Fig. 6.

Besides the potential, the intensity of the streams depends on the frequency; but if the coil be very large they show themselves, no matter how low the frequencies used. For instance, in a very large coil of a resistance of 67,000 ohms, constructed by me some time ago, they appear with as low as 100 alternations per second and less, the insulation of the secondary being ¾ inch of ebonite. When very intense they produce a noise similar to that produced by the charging of a Holtz machine, but much more powerful, and they emit a strong smell of ozone. The lower the frequency, the more apt they are to suddenly injure the coil. With excessively high frequencies they may pass freely without producing any other effect than to heat the insulation slowly and uniformly.

The existence of these streams shows the importance of constructing an expensive coil so as to permit of one's seeing through the tube surrounding the primary, and the latter should be easily exchangeable; or else the space between the primary and secondary should be completely filled up with insulating material so as to exclude all air.

The non-observance of this simple rule in the construction of commercial coils is responsible for the destruction of many an expensive coil.

At the stage when the streaming discharge occurs, or with somewhat higher frequencies, one may, by approaching the terminals quite nearly, and regulating properly the effect of capacity, produce a veritable spray of small silver-white sparks, or a bunch of excessively thin silvery threads (Fig. 6) amidst a powerful brush — each spark or thread possibly corresponding to one alternation. This, when produced under proper conditions, is probably the most beautiful discharge, and when an air blast is directed against it, it presents a singular appearance. The spray of sparks, when received through the body, causes some inconvenience, whereas, when the discharge simply streams, nothing at all is likely to be felt if large conducting objects are held in the hands to protect them from receiving small burns.

If the frequency is still more increased, then the coil refuses to give any spark unless at comparatively small distances, and the fifth typical form of discharge may be observed (Fig. 7). The tendency to stream out and dissipate is then so great that when the brush is produced at one terminal no sparking occurs, even if, as I have repeatedly tried, the hand, or any conducting object, is held within the stream; and, what is more singular, the luminous stream is not at all easily deflected by the approach of a conducting body.

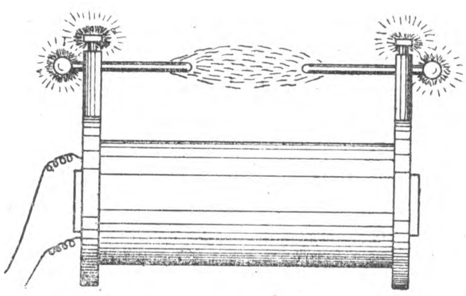


Fig. 7.

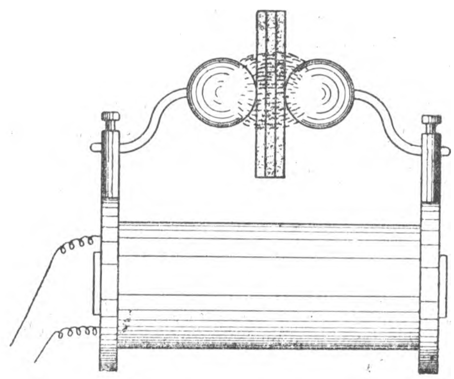


Fig. 8.

At this stage the streams seemingly pass with the greatest freedom through considerable thicknesses of insulators, and it is particularly interesting to study their behavior. For this purpose it is convenient to connect to the terminals of the coil two metallic spheres which may be placed at any desired distance, Fig. 8. Spheres, are preferable to plates, as the discharge can be better observed. By inserting dielectric bodies between the spheres, beautiful discharge phenomena may be observed. If the spheres be quite close and the spark be playing between them, by interposing a thin plate of ebonite between the spheres the spark instantly ceases and the discharge spreads into an intensely luminous circle several inches in diameter, provided the spheres are sufficiently large. The passage of the streams heats, and, after a while, softens, the rubber so much that two plates may be made to stick together in this manner. If the spheres are so far apart that no spark occurs, even if they are far beyond the striking distance, by inserting a thick plate of glass the discharge is instantly induced to pass from the spheres to the glass in the form of luminous streams. It appears almost as though these streams pass *through* the dielectric. In reality this is not the case, as the streams are due to the molecules of the air which are violently agitated in the space between the oppositely charged surfaces of the spheres. When no dielectric other than air is present, the bombardment goes on, but is too weak to be visible; by inserting a dielectric the inductive effect is much increased, and besides, the projected air molecules find an obstacle and the bombardment becomes so intense that the streams become luminous. If by any mechanical means we could effect such a violent agitation of the molecules we could produce the same phenomenon. A jet of air escaping through a small hole under enormous pressure and striking against an insulating substance, such as glass, may be luminous in the dark, and it might be possible to produce a, phosphorescence of the glass or other insulators in this manner.

The greater the specific inductive capacity of the interposed dielectric, the more powerful the effect produced. Owing to this, the streams show themselves with excessively high potentials even if the glass be as much as one and one-half to two inches thick. But besides the heating due to bombardment, some heating goes on undoubtedly in the dielectric, being apparently greater in glass than in ebonite. I attribute this to the greater specific inductive capacity of the glass, in consequence of which, with the same potential difference, a greater amount of energy is taken up in it than in rubber. It is like connecting to a battery a copper and a brass wire of the same dimensions. The copper wire, though a more perfect conductor, would heat more by reason of its taking more current. Thus what is otherwise considered a virtue of the glass is here a defect. Glass usually gives way much quicker than ebonite; when it is heated to a certain degree, the discharge suddenly breaks through at one point, assuming then the ordinary form of an arc.

The heating effect produced by molecular bombardment of the dielectric would, of course, diminish as the pressure of the air is increased, and at enormous pressure it would be negligible, unless the frequency would increase correspondingly.

It will be often observed in these experiments that when the spheres are beyond the striking distance, the approach of a glass plate, for instance, may induce the spark to jump between the spheres. This occurs when the capacity of the spheres is somewhat below the critical value which gives the greatest difference of potential at the terminals of the coil. By approaching a dielectric, the specific inductive capacity of the space between the spheres is increased, producing the same effect as if the capacity of the spheres were increased. The potential at the terminals may then rise so high that the air space is cracked. The experiment is best performed with dense glass or mica.

Another interesting observation is that a plate of insulating material, when the discharge is passing through it, is strongly attracted by either of the spheres, that is by the nearer one, this being obviously due to the smaller mechanical effect of the bombardment on that side, and perhaps also to the greater electrification.

From the behavior of the dielectrics in these experiments, we may conclude that the best insulator for these rapidly alternating currents would be the one possessing the smallest specific inductive capacity and at the same time one capable of withstanding the greatest differences of potential; and thus two diametrically opposite ways of securing the required insulation are indicated, namely, to use either a perfect vacuum or a gas under great pressure; but the former would be preferable. Unfortunately neither of these two ways is easily carried out in practice.

It is especially interesting to note the behavior of an excessively high vacuum in these experiments. If a test tube, provided with external electrodes and exhausted to the highest possible degree, be connected to the terminals of the coil, Fig. 9, the electrodes of the tube are instantly brought to a high temperature and the glass at each end of the tube is rendered intensely phosphorescent, but the middle appears comparatively dark, and for a while remains cool.

When the frequency is so high that the discharge shown in Fig. 7 is observed, considerable dissipation no doubt occurs in the coil. Nevertheless the coil may be worked for a long time, as the heating is gradual.

In spite of the fact that the difference of potential may be enormous, little is felt when the discharge is passed through the body, provided the hands are armed. This is to some extent due to the higher frequency, but principally to the fact that less energy is available externally, when the difference of potential reaches an enormous value, owing to the circumstance that, with the rise of potential, the energy absorbed in the coil increases as the square of the potential. Up to a certain point the energy available externally increases with the rise of potential, then it begins to fall off rapidly. Thus, with the ordinary high tension induction coil, the curious paradox exists, that, while with a given current through the primary the shock might be fatal, with many times that current it might be perfectly harmless, even if the frequency be the same. With high frequencies and excessively high potentials when the terminals are not connected to bodies of some size, practically all the energy supplied to the primary is taken up by the coil. There is no breaking through, no local injury, but all the material, insulating and conducting, is uniformly heated.

To avoid misunderstanding in regard to the physiological effect of alternating currents of very high frequency, I think it necessary to state that, while it is an undeniable fact that they are incomparably less dangerous than currents of low

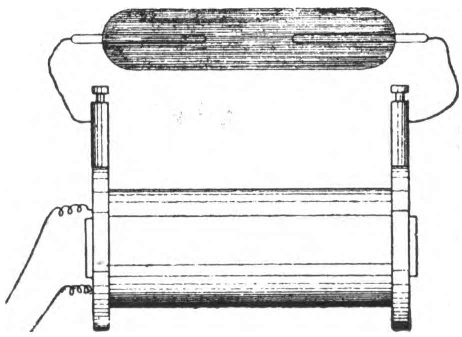


Fig. 9.

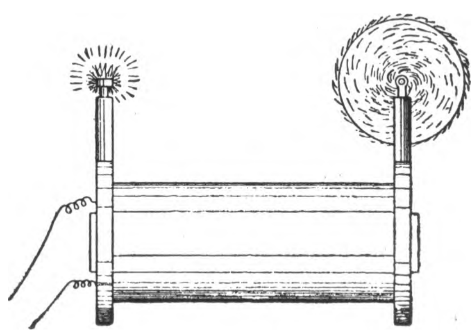


Fig. 10.

frequencies, it should not be thought that they are altogether harmless. What has just been said refers only to currents from an ordinary high tension induction coil, which currents are necessarily very small; if received directly from a machine or from a secondary of low resistance, they produce more or less powerful effects, and may cause serious injury, especially when used in conjunction with condensers.

The streaming discharge of a high tension induction coil differs in many respects from that of a powerful static machine. In color it has neither the violet of the positive, nor the brightness of the negative, static discharge, but lies somewhere between, being, of course, alternatively positive and negative. But since the streaming is more powerful when the point or terminal is electrified positively, than when electrified negatively, it follows that the point of the brush is more like the positive, and the root more like the negative, static discharge. In the dark, when the brush is very powerful, the root may appear almost white. The wind produced by the escaping streams, though it may be very strong — often indeed to such a degree that it may be felt quite a distance from the coil — is, nevertheless, considering the quantity of the discharge, smaller than that produced by the positive brush of a static machine, and it affects the flame much less powerfully. From the nature of the phenomenon we can conclude that the higher the frequency, the smaller must, of course, be the wind produced by the streams, and with sufficiently high frequencies no wind at all would be produced at the ordinary atmospheric pressures.

With frequencies obtainable by means of a machine, the mechanical effect is sufficiently great to revolve, with considerable speed, large pin-wheels, which in the dark present a beautiful appearance owing to the abundance of the streams (Fig. 10).

In general, most of the experiments usually performed with a static machine can be performed with an induction coil when operated with very rapidly alternating currents. The effects produced, however, are much more striking, being of incomparably greater power. When a small length of ordinary cotton covered wire, Fig. 11, is attached to one terminal of the coil, the streams issuing from all points of the wire may be so intense as to produce a considerable light effect. When the potentials and frequencies are very high, a wire insulated with gutta percha or rubber and attached to one of the terminals, appears to be covered with a luminous film. A very thin bare wire when attached to a terminal emits powerful streams and vibrates continually to and fro or spins in a circle, producing a singular effect (Fig. 12). Some of these experiments have been described by me in *The Electrical World,* of February 21, 1891.

Another peculiarity of the rapidly alternating discharge of the induction coil is its radically different behavior with respect to points and rounded surfaces.

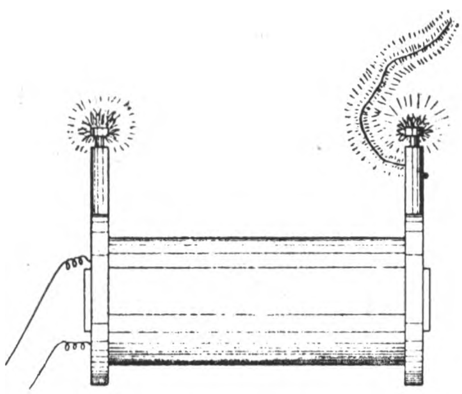


Fig. 11.

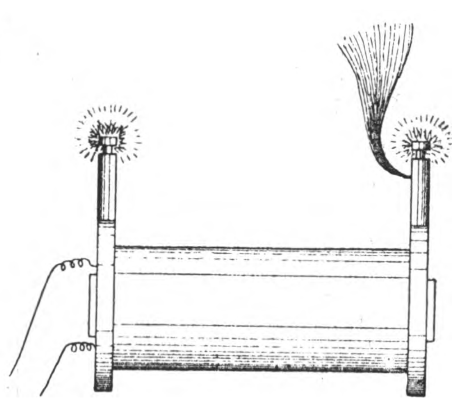


Fig. 12.

If a thick wire, provided with a ball at one end and with a point at the other, be attached to the positive terminal of a static machine, practically all the charge will be lost through the point, on account of the enormously greater tension, dependent on the radius of curvature. But if such a wire is attached to one of the terminals of the induction coil, it will be observed that with very high frequencies streams issue from the ball almost as copiously as from the point (Fig. 13).

It is hardly conceivable that we could produce such a condition to an equal degree in a static machine, for the simple reason, that the tension increases as the square of the density, which in turn is proportional to the radius of curvature; hence, with a steady potential an enormous charge would be required to make streams issue from a polished ball while it is connected with a point. But with an induction coil the discharge of which alternates with great rapidity it is different. Here we have to deal with two distinct tendencies. First, there is the tendency to escape which exists in a condition of rest, and which depends on the radius of curvature; second, there is the tendency to dissipate into the surrounding air by condenser action, which depends on the surface. When one of these tendencies is at a maximum, the other is at a minimum. At the point the luminous stream is principally due to the air molecules coming bodily in contact with the point; they are attracted and repelled, charged and discharged, and, their atomic charges being thus disturbed, vibrate and emit light waves. At the ball, on the contrary, there is no doubt that the effect is to a great extent produced inductively, the air molecules not *necessarily* coming in contact with the ball, though they undoubtedly do so. To convince ourselves of this we only need to exalt the condenser action, for instance, by enveloping the ball, at some distance, by a better conductor than the surrounding medium, the conductor being, of course, insulated; or else by surrounding it with a better dielectric and approaching an insulated conductor; in both cases the streams will break forth more copiously. Also, the larger the ball with a given frequency, or the higher the frequency, the more will the ball have the advantage over the point. But, since a certain intensity of action is required to render the streams visible, it is obvious that in the experiment described the ball should not be taken too large.

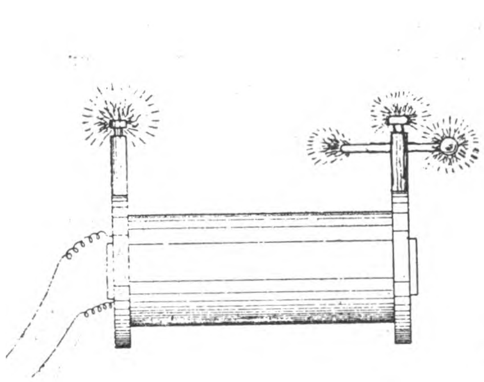


Fig. 13.

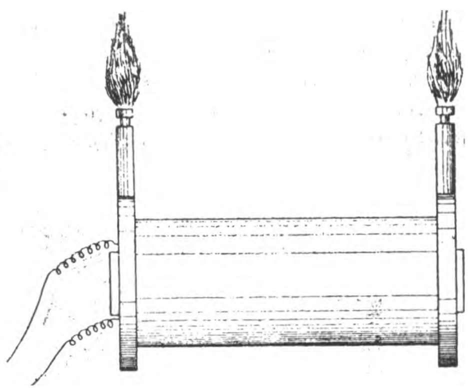


Fig. 14.

In consequence of this two-fold tendency, it is possible to produce by means of points, effects identical to those produced by capacity. Thus, for instance, by attaching to one terminal of the coil a small length of soiled wire, presenting many points and offering great facility to escape, the potential of the coil may be raised to the same value as by attaching to the terminal a polished ball of a surface many times greater than that of the wire.

An interesting experiment, showing the effect of the points, may be performed in the following manner: Attach to one of the terminals of the coil a cotton covered wire about two feet in length, and adjust the conditions so that streams issue from the wire. In this experiment the primary coil should be preferably placed so that it extends only about half way into the secondary coil. Now touch the free terminal of the secondary with a conducting object held in the hand, or else connect it to an insulated body of some size. In this manner the potential on the wire may be enormously raised. The effect of this will be either to increase, or to diminish, the streams. If they increase, the wire is too short; if they diminish, it is too long, By adjusting the length of the wire, a point is found where the touching of the other terminal does not at all affect the streams. In this case the rise of potential is exactly-counteracted by the drop through the coil. It will be observed that small lengths of wire produce considerable difference in the magnitude and luminosity of the streams. The primary coil is placed sidewise for. two reasons: First, to increase the potential at the wire; and, second, to increase the drop through the coil. The sensitiveness is thus augmented.

There is still another and far more striking peculiarity of the brush discharge produced by very rapidly alternating currents. To observe this it is best to replace the usual terminals of the coil by two metal columns insulated with a good thickness of ebonite. It is also well to close all fissures and cracks with wax so that the brushes cannot form anywhere except at the tops of the columns. If the conditions are carefully adjusted which, of course, must be left to the skill of the experimenter — so that the potential rises to an enormous value, one may produce two powerful brushes several inches long, nearly white at their roots, which in the dark bear a striking resemblance to two flames of a gas escaping under pressure (Fig; 14). But they do not only *resemble,* they *are* veritable flames, for they are hot. Certainly they are not as hot as a gas burner, *but they would be so if the frequency and the potential would be sufficiently high.* Produced with, say, twenty thousand alternations per second, the heat is easily perceptible even if the potential is not excessively high. The heat developed is, of course, due to the impact of the air molecules against the terminals and against each other. As, at the ordinary pressures, the mean free path is excessively small, it is possible that in spite Of the enormous initial speed imparted to each molecule upon coming in contact with the terminal, its progress — by collision with other molecules — is retarded to such an extent, that it does not get away far from the terminal, but may strike the same many times in succession. The higher the frequency, the less the molecule is able to get away, and this the more so, as for a given effect the potential required is smaller; and a frequency is conceivable — perhaps even obtainable — at which practically the same molecules would strike the terminal. Under such conditions the exchange of the molecules would be very slow, and the heat produced at, and very near, the terminal Would be excessive. But if the frequency would go on increasing constantly, the heat produced would begin to diminish for obvious reasons. In the positive brush of a static machine the exchange of the molecules is very rapid, the stream is constantly of one direction, and there are fewer collisions; hence the heating effect must be very small. Anything that impairs the facility of exchange tends to increase the local heat produced. Thus, if a bulb be held over the terminal of the coil so as to enclose the brush, the air. contained in the bulb is very quickly brought to a high temperature, if a glass tube be held over the brush so as to allow the draught to carry the brush upwards, scorching hot air escapes at the top of the tube. Anything held within the brush is, of course, rapidly heated, and the possibility of using such heating effects for some purpose or other suggests itself.

When contemplating this singular phenomenon of the hot brush, we cannot help being convinced that a similar process must take place in the ordinary flame, and it seems strange that after all these centuries past of familiarity With the flame, now, in this era of electric lighting and heating, we are finally led to recognize, that since time immemorial we have, after all, always had "electric light and heat" at our disposal. It is also of no little interest to contemplate, that we have a possible way of producing — by other than chemical means — a veritable flame, which would give light and heat without any material being consumed, without any chemical process taking place, and to accomplish this, we only need to perfect methods of producing enormous frequencies and potentials. I have no doubt that if the potential could be made to alternate with sufficient rapidity and power, the brush formed at the end of a wire would lose its electrical characteristics and would become flamelike. The flame must be due to electrostatic molecular action.

This phenomenon now explains in a manner which can hardly be doubted the frequent accidents occurring in storms. It is well known that objects are often set on fire without the lightning striking them. We shall presently see how this can happen. On a nail in a roof, for instance, or on a projection of any kind, more or less conducting, or rendered so by dampness, a powerful brush may appear. If the lightning strikes somewhere in the neighborhood the enormous potential may be made to alternate or fluctuate perhaps many million times a second. The air molecules are violently attracted and repelled, and by their impact produce such a powerful heating effect that a fire is started. It is conceivable that a ship at sea may, in this manner, catch fire at many points at once. When we consider, that even with the comparatively low frequencies obtained from a dynamo machine, and with potentials of no more than one or two hundred thousand volts, the heating effects are considerable, we may imagine how much more powerful they must be with frequencies and potentials many times greater; and the above explanation seems, to say the least, very probable. Similar explanations may have been suggested, but I am not aware that, up to the present, the heating effects of a brush produced by a rapidly alternating potential have been experimentally demonstrated, at least not to such a remarkable degree.

By preventing completely the exchange of the air molecules, the local heating effect may be so exalted as to bring a body to incandescence. Thus, for instance, if a small button, or preferably a very thin wire or filament be enclosed in an unexhausted globe and connected with the terminal of the coil, it may be rendered incandescent. The phenomenon is made much more interesting by the rapid spinning round in a circle of the top of the filament, thus presenting the appearance of a luminous funnel, Fig. 15, which widens when the potential is increased. When the potential is small the end of the filament may perform irregular motions, suddenly changing from one to the other, or it may describe an ellipse; but when the potential is very high it always spins in a circle; and so does generally a thin straight wire attached freely to the terminal of the coil. These motions are, of course, due to the impact of the molecules, and the irregularity in the distribution of the potential, owing to the roughness and dissymmetry

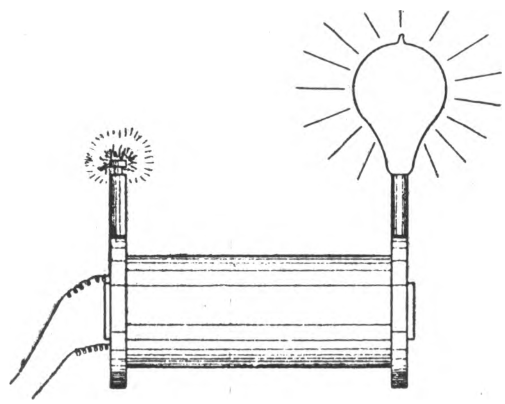


Fig. 15.

of the wire or filament. With a perfectly symmetrical and polished wire such motions would probably not occur. That the motion is not likely to be due to other causes is evident from the fact that it is not of a definite direction, and that in a very highly exhausted globe it ceases altogether. The possibility of bringing a body to incandescence in an exhausted globe, or even when not at all enclosed, would seem to afford a possible way of obtaining light effects, which, in perfecting methods of producing rapidly alternating potentials, might be rendered available for useful purposes.

In employing a commercial coil, the production of very powerful brush effects is attended with considerable difficulties, for when these high frequencies and enormous potentials are used, the best insulation is apt to give way. Usually the coil is insulated well enough to stand the strain from convolution to convolution, since two double silk covered paraffined wires will withstand a pressure of several thousand volts; the difficulty lies principally in preventing the breaking through from the secondary to the primary, which is greatly facilitated by the streams issuing from the latter. In the coil, of course, the strain is greatest from section to section, but usually in a larger coil there are so many sections that the danger of a sudden giving way is not very great. No difficulty will generally be encountered in that direction, and besides, the liability of injuring the coil internally is very much reduced by the fact that the effect most likely to be produced is simply a gradual heating, which, when far enough advanced, could not fail to be observed. The principal necessity is then to prevent the streams between the primary and the tube, not only on account of the heating and possible injury, but also because the streams may diminish very considerably the potential difference available at the terminals. A few hints as to how this may be accomplished will probably be found useful in most of these experiments with the ordinary induction coil.

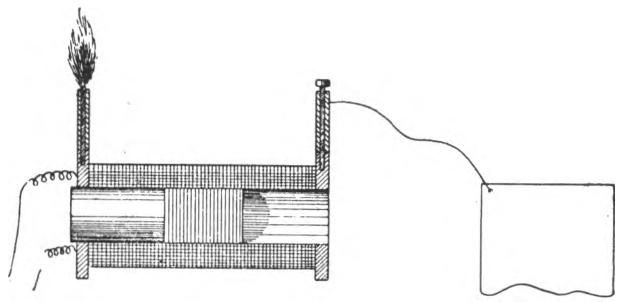


Fig. 16a.

One of the ways is to wind a short primary, Fig. 16a, so that the difference of potential is not at that length great enough to cause the breaking forth of the streams through the insulating tube. The length of the primary should be determined by experiment. Both the ends of the coil should be brought out on one end through a plug of insulating material fitting in the tube as illustrated. In such a disposition one terminal of the secondary is attached to a body, the surface of which is determined with the greatest care so as to produce the greatest rise in the potential. At the other terminal a powerful brush appears, which may be experimented upon.

The above plan necessitates the employment of a primary of comparatively small size, and it is apt to heat when powerful effects are desirable for a certain length of time. In such a case it is better to employ a larger coil, Fig. 16b, and introduce it from one side of the tube, until the streams begin to appear. In this case the nearest terminal of the secondary may be connected to the primary or to the ground, which is practically the same thing, if the primary is connected directly to the machine. In the case of ground connections it is well to determine experimentally the frequency which is best suited under the conditions of the test. Another way of obviating the streams, more or less, is to make the primary in sections and supply it from separate, well insulated sources.

In many of these experiments, when powerful effects are wanted for a short time, it is advantageous to use iron cores with the primaries. In such case a very large primary coil may be wound and placed side by side with the secondary, and, the nearest terminal of the latter being connected to the primary, a laminated iron core is introduced through the primary into the secondary as far as the streams will permit. Under these conditions an excessively powerful brush, several inches long, which may be appropriately called “St. Elmo’s hot fire”, may be caused to appear at the other terminal of the secondary, producing striking effects. It is a most powerful ozonizer, so powerful indeed, that only a few minutes are sufficient to fill the whole room with the smell of ozone, and it undoubtedly possesses the quality of exciting chemical affinities.

For the production of ozone, alternating currents of very high frequency are eminently suited, not only on account of the advantages they offer in the way of conversion but also because of the fact, that the ozonizing action of a discharge is dependent on the frequency as well as on the potential, this being undoubtedly confirmed by observation.

In these experiments if an iron core is used it should be carefully watched, as it is apt to get excessively hot in an incredibly short time. To give an idea of the rapidity of the heating, I will state, that by passing a powerful current through a coil with many turns, the inserting within the same of a thin iron wire for no more than one second's time is sufficient to heat the wire to something like 100ºC.

But this rapid heating need not discourage us in the use of iron cores in connection with rapidly alternating currents. I have for a long time been convinced that in the industrial distribution by means of transformers, some such plan as the following might be practicable. We may use a comparatively small iron core, subdivided, or perhaps not even subdivided. We may surround this core with a considerable thickness of material which is fire-proof and conducts the heat poorly, and on top of that we may place the

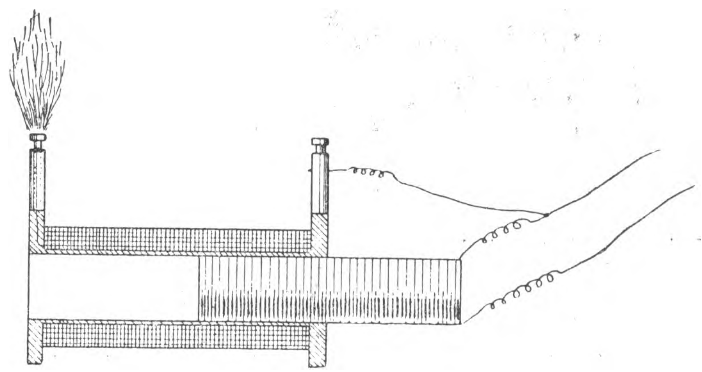


Fig. 16b.

primary and secondary windings. By using either higher frequencies or greater magnetizing forces, we may by hysteresis and eddy currents heat the iron core so far as to bring it neatly to its maximum permeability, which, as Hopkinson has shown, may be as much as sixteen times greater than that at ordinary temperatures. If the iron core were perfectly enclosed, it would not be deteriorated by the heat, and, if the enclosure of fire-proof material would be sufficiently thick, only a limited amount of energy Could be radiated in spite of the high temperature. Transformers have been constructed by me on that plan, but for lack of time, no thorough tests have as yet been made.

Another way of adapting the iron core to rapid alternations, or, generally speaking, reducing the frictional losses, is to produce by continuous magnetization a flow of something like seven thousand or eight thousand lines per square centimetre through the core, and then work with weak magnetizing forces and preferably high frequencies around the point of greatest permeability. A higher efficiency of conversion and greater output are obtainable in this manner. I have also employed this principle in connection with machines in which there is no reversal of polarity. In these types of machines, as long as there are only few pole projections, there is no great gain, as the maxima and minima of magnetization are far from the point of maximum permeability; but when the number of the pole projections is very great, the required rate of change may be obtained, without the magnetization varying so far as to depart greatly from the point of maximum permeability, and the gain is considerable.

The above described arrangements refer only to the use of commercial coils as ordinarily constructed. If it is desired to construct a coil for the express purpose of performing with it such experiments as I have described, or, generally, rendering it capable of withstanding the greatest possible difference of potential, then a construction as indicated in Fig. 17 will be found of advantage. The coil in this case is formed of two independent parts which are wound oppositely, the connection between both being made near the primary. The potential in the middle being zero, there is not much tendency to jump to the primary and not much insulation is required. In some cases the middle point may, however, be connected to the primary or to the ground. In such a coil the places of greatest difference of potential are far apart and the coil is capable of withstanding an enormous strain. The two parts may be movable so as to allow a slight adjustment of the capacity effect.

As to the manner of insulating the coil, it will be found convenient to proceed in the following way: First, the wire should be boiled in paraffine until all the air is out; then the coil is wound by running the wire through melted paraffine, merely for the purpose of fixing the wire. The coil is then taken off from the spool, immersed in a cylindrical vessel filled with pure melted wax and boiled for a long time until the bubbles cease to appear. The whole is then left to cool down thoroughly, and then the mass is taken out of the vessel and turned up in a lathe. A coil made in this manner and with care is capable of withstanding enormous potential differences.

It may be found convenient to immerse the coil in paraffine oil or some other kind of oil; it is a most effective way of insulating, principally on account of the perfect exclusion of air, but it may be found that, after all, a vessel filled with oil is not a very convenient thing to handle in a laboratory.

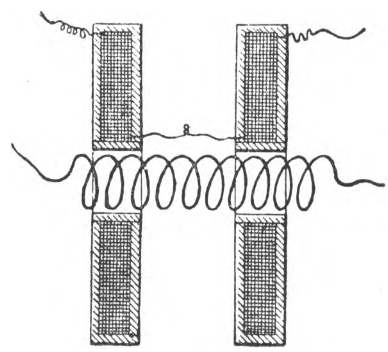


Fig. 17.

If an ordinary coil can be dismounted, the primary may be taken out of the tube and the latter plugged up at one end, filled with oil, and the primary reinserted. This affords an excellent insulation and prevents the formation of the streams.

Of all the experiments which may be performed with rapidly alternating currents the most interesting are those which concern the production of a practical illuminant. It cannot be denied that the present methods, though they were brilliant advances, are very wasteful. Some better methods must be invented, some more perfect apparatus devised. Modern research has opened new possibilities for the production of an efficient source of light, and the attention of all has been turned in the direction indicated by able pioneers. Many have been carried away by the enthusiasm and passion to discover, but in their zeal to reach results, some have been misled. Starting with the idea of producing electro-magnetic waves, they turned their attention, perhaps, too much to the study of electro-magnetic effects, and neglected the study of electrostatic phenomena. Naturally, nearly every investigator availed himself of an apparatus similar to that used in earlier experiments. But in those forms of apparatus, while the electro-magnetic inductive effects are enormous, the electrostatic effects are excessively small.

In the Hertz experiments, for instance, a high tension induction coil is short circuited by an arc, the resistance of which is very small, the smaller, the more capacity is attached to the terminals; and the difference of potential at these is enormously diminished. On the other hand, when the discharge is not passing between the terminals, the static effects may be considerable, but only qualitatively so, not quantitatively, since their rise and fall is very sudden, and since their frequency is small. In neither case, therefore, are powerful electrostatic effects perceivable. Similar conditions exist when, as in some interesting experiments of Dr. Lodge, Leyden jars are discharged disruptively. It has been thought — and I believe asserted — that in such cases most of the energy is radiated into space. In the light of the experiments which I have described above, it will now not be thought so. I feel safe in asserting that in such cases most of the energy is partly taken up and converted into heat in the arc of the discharge and in the conducting and insulating material of the jar, some energy being, of course, given off by electrification of the air; but the amount of the directly radiated energy is very small.

When a high tension induction coil, operated by currents alternating only 20,000 times a second, has its terminals closed through even a very small jar, practically all the energy passes through the dielectric of the jar, which is heated, and the electrostatic effects manifest themselves outwardly only to a very weak degree. Now the external circuit of a Leyden jar, that is, the arc and the connections of the coatings, may be looked upon as a circuit generating alternating currents of excessively high frequency and fairly high potential, which is closed through the coatings and the dielectric between them, and from the above it is evident that the external electrostatic effects must be very small, even if a recoil circuit be used. These conditions make it appear that with the apparatus usually at hand, the observation of powerful electrostatic effects was impossible, and what experience has been gained in that direction is only due to the great ability of the investigators.

But powerful electrostatic effects are a *sine qua non* of light production on the lines indicated by theory. Electro-magnetic effects are primarily unavailable, for the reason that to produce the required effects we would have to pass current impulses through a conductor, which, long before the required frequency of the impulses could be reached, would cease to transmit them. On the other hand, electro-magnetic waves many times longer than those of light, and producible by sudden discharge of a condenser, could not be utilized, it would seem, except we avail ourselves of their effect upon conductors as in the present methods, which are wasteful. We could not affect by means of such waves the static molecular or atomic charges of a gas, cause them to vibrate and to emit light. Long transverse waves cannot, apparently, produce such effects, since excessively small electro-magnetic disturbances may pass readily through miles of air. Such dark waves, unless they are of the length of true light waves, cannot, it would seem, excite luminous radiation in a Geissler tube, and the luminous effects, which are producible by induction in a tube devoid of electrodes, I am inclined to consider as being of an electrostatic nature.

To produce such luminous effects, straight electrostatic thrusts are required; these, whatever be their frequency, may disturb the molecular charges and produce light. Since current impulses of the required frequency cannot pass through a conductor of measurable dimensions, we must work with a gas, and then the production of powerful electrostatic effects becomes an imperative necessity.

It has occurred to me, however, that electrostatic effects are in many ways available for the production of light. For instance, we may place a body of some refractory material in a closed, and preferably more or less exhausted, globe, connect it to a source of high, rapidly alternating potential, causing the molecules of the gas to strike it many times a second at enormous speeds, and in this manner, with trillions of invisible hammers, pound it until it gets incandescent; or we may place a body in a very highly exhausted globe, in a non-striking vacuum, and, by employing very high frequencies and potentials, transfer sufficient energy from it to other bodies in the vicinity, or in general to the surroundings, to maintain it at any degree of incandescence; or we may, by means of such rapidly alternating high potentials, disturb the ether carried by the molecules of a gas or their static charges, causing them to vibrate and to emit light.

But, electrostatic effects being dependent upon the potential and frequency, to produce the most powerful action it is desirable to increase both as far as practicable. It may be possible to obtain quite fair results by keeping either of these factors small, provided the other is sufficiently great; but we are limited in both directions. My experience demonstrates that we cannot go below a certain frequency, for, first, the potential then becomes so great that it is dangerous; and, secondly, the light production is less efficient.

I have found that, by using the ordinary low frequencies, the physiological effect of the current required to maintain at a certain degree of brightness a tube four feet long, provided at the ends with outside and inside condenser coatings, is so powerful that, I think, it might produce serious injury to those not accustomed to such shocks; whereas, with twenty thousand alternations per second, the tube may be maintained at the same degree of brightness without any effect being felt. This is due principally to the fact that a much smaller potential is required to produce the same light effect, and also to the higher efficiency in the light production. It is evident that the efficiency in such cases is the greater, the higher the frequency, for the quicker the process of

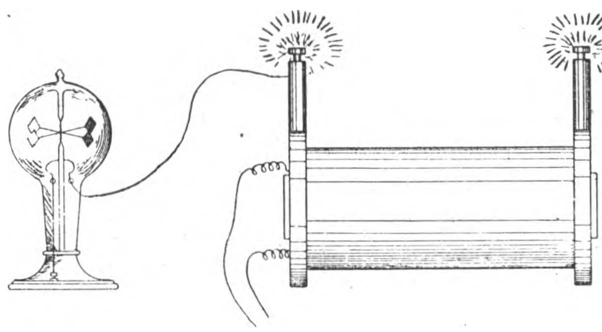


Fig. 18.

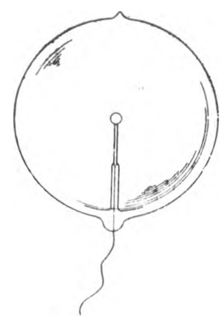


Fig. 19.

charging and discharging the molecules, the less energy will be lost in the form of dark radiation. But, unfortunately, we cannot go beyond a certain frequency on account of the difficulty of producing and conveying the effects.

I have stated above that a body inclosed in an unexhausted bulb may be intensely heated by simply connecting it with a source of rapidly alternating potential. The heating in such a case is, in all probability, due mostly to the bombardment of the molecules of the gas contained in the bulb. When the bulb is exhausted, the heating of the body is much more rapid, and there is no difficulty whatever in bringing a wire or filament to any degree of incandescence by simply connecting it to one terminal of a coil of the proper dimensions. Thus, if the well-known apparatus of Prof. Crookes, consisting of a bent platinum wire with vanes mounted over it (Fig. 18), be connected to one terminal of the coil — either one or both ends of the platinum wire being connected — the wire is rendered almost instantly incandescent, and the mica vanes are rotated as though a current from a battery were used. A thin carbon filament, or, preferably, a button of some refractory material (Fig. 19), even if it be a comparatively poor conductor, inclosed in an exhausted globe, may be rendered highly incandescent; and in this manner a simple lamp capable of giving any desired candle power is provided.

The success of lamps of this kind would depend largely on the selection of the light-giving bodies contained within the bulb. Since, under the conditions described, refractory bodies — which are very poor conductors and capable of withstanding for a long time excessively high degrees of temperature — may be used, such illuminating devices may be rendered successful.

It might be thought at first that if the bulb, containing the filament or button of refractory material, be perfectly well exhausted — that is, as far as it can be done by the use of the best apparatus — the heating would be much less intense, and that in a perfect vacuum it could not occur at all. This is not confirmed by my experience; quite the contrary, the better the vacuum the more easily the bodies are brought to incandescence. This result is interesting for many reasons.

At the outset of this work the idea presented itself to me, whether two bodies of refractory material enclosed in a bulb exhausted to such a degree that the discharge of a large induction coil, operated in the usual manner, cannot pass through, could be rendered incandescent by mere condenser action. Obviously, to reach this result enormous potential differences and very high frequencies are required, as is evident from a simple calculation.

But such a lamp would possess a vast advantage over an ordinary incandescent lamp in regard to efficiency. It is well-known that the efficiency of a lamp is to some extent a function of the degree of incandescence, and that, could we but work a filament

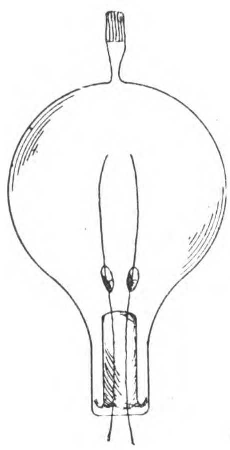


Fig. 20.

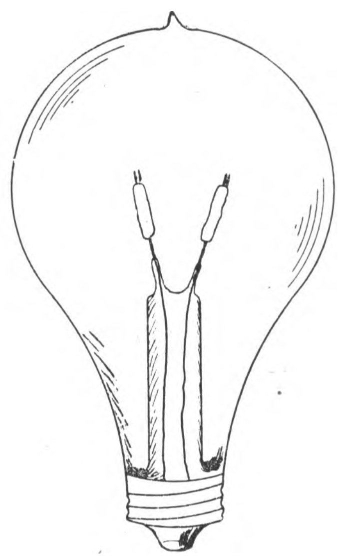


Fig. 21.

at many times higher degrees of incandescence, the efficiency would be much greater. In an ordinary lamp this is impracticable on account of the destruction of the filament, and it has been determined by experience how far it is advisable to push the incandescence. It is impossible to tell how much higher efficiency could be obtained if the filament could withstand indefinitely, as the investigation to this end obviously cannot be carried beyond a certain stage; but there are reasons for believing that it would be very considerably higher. An improvement might be made in the ordinary lamp by employing a short and thick carbon; but then the leading-in wires would have to be thick, and, besides, there are many other considerations which render such a modification entirely impracticable. But in a lamp as above described, the leading-in wires may be very small, the incandescent refractory material may be in the shape of blocks offering a very small radiating surface, so that less energy would be required to keep them at the desired incandescence; and in addition to this, the refractory material need not be carbon, but may be manufactured from mixtures of oxides, for instance, with carbon or other material, or may be selected from bodies which are practically non-conductors, and capable of withstanding enormous degrees of temperature.

All this would point to the possibility of obtaining a much higher efficiency with such a lamp than is obtainable in ordinary lamps. In my experience it has been demonstrated that the blocks are brought to high degrees of incandescence with much lower potentials than those determined by calculation, and the blocks may be set at greater distances from each other. We may freely assume, and it is probable, that the molecular bombardment is an important element in the heating, even if the globe be exhausted with the utmost care, as I have done; for although the number of the molecules is, comparatively speaking, insignificant, yet on account of the mean free path being very great, there are fewer collisions, and the molecules may reach much higher speeds, so that the heating effect due to this cause may be considerable, as in the Crookes experiments with radiant matter.

But it is likewise possible that we have to deal here with an increased facility of losing the charge in very high vacuum, when the potential is rapidly alternating, in which case most of the heating would be directly due to the surging of the charges in the heated bodies. Or else the observed fact may be largely attributable to the effect of the points which I have mentioned above, in consequence of which the blocks or filaments contained in the vacuum are equivalent to condensers of many times greater surface than that calculated from their geometrical dimensions. Scientific men still differ in opinion as to whether a charge should, or should not, be lost in a perfect vacuum, or in other words, whether ether is, or is not, a conductor. If the former were the case, then a thin filament enclosed in a perfectly exhausted globe, and connected to a source of enormous, steady potential, would be brought to incandescence.

Various forms of lamps on the above described principle, with the refractory bodies in the form of filaments, Fig. 20, or blocks, Fig. 21, have been constructed and operated by me, and investigations are being carried on in this line. There is no difficulty in reaching such high degrees of incandescence that ordinary carbon is to all appearance melted and volatilized. If the vacuum could be made absolutely perfect, such a lamp, although inoperative with apparatus ordinarily used, would, if operated with currents of the required character, afford an illuminant which would never be destroyed, and which would be far more efficient than an ordinary incandescent lamp. This perfection can, of course, never be reached, and a very slow destruction and gradual diminution in size always occurs, as in incandescent filaments; but there is no possibility of a sudden and premature disabling which occurs in the latter by the breaking of the filament, especially when the incandescent bodies are in the shape of blocks.

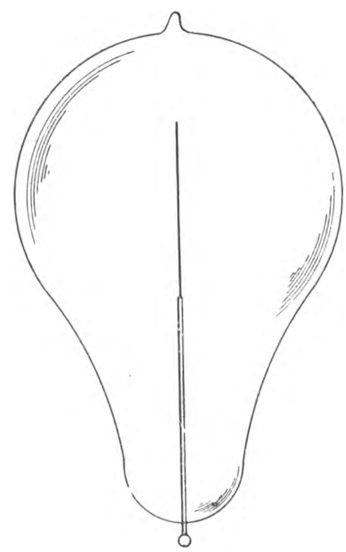


Fig. 22.

With these rapidly alternating potentials there is, however, no necessity of enclosing two blocks in a globe, but a single block, as in Fig. 19, or filament, Fig. 22, may be used. The potential in this case must of course be higher, but is easily obtainable, and besides it is not necessarily dangerous.

The facility with which the button or filament in such a lamp is brought to incandescence, other things being equal, depends on the size of the globe. If a perfect vacuum could be obtained, the size of the globe would not be of importance, for then the heating would be wholly due to the surging of the charges, and all the energy would be given off to the surroundings by radiation. But this can never occur in practice. There is always some gas left in the globe, and although the exhaustion may be carried to the highest degree, still the space inside of the bulb must be considered as conducting when such high potentials are used, and I assume that, in estimating the energy that may be given off from the filament to the surroundings, we may consider the inside surface of the bulb as one coating of a condenser, the air and other objects surrounding the bulb forming the other coating. When the alternations are very low there is no doubt that a considerable portion of the energy is given off by the electrification of the surrounding air.

In order to study this subject better, I carried on some experiments with excessively high potentials and low frequencies. I then observed that when the hand is approached to the bulb, — the filament being connected with one terminal of the coil, — a powerful vibration is felt, being due to the attraction and repulsion of the molecules of the air

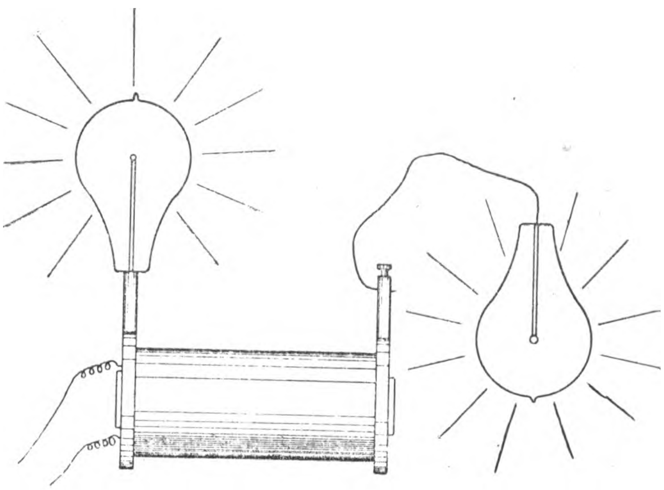


Fig. 23.

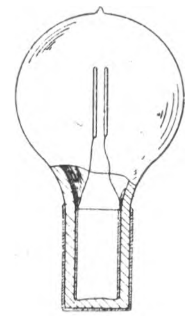


Fig. 24.

which are electrified by induction through the glass. In some cases when the action is very intense I have been able to hear a sound, which must be due to the same cause.

When the alternations are low, one is apt to get an excessively powerful shock from the bulb. In general, when one attaches bulbs or objects of some size to the terminals of the coil, one should look out for the rise of potential, for it may happen that by merely connecting a bulb or plate to the terminal, the potential may rise to many times its original value. When lamps are attached to the terminals, as illustrated in Fig. 23, then the capacity of the bulbs should be such as to give the maximum rise of potential under the existing conditions. In this manner one may obtain the required potential with fewer turns of wire.

The life of such lamps as described above depends, of course, largely on the degree of exhaustion, but to some extent also on the shape of the block of refractory material. Theoretically it would seem that a small sphere of carbon enclosed in a sphere of glass would not suffer deterioration from molecular bombardment, for, the matter in the globe being radiant, the molecules would move in straight lines, and would seldom strike the sphere obliquely. An interesting thought in connection with such a lamp is, that in it "electricity" and electrical energy apparently must move in the same lines.

The use of alternating currents of very high frequency makes it possible to transfer, by electrostatic or electromagnetic induction through the glass of a lamp, sufficient energy to keep a filament at incandescence and so do away with the leading-in wires. Such lamps have been proposed, but for want of proper apparatus they have not been successfully operated. Many forms of lamps on this principle with continuous and broken filaments have been constructed by me and experimented upon. When using a secondary enclosed within the lamp, a condenser is advantageously combined with the secondary. When the transference is effected by electrostatic induction, the potentials used are, of course, very high with frequencies obtainable from a machine. For instance, with a condenser surface of forty square centimetres, which is not impracticably large, and with glass of good quality 1 mm. thick, using currents alternating twenty thousand times a second, the potential required is approximately 9,000 volts. This may seem large, but since each lamp may be included in the secondary of a transformer of very small dimensions, it would not be inconvenient, and, moreover, it would not produce fatal injury. The transformers would all be preferably in series. The regulation would offer no difficulties, as with currents of such frequencies it is very easy to maintain a constant current.

In the accompanying engravings some of the types of lamps of this kind are shown. Fig. 24 is such a lamp with a broken filament, and Figs. 25a and 25b one with a single outside and inside coating and a single filament. I have also made lamps with two outside and inside coatings and a continuous loop connecting the latter. Such lamps have been operated by me with current impulses of the enormous frequencies obtainable by the disruptive discharge of condensers.

The disruptive discharge of a condenser is especially suited for operating such lamps — with no outward electrical connections — by means of electromagnetic induction, the electromagnetic inductive effects being excessively high; and I have been able to produce the desired incandescence with only a few short turns of wire. Incandescence may also be produced in this manner in a simple closed filament.

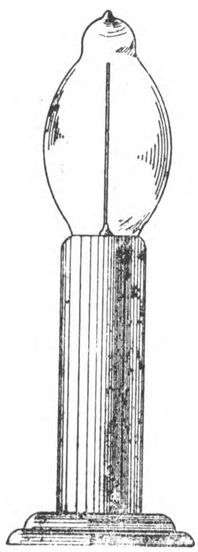


Fig. 25a.

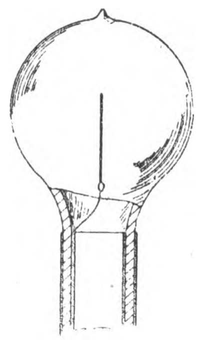


Fig. 25b.

Leaving now out of consideration the practicability of such lamps, I would only say that they possess a beautiful and desirable feature, namely, that they can be rendered, at will, more or less brilliant simply by altering the relative position of the outside and inside condenser coatings, or inducing and induced circuits.

When a lamp is lighted by connecting it to one terminal only of the source, this may be facilitated by providing the globe with an outside condenser coating, which serves at the same time as a reflector, and connecting this to an insulated body of some size. Lamps of this kind are illustrated in Fig. 26 and Fig. 27. Fig. 28 shows the plan of connection. The brilliancy of the lamp may, in this case, be regulated within wide limits by varying the size of the insulated metal plate to which the coating is connected.

It is likewise practicable to light with one leading wire lamps such as illustrated in Fig. 20 and Fig. 21, by connecting one terminal of the lamp to one terminal of the source, and the other to an insulated body of the required size. In all cases the insulated body serves to give off the energy into the surrounding space, and is equivalent to a return wire. Obviously, in the two last-named cases, instead of connecting the wires to an insulated body, connections may be made to the ground.

The experiments which will prove most suggestive and of most interest to the investigator are probably those performed with exhausted tubes. As might be anticipated, a source of such rapidly alternating potentials is capable of exciting the tubes at a considerable distance, and the light effects produced are remarkable.

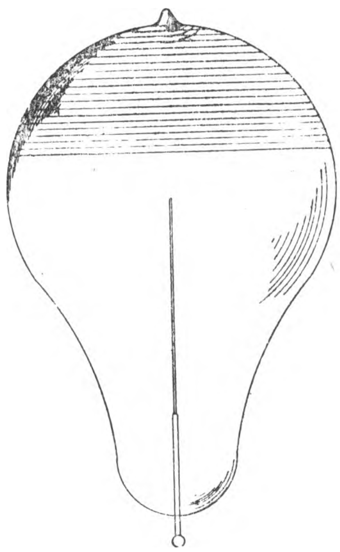


Fig. 26

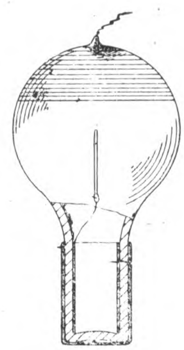


Fig. 27

During my investigations in this line I endeavored to excite tubes, devoid of any electrodes, by electromagnetic induction, making the tube the secondary of the induction device, and passing through the primary the discharges of a Leyden jar. These tubes were made of many shapes, and I was able to obtain luminous effects which I then thought were due wholly to electromagnetic induction. But on carefully investigating the phenomena I found that the effects produced were more of an electrostatic nature. It may be attributed to this circumstance that this mode of exciting tubes is very wasteful, namely, the primary circuit being closed, the potential, and consequently the electrostatic inductive effect, is much diminished.

When an induction coil, operated as above described, is used, there is no doubt that the tubes are excited by electrostatic induction, and that electromagnetic induction has little, if anything, to do with the phenomena.

This is evident from many experiments. For instance, if a tube be taken in one hand, the observer being near the coil, it is brilliantly lighted and remains so no matter in what position it is held relatively to the observer's body. Were the action electromagnetic, the tube could not be lighted when the observer's body is interposed between it and the coil, or at least its luminosity should be considerably diminished. When the tube is held exactly over the centre of the coil — the latter being wound in sections and the primary placed symmetrically to the secondary — it may remain completely dark, whereas it is rendered intensely luminous by moving it slightly to the right or left from the centre of the coil. It does not light because in the middle both halves of the coil neutralize each other, and the electric potential is zero. If the action were electromagnetic, the tube should light best in the plane through the centre of the coil, since the electromagnetic effect there should be a maximum. When an arc is established between the terminals, the tubes and lamps in the vicinity of the coil go out, but light up again when the arc is broken, on account of the rise of potential. Yet the electromagnetic effect should be practically the same in both cases.

By placing a tube at some distance from the coil, and nearer to one terminal — preferably at a point on the axis of the coil — one may light it by touching the remote terminal with an insulated body of some size or with the hand, thereby raising the potential at that terminal nearer to the tube. If the tube is shifted nearer to the coil so that it is lighted by the action of the nearer terminal, it may be made to go out by holding, on an insulated support, the end of a wire connected to the remote terminal, in the vicinity of the nearer terminal, by this means counteracting the action of the latter upon the tube. These effects are evidently electrostatic. Likewise, when a tube is placed at a considerable distance from the coil, the observer may, standing upon an insulated support between coil and tube, light the latter by approaching the hand to it; or he may even render it luminous by simply stepping between if and the coil. This would be impossible with electro-magnetic induction, for the body of the observer would act as a screen.

When the coil is energized by excessively weak currents, the experimenter may, by touching one terminal of the coil with the tube, extinguish the latter, and may again light it by bringing it out of contact with the terminal and allowing a small arc to form. This is clearly due to the respective lowering and raising of the potential at that terminal. In the above experiment, when the tube is lighted through a small arc, it may go out when the arc is broken, because the electrostatic inductive effect alone is too weak, though the potential may be much higher; but when the arc is established, the electrification of the end of the tube is much greater, and it consequently lights.

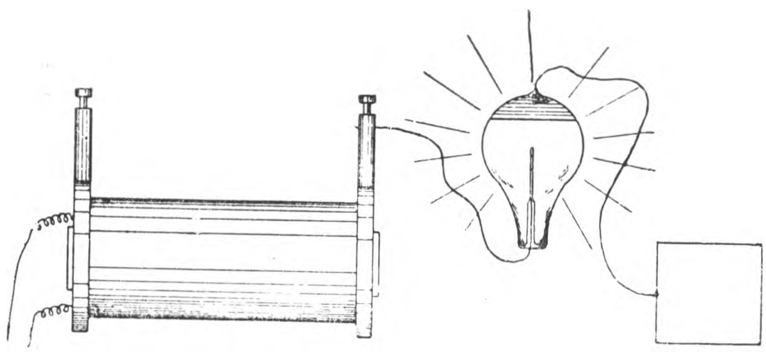


Fig. 28.

If a tube is lighted by holding it near to the coil, and in the hand which is remote, by grasping the tube anywhere with the other hand, the part between the hands is rendered dark, and the singular effect of wiping out the light of the tube may be produced by passing the hand quickly along the tube and at the same time withdrawing it gently from the coil, judging properly the distance so that the tube remains dark afterwards.

If the primary coil is placed sidewise, as in Fig. 16b for instance, and an exhausted tube be introduced from the other side in the hollow space, the tube is lighted most intensely because of the increased condenser action, and in this position the striae are most sharply defined. In all these experiments described, and in many others, the action is clearly electrostatic.

The effects of screening also indicate the electrostatic nature of the phenomena and show something of the nature of electrification through the air. For instance, if a tube is placed in the direction of the axis of the coil, and an insulated metal plate be interposed, the tube will generally increase in brilliancy, or if it be too far from the coil to light, it may even be rendered luminous by interposing an insulated metal plate. The magnitude of the effects depends to some extent on the size of the plate. But if the metal plate be connected by a wire to the ground, its interposition will always make the tube go out even if it be very near the coil. In general, the interposition of a body between the coil and tube, increases or diminishes the brilliancy of the tube, or its facility to light up, according to whether it increases or diminishes the electrification. When experimenting with an insulated plate, the plate should not be taken too large, else it will generally produce a weakening effect by reason of its great facility for giving off energy to the surroundings.

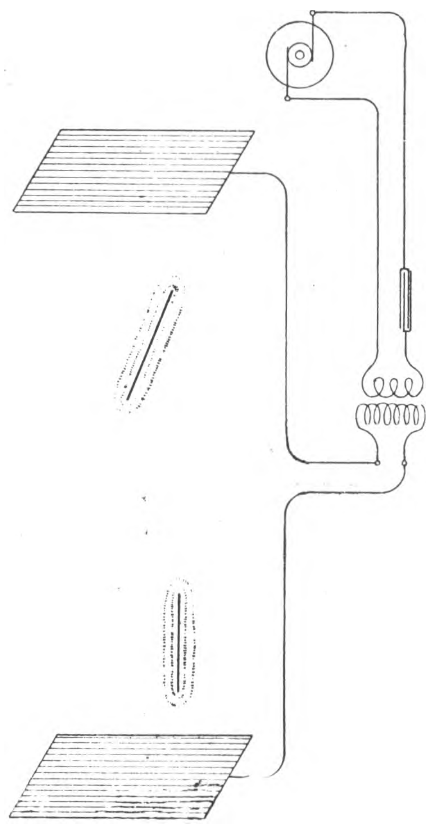


Fig. 29.

If a tube be lighted at some distance from the coil, and a plate of hard rubber or other insulating substance be interposed, the tube may be made to go out. The interposition of the dielectric in this case only slightly increases the inductive effect, but diminishes considerably the electrification through the air.

In all cases, then, when we excite luminosity in exhausted tubes by means of such a coil, the effect is due to the rapidly alternating electrostatic potential; and, furthermore, it must be attributed to the harmonic alternation produced directly by the machine, and not to any superimposed vibration which might be thought to exist. Such superimposed vibrations are impossible when we work with an alternate current machine. If a spring be gradually tightened and released, it does not perform independent vibrations; for this a sudden release is necessary. So with the alternate currents from a dynamo machine; the medium is harmonically strained and released, this giving rise to only one kind of waves; a sudden contact or break, or a sudden giving way of the dielectric, as in the disruptive discharge of a Leyden jar, are essential for the production of superimposed waves.

In all the last described experiments, tubes devoid of any electrodes may be used, and there is no difficulty in producing by their means sufficient light to read by. The light effect is, however, considerably increased by the use of phosphorescent bodies such as yttria, uranium glass, etc. A difficulty will be found when the phosphorescent material is used, for with these powerful effects, it is carried gradually away, and it is preferable to use material in the form of a solid.

Instead of depending on induction at a distance to light the tube, the same may be provided with an external — and, if desired, also with an internal — condenser coating, and it may then be suspended anywhere in the room from a conductor connected to one terminal of the coil, and in this manner a soft illumination may be provided.

The ideal way of lighting a hall or room would, however, be to produce such a condition in it that an illuminating device could be moved and put anywhere, and that it is lighted, no matter where it is put and without being electrically connected to anything. I have been able to produce such a condition by creating in the room a powerful, rapidly alternating electrostatic field. For this purpose I suspend a sheet of metal a distance from the ceiling on insulating cords and connect it to one terminal of the induction coil, the other terminal being preferably connected to the ground. Or else I suspend two sheets as illustrated in Fig. 29, each sheet being connected with one of the terminals of the coil, and their size being carefully determined. An exhausted tube may then be carried in the hand anywhere between the sheets or placed anywhere, even a certain distance beyond them; it remains always luminous.

In such an electrostatic field interesting phenomena may be observed, especially if the alternations are kept low and the potentials excessively high. In addition to the luminous phenomena mentioned, one may observe that any insulated conductor gives sparks when the hand or another object is approached to it, and the sparks may often be powerful. When a large conducting object is fastened on an insulating support, and the hand approached to it, a vibration, due to the rythmical motion of the air molecules is felt, and luminous streams may be perceived when the hand is held near a pointed projection. When a telephone receiver is made to touch with one or both of its terminals an insulated conductor of some size, the telephone emits a loud sound; it also emits a sound when a length of wire is attached to one or both terminals, and with very powerful fields a sound may be perceived even without any wire.

How far this principle is capable of practical application, the future will tell. It might be thought that electrostatic effects are unsuited for such action at a distance. Electromagnetic inductive effects, if available for the production of light, might be thought better suited. It is true the electrostatic effects diminish nearly with the cube of the distance from the coil, whereas the electromagnetic inductive effects diminish simply with the distance. But when we establish an electrostatic field of force, the condition is very different, for then, instead of the differential effect of both the terminals, we get their conjoint effect. Besides, I would call attention to the effect that in an alternating electrostatic field, a conductor, such as an exhausted tube, for instance, tends to take up most of the energy, whereas in an electromagnetic alternating field the conductor tends to take up the least energy, the waves being reflected with but little loss. This is one reason why it is difficult to excite an exhausted tube, at a distance, by electromagnetic induction. I have wound coils of very large diameter and of many turns of wire, and connected a Geissler tube to the ends of the coil with the object of exciting the tube at a distance; but even with the powerful inductive effects producible by Leyden jar discharges, the tube could not be excited unless at a very small distance, although some judgment was used as to the dimensions of the coil. I have also found that even the most powerful Leyden jar discharges are capable of exciting only feeble luminous effects in a closed exhausted tube, and even these effects upon thorough examination I have been forced to consider of an electrostatic nature.

How then can we hope to produce the required effects at a distance by means of electromagnetic action, when even in the closest proximity to the source of disturbance, under the most advantageous conditions, we can excite but faint luminosity? It is true that when acting at a distance we have the resonance to help us out. We can connect an exhausted tube, or whatever the illuminating device may be, with an insulated system of the proper capacity, and so it may be possible to increase the effect qualitatively, and only qualitatively, for we would not get *more* energy through the device. So we may, by resonance effect, obtain the required electromotive force in an exhausted tube, and excite faint luminous effects, but we cannot get enough energy to render the light practically available, and a simple calculation, based on experimental results, shows that even if all the energy which a tube would receive at a certain distance from the source should be wholly converted into light, it would hardly satisfy the practical requirements. Hence the necessity of directing, by means of a conducting circuit, the energy to the place of transformation. But in so doing we cannot very sensibly depart from present methods, and all we could do would be to improve the apparatus.

From these considerations it would seem that if this ideal way of lighting is to rendered practicable it will be only by the use of electrostatic effects. In such a case the most powerful electrostatic inductive effects are needed; the apparatus employed must, therefore, be capable of producing high electrostatic potentials changing in value with extreme rapidity. High frequencies are especially wanted, for practical considerations make it desirable to keep down the potential. By the employment of machines, or, generally speaking, of any mechanical apparatus, but low frequencies can be reached; recourse must, therefore, be had to some other means. The discharge of a condenser affords us a means of obtaining frequencies by far higher than are obtainable mechanically, and I have accordingly employed condensers in the experiments to the above end.

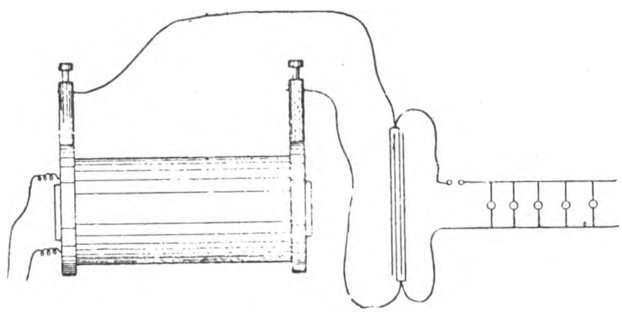


Fig. 30.

When the terminals of a high tension induction coil, Fig. 30, are connected to a Leyden jar, and the latter is discharging disruptively into a circuit, we may look upon the arc playing between the knobs as being a source of alternating, or generally speaking, undulating currents, and then we have to deal with the familiar system of a generator of such currents, a circuit connected to it, and a condenser bridging the circuit. The condenser in such case is a veritable transformer, and since the frequency is excessive, almost any ratio in the strength of the currents in both the branches may be obtained. In reality the analogy is not quite complete, for in the disruptive discharge we have most generally a fundamental instantaneous variation of comparatively low frequency, and a superimposed harmonic vibration, and the laws governing the flow of currents are not the same for both.

In converting in this manner, the ratio of conversion should not be too great, for the loss in the arc between the knobs increases with the square of the current, and if the jar be discharged through very thick and short conductors, with the view of obtaining a very rapid oscillation, a very considerable portion of the energy stored is lost. On the other hand, too small ratios are not practicable for many obvious reasons.

As the converted currents flow in a practically closed circuit, the electrostatic effects are necessarily small, and I therefore convert them into currents or effects of the required character. I have effected such conversions in several ways. The preferred plan of connections is illustrated in Fig. 31. The manner of operating renders it easy to obtain by means of a small and inexpensive apparatus enormous differences of potential which have been usually obtained by means of large and expensive coils. For this it is only necessary to take an ordinary small coil, adjust to it a condenser and discharging circuit, forming the primary of an auxiliary small coil, and convert upward. As the inductive effect of the primary currents is excessively great, the second coil need have comparatively but very few turns. By properly adjusting the elements, remarkable results may be secured.

In endeavoring to obtain the required electrostatic effects in this manner, I have, as might be expected, encountered many difficulties which I have been gradually overcoming, but I am not as yet prepared to dwell upon my experiences in this direction.

I believe that the disruptive discharge of a condenser will play an important part in the future, for it offers vast possibilities, not only in the way of producing light in a more efficient manner and in the line indicated by theory, but also in many other respects.

For years the efforts of inventors have been directed towards obtaining electrical energy from heat by means of the thermopile. It might seem invidious to remark that but few know what is the real trouble with the thermopile. It is not the inefficiency or small output — though these are great drawbacks — but the fact that the thermopile has its phylloxera, that is, that by constant use it is deteriorated, which has thus far prevented its introduction on an industrial scale. Now that all modern research seems to point with certainty to the use of electricity of excessively high tension, the question must present itself to many whether it is not possible to obtain in a practicable manner this form of energy from heat. We have been used to look upon an electrostatic machine

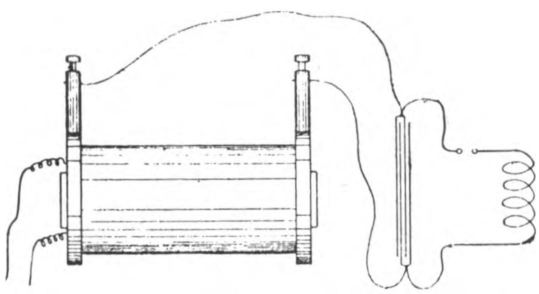


Fig. 31.

as a plaything, and somehow we couple with it the idea of the inefficient and impractical. But now we must think differently, for now we know that everywhere we have to deal with the same forces, and that it is a mere question of inventing proper methods or apparatus for rendering them available.

In the present systems of electrical distribution, the employment of the iron with its wonderful magnetic properties allows us to reduce considerably the size of the apparatus; but, in spite of this, it is still very cumbersome. The more we progress in the study of electric and magnetic phenomena, the more we become convinced that the present methods will be short-lived. For the production of light, at least, such heavy machinery would seem to be unnecessary. The energy required is very small, and if light can be obtained as efficiently as, theoretically, it appears possible, the apparatus need have but a very small output. There being a strong probability that the illuminating methods of the future will involve the use of very high potentials, it seems very desirable to perfect a contrivance capable of converting the energy of heat into energy of the requisite form. Nothing to speak of has been done towards this end, for the thought that electricity of some 50,000 or 100,000 volts pressure or more, even if obtained, would be unavailable for practical purposes, has deterred inventors from working in this direction.

In Fig. 30 a plan of connections is shown for converting currents of high, into currents of low, tension by means of the disruptive discharge of a condenser. This plan has been used by me frequently for operating a few incandescent lamps required in the laboratory. Some difficulties have been encountered in the arc of the discharge which I have been able to overcome to a great extent; besides this, and the adjustment necessary for the proper working, no other difficulties have been met with, and it was easy to operate ordinary lamps, and even motors, in this manner. The line being connected to the ground, all the wires could be handled with perfect impunity, no matter how high the potential at the terminals of the condenser. In these experiments a high tension induction coil, operated from a battery or from an alternate current machine, was employed to charge the condenser; but the induction coil might be replaced by an apparatus of a different kind, capable of giving electricity of such high tension. In this manner, direct or alternating currents may be converted, and in both cases the current-impulses may be of any desired frequency. When the currents charging the condenser are of the same direction, and it is desired that the converted currents should also be of one direction, the resistance of the discharging circuit should, of course, be so chosen that there are no oscillations.

In operating devices on the above plan I have observed curious phenomena of impedance which are of interest. For instance if a thick copper bar be bent, as indicated in Fig. 32, and shunted by ordinary incandescent lamps, then, by passing the discharge between the knobs, the lamps may be brought to incandescence although they are short-circuited. When a large induction coil is employed it is easy to obtain nodes on the bar, which are rendered evident by the different degree of brilliancy of the lamps, as shown roughly in Fig. 32. The nodes are never clearly defined, but they are simply maxima and minima of potentials along the bar. This is probably due to the irregularity of the arc between the knobs. In general when the above-described plan of conversion from high to low tension is used, the behavior of the disruptive discharge may be closely studied. The nodes may also be investigated by means of an ordinary Cardew voltmeter which should be well insulated. Geissler tubes may also be lighted across the points of the bent bar; in this case, of course, it is better to employ smaller capacities. I have found it practicable to light up in this manner a lamp, and even a Geissler tube, shunted by a short, heavy block of metal, and this result seems at first very curious. In fact, the thicker the copper bar in Fig. 32, the better it is for the success of the experiments, as they appear more striking. When lamps with long slender filaments are used it will be often noted that the filaments are from time to time violently vibrated, the vibration being smallest at the nodal points. This vibration seems to be due to an electrostatic action between the filament and the glass of the bulb.

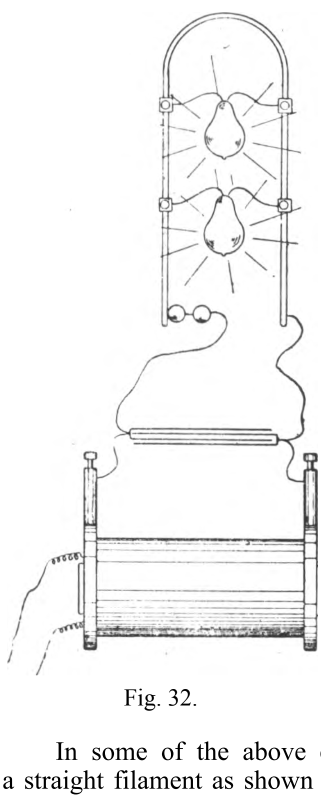


Fig. 32.

In some of the above experiments it is preferable to use special lamps having a straight filament as shown in Fig. 33. When such a lamp is used a still more curious phenomenon than those described may be observed. The lamp may be placed across the copper bar and lighted, and by using somewhat larger capacities, or, in other words, smaller frequencies or smaller impulsive impedances, the filament may be brought to any desired degree of incandescence. But when the impedance is increased, a point is reached when comparatively little current passes through the carbon, and most of it.

through the rarefied gas; or perhaps it may be more correct to state that the current divides nearly evenly through both, in spite of the enormous difference in the resistance, and this would be true unless the gas and the filament behave differently. It is then noted that the whole bulb is brilliantly illuminated, and the ends of the leading-in wires become incandescent and often throw off sparks in consequence of the violent bombardment, but the carbon filament remains dark. This is illustrated in Fig. 33. Instead of the filament a single wire extending through the whole bulb may be used, and in this case the phenomenon would seem to be still more interesting.

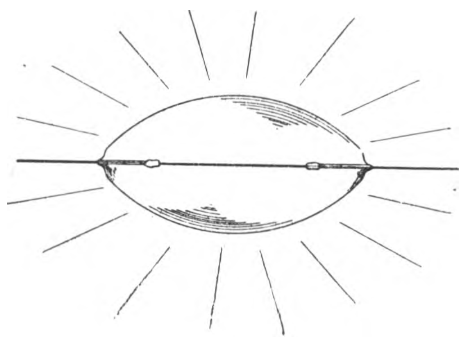


Fig. 33.

From the above experiment it will be evident, that when ordinary lamps are operated by the converted currents, those should be preferably taken in which the platinum wires are far apart, and the frequencies used should not be too great, else the discharge will occur at the ends of the filament or in the base of the lamp between the leading-in wires, and the lamp might then be damaged.

In presenting to you these results of my investigation on the subject under consideration, I have paid only a passing notice to facts upon which I could have dwelt at length, and among many observations I have selected only those which I thought most likely to interest you. The field is wide and completely unexplored, and at every step a new truth is gleaned, a novel fact observed.

How far the results here borne out are capable of practical applications will be decided in the future. As regards the production of light, some results already reached are encouraging and make me confident in asserting that the practical solution of the problem lies in the direction I have endeavored to indicate. Still, whatever may be the immediate outcome of these experiments I am hopeful that they will only prove a step in further developments towards the ideal and final perfection. The possibilities which are opened by modern research are so vast that even the most reserved must feel sanguine of the future. Eminent scientists consider the problem of utilizing one kind of radiation without the others a rational one. In an apparatus designed for the production of light by conversion from any form of energy into that of light, such a result can never be reached, for no matter what the process of producing the required vibrations, be it electrical, chemical or any other, it will not be possible to obtain the higher light vibrations without going through the lower heat vibrations. It is the problem of imparting to a body a certain velocity without passing through all lower velocities. But there is a possibility of obtaining energy not only in the form of light, but motive power, and energy of any other form, in some more direct way from the medium. The time will be when this will be accomplished, and the time has come when one may utter such words before an enlightened audience without being considered a visionary. We are whirling through endless space with an inconceivable speed, all around us everything is spinning, everything is moving, everywhere is energy. There *must* be some way of availing ourselves of this energy more directly. Then, with the light obtained from the medium, with the power derived from it, with every form of energy obtained without effort, from the store forever inexhaustible, humanity will advance with giant strides. The mere contemplation of these magnificent possibilities expands our minds, strengthens our hopes and fills our hearts with supreme delight.

3

EXPERIMENTS WITH ALTERNATE CURRENTS OF HIGH POTENTIAL AND HIGH FREQUENCY*

I cannot find words to express how deeply I feel the honor of addressing some of the foremost thinkers of the present time, and so many able scientific men, engineers and electricians, of the country greatest in scientific achievements.

The results which I have the honor to present before such a gathering I cannot call my own. There are among you not a few who can lay better claim than myself on any feature of merit which this work may contain. I need not mention many names which are world-known — names of those among you who are recognized as the leaders in this enchanting science; but one, at least, I must mention — a name which could not be omitted in a demonstration of this kind. It is a name associated with the most beautiful invention ever made: it is Crookes!

When I was at college, a good time ago, I read, in a translation (for then I was not familiar with you magnificent language), the description of his experiments on radiant matter. I read it only once in my life — that time — yet every detail about that charming work I can remember this day. Few are the books, let me say, which can make such an impression upon the mind of a student.

But if, on the present occasion, I mention this name as one of many your institution can boast of, it is because I have more than one reason to do so. For what I have to tell you and to show you this evening concerns, in a large measure, that same vague world which Professor Crookes has so ably explored; and, more than this, when I trace back the mental process which led me to these advances — which even by myself cannot be considered trifling, since they are so appreciated by you — I believe that their real origin, that which started me to work in this direction, and brought me to them, after a long period of constant thought, was that fascinating little book which I read many years ago.

And now that I have made a feeble effort to express my homage and acknowledge my indebtedness to him and others among you, I will make a second effort, which I hope you will not find so feeble as the first, to entertain you.

Give me leave to introduce the subject in a few words.

A short time ago I had the honor to bring before our American Institute of Electrical Engineers some results then arrived at by me in a novel line of work. I need not assure you that the many evidences which I have received that English scientific men and engineers were interested in this work have been for me a great reward and encouragement. I will not dwell upon the experiments already described, except with the view of completing, or more clearly expressing, some ideas advanced by me before, and also with the view of rendering the study here presented self-contained, and my remarks on the subject of this evening's lecture consistent.

* Lecture delivered before the I.E.E., London, February, 1892.

This investigation, then, it goes without saying, deals with alternating currents, and, to be more precise, with alternating currents of high potential and high frequency. Just in how much a very high frequency is essential for the production of the results presented is a question which, even with my present experience, would embarrass me to answer. Some of the experiments may be performed with low frequencies; but very high frequencies are desirable, not only on account of the many effects secured by their use, but also as a convenient means of obtaining, in the induction apparatus employed, the high potentials, which in their turn are necessary to the demonstration of most of the experiments here contemplated.

Of the various branches of electrical investigation, perhaps the most interesting and immediately the most promising is that dealing with alternating currents. The progress in this branch of applied science has been so great in recent years that it justifies the most sanguine hopes. Hardly have we become familiar with one fact, when novel experiences are met with and new avenues of research are opened. Even at this hour possibilities not dreamed of before are, by the use of these currents, partly realized. As in nature all is ebb and tide, all is wave motion, so it seems that in all branches of industry alternating currents — electric wave motion — will have the sway.

One reason, perhaps, why this branch of science is being so rapidly developed is to be found in the interest which is attached to its experimental study. We wind a simple ring of iron with coils; we establish the connections to the generator, and with wonder and delight we note the effects of strange forces which we bring into play, which allow us to transform, to transmit and direct energy at will. We arrange the circuits properly, and we see the mass of iron and wires behave as though it were endowed with life, spinning a heavy armature, through invisible connections, with great speed and power — with the energy possibly conveyed from a great distance. We observe how the energy of an alternating current traversing the wire manifests itself — not so much in the wire as in the surrounding space — in the most surprising manner, taking the forms of heat, light, mechanical energy, and, most surprising of all, even chemical affinity. All these observations fascinate us, and fill us with an intense desire to know more about the nature of these phenomena. Each day we go to our work in the hope of discovering, — in the hope that some one, on matter who, may find a solution of one of the pending great problems, — and each succeeding day we return to our task with renewed ardor; and even if we *are* unsuccessful, our work has not been in vain, for in these strivings, in these efforts, we have found hours of untold pleasure, and we have directed our energies to the benefit of mankind.

We may take — at random, if you choose — any of the many experiments which may be performed with alternating currents; a few of which only, and by no means the most striking, form the subject of this evening's demonstration; they are all equally interesting, equally inciting to thought.

Here is a simple glass tube from which the air has been partially exhausted. I take hold of it; I bring my body in contact with a wire conveying alternating currents of high potential, and the tube in my hand is brilliantly lighted. In whatever position I may put it, wherever I may move it in space, as far as I can reach, its soft, pleasing light persists with undiminished brightness.

Here is an exhausted bulb suspended from a single wire. Standing on an insulated support, I grasp it, and a platinum button mounted in it is brought to vivid incandescence.

Here, attached to a leading wire, is another bulb, which, as I touch its metallic socket, is filled with magnificent colors of phosphorescent light.

Here still another, which by my fingers' touch casts a shadow — the Crookes shadow, of the stem inside of it.

Here, again, insulated as I stand on this platform, I bring my body in contact with one of the terminals of the secondary of this induction coil — with the end of a wire many miles long — and you see streams of light break forth from its distant end, which is set in violent vibration.

Here, once more, I attach these two plates of wire gauze to the terminals of the coil, I set them a distance apart, and I set the coil to work. You may see a small spark pass between the plates. I insert a thick plate of one of the best dielectrics between them, and instead of rendering altogether impossible, as we are used to expect, I *aid* the passage of the discharge, which, as I insert the plate, merely changes in appearance and assumes the form of luminous streams.

Is there, I ask, can there be, a more interesting study than that of alternating currents?

In all these investigations, in all these experiments, which are so very, very interesting, for many years past — ever since the greatest experimenter who lectured in this hall discovered its principle — we have had a steady companion, an appliance familiar to every one, a plaything once, a thing of momentous importance now — the induction coil. There is no dearer appliance to the electrician. From the ablest among you, I dare say, down to the inexperienced student, to your lecturer, we all have passed many delightful hours in experimenting with the induction coil. We have watched its play, and thought and pondered over the beautiful phenomena which it disclosed to our ravished eyes. So well known is this apparatus, so familiar are these phenomena to every one, that my courage nearly fails me when I think that I have ventured to address so able an audience, that I have ventured to entertain you with that same old subject. Here in reality is the same apparatus, and here are the same phenomena, only the apparatus is operated somewhat differently, the phenomena are presented in a different aspect. Some of the results we find as expected, others surprise us, but all captivate our attention, for in scientific investigation each novel result achieved may be the centre of a new departure, each novel fact learned may lead to important developments.

Usually in operating an induction coil we have set up a vibration of moderate frequency in the primary, either by means of an interrupter or break, or by the use of an alternator. Earlier English investigators, to mention only Spottiswoode and J. E. H. Gordon, have used a rapid break in connection with the coil. Our knowledge and experience of today enables us to see clearly why these coils under the conditions of the tests did not disclose any remarkable phenomena, and why able experimenters failed to perceive many of the curious effects which have since been observed.

In the experiments such as performed this evening, we operate the coil either from a specially constructed alternator capable of giving many thousands of reversals of current per second, or, by disruptively discharging a condenser through the primary, we set up a vibration in the secondary circuit of a frequency of many hundred thousand or millions per second, if we so desire; and in using either of these means we enter a field as yet unexplored.

It is impossible to pursue an investigation in any novel line without finally making some interesting observation or learning some useful fact. That this statement is applicable to the subject of this lecture the many curious and unexpected phenomena which we observe afford a convincing proof. By way of illustration, take for instance the most obvious phenomena, those of the discharge of the induction coil.

Here is a coil which is operated by currents vibrating with extreme rapidity, obtained by disruptively discharging a Leyden jar. It would not surprise a student were the lecturer to say that the secondary of this coil consists of a small length of comparatively stout wire; it would not surprise him were the lecturer to state that, in spite of this, the coil is capable of giving any potential which the best insulation of the turns is able to withstand; but although he may be prepared, and even be indifferent as to the anticipated result, yet the aspect of the discharge of the coil will surprise and interest him. Every one is familiar with the discharge of an ordinary coil; it need not be reproduced here. But, by way of contrast, here is a form of discharge of a coil, the primary current of which is vibrating several hundred thousand times per second. The discharge of an ordinary coil appears as a simple line or band of light. The discharge of this coil appears in the form of powerful brushes and luminous streams issuing from all points of the two straight wires attached to the terminals of the secondary (Fig. 1.)

Now compare this phenomenon which you have just witnessed with the discharge of a Holtz or Wimshurst machine — that other interesting appliance so dear to the experimenter. What a difference there is between these phenomena! And yet, had I made the necessary arrangements — which could have been made easily, were it not that they would interfere with other experiments — I could have produced with this coil sparks which, had I the coil hidden from your view and only two knobs exposed, even the keenest observer among you would find it difficult, if not impossible, to distinguish from those of an influence or friction machine. This may be done in many ways — for instance, by operating the induction coil which charges the condenser from an alternating-current machine of very low frequency, and preferably adjusting the discharge circuit so that there are no oscillations set up in it. We then obtain in the secondary circuit, if the knobs are of the required size and properly set, a more or less rapid succession of sparks of great intensity and small quantity, which possess the same brilliancy, and are accompanied by the same sharp crackling sound, as those obtained from a friction or influence machine.

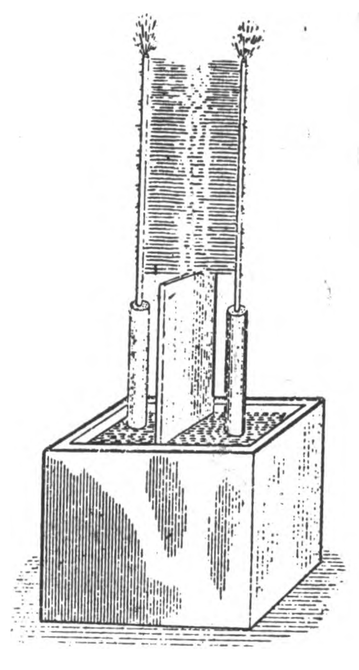


Fig. 1.

Another way is to pass through two primary circuits, having a common secondary, two currents of a slightly different period, which produce in the secondary circuit sparks occurring at comparatively long intervals. But. even with the means at hand this evening, I may succeed in imitating the spark of a Holtz machine. For this purpose I establish between the terminals of the coil which charges the condenser a long, unsteady arc, which is periodically interrupted by the upward current of air produced by it. To increase the current of air I place on each side of the arc, and close to it, a large plate of mica. The condenser charged from this coil discharges into the primary circuit of a second coil through a small air gap, which is necessary to produce a sudden rush of current through the primary. The scheme of connections in the present experiment is indicated in Fig. 2.

G is an ordinarily constructed alternator, supplying the primary *P* of an induction coil, the secondary *S* of which charges the condensers or jars *C C.* The terminals of the secondary are connected to the inside coatings of the jars, the outer coatings being connected to the ends of the primary *p p* of a second induction coil. This primary *p p* has a small air gap *a b.*

The secondary *s* of this coil is provided with knobs or spheres *K K* of the proper size and set at a distance suitable for the experiment.

A long arc is established between the terminals *A B* of the first induction coil. *M M* are the mica plates.

Each time the arc is broken between *A* and *B* the jars are quickly charged and discharged through the primary *p p,* producing a snapping spark between the knobs *K K.* Upon the arc forming between *A* and *B* the potential falls, and the jars cannot be charged to such high potential as to break through the air gap *a b* until the arc is again broken by the draught.

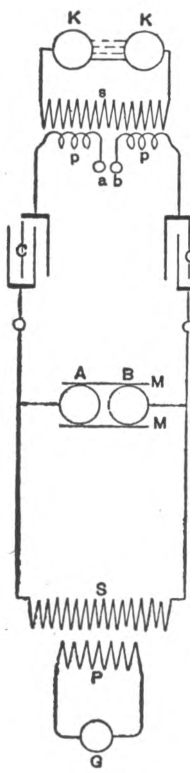


Fig. 2.

In this manner sudden impulses, at long intervals, are produced in the primary *p p,* which in the secondary *s* give a corresponding number of impulses of great intensity. If the secondary knobs or spheres, *K K,* are of the proper size, the sparks show much resemblance to those of a Holtz machine.

But these two effects, which to the eye appear so very different, are only two of the many discharge phenomena. We only need to change the conditions of the test, and again we make other observations of interest.

When, instead of operating the induction coil as in the last two experiments, we operate it from a high frequency alternator, as in the next experiment, a systematic study of the phenomena is rendered much more easy. In such case, in varying the strength and frequency of the currents through the primary, we may observe five distinct forms of discharge, which I have described in my former paper on the subject* before the American Institute of Electrical Engineers, May 20, 1891.

It would take too much time, and it would lead us too far from the subject presented this evening, to reproduce all these forms, but it seems to me desirable to show you one of them. It is a brush discharge, which is interesting in more than one respect. Viewed from a near position it resembles much a jet of gas escaping under great pressure. We know that the phenomenon is due to the agitation of the molecules near the terminal, and we anticipate that some heat must be developed by the impact of the molecules against the terminal or against each other. Indeed, we find that the brush is hot, and only a little thought leads us to the conclusion that, could we but reach sufficiently high frequencies, we could produce a brush which would give intense light and heat, and which would resemble in every particular an ordinary flame, save, perhaps, that both phenomena might not be due to the same agent — save, perhaps, that chemical affinity might not be *electrical* in its nature.

As the production of heat and light is here due to the impact of the molecules, or atoms of air, or something else besides, and, as we can augment the energy simply by raising the potential, we might, even with frequencies obtained from a dynamo machine, intensify the action to such a degree as to bring the terminal to melting heat. But with such low frequencies we would have to deal always with something of the nature of an electric current. If I approach a conducting object to the brush, a thin little spark passes, yet, even with the frequencies used this evening, the tendency to spark is not very great. So, for instance, if I hold a metallic sphere at some distance above the

* See The Electrical World, July 11, 1891.

terminal you may see the whole space between the terminal and sphere illuminated by the streams without the spark passing; and with the much higher frequencies obtainable by the disruptive discharge of a condenser, were it not for the sudden impulses, which are comparatively few in number, sparking would not occur even at very small distances. However, with incomparably higher frequencies, which we may yet find means to produce efficiently, and provided that electric impulses of such high frequencies could be transmitted through a conductor, the electrical characteristics of the brush discharge would completely vanish — no spark would pass, no shock would be felt — yet we would still have to deal with an *electric* phenomenon, but in the broad, modern interpretation of the word. In my first paper before referred to I have pointed out the curious properties of the brush, and described the best manner of producing it, but I have thought it worth while to endeavor to express myself more clearly in regard to this phenomenon, because of its absorbing interest.

When a coil is operated with currents of very high frequency, beautiful brush effects may be produced, even if the coil be of comparatively small dimensions. The experimenter may vary them in many ways, and, if it were nothing else, they afford a pleasing sight. What adds to their interest is that they may be produced with one single terminal as well as with two — in fact, often better with one than with two.

But of all the discharge phenomena observed, the most pleasing to the eye, and the most instructive, are those observed with a coil which is operated by means of the disruptive discharge of a condenser. The power of the brushes, the abundance of the sparks, when the conditions are patiently adjusted, is often amazing. With even a very small coil, if it be so well insulated as to stand a difference of potential of several thousand volts per turn, the sparks may be so abundant that the whole coil may appear a complete mass of fire.

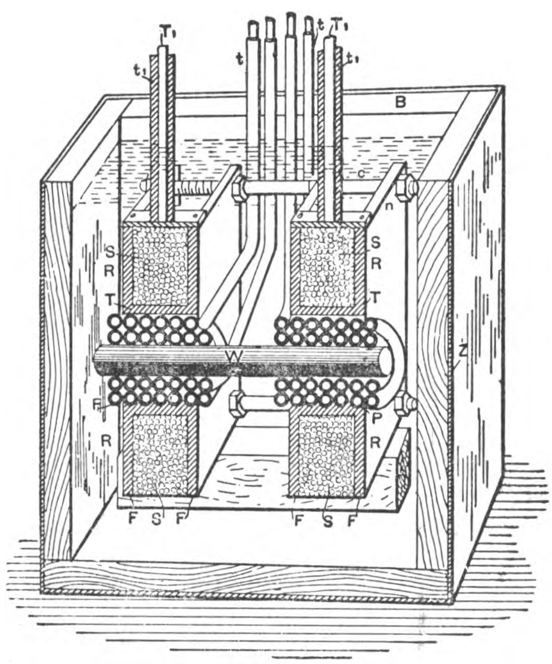


Fig. 3.

Curiously enough the sparks, when the terminals of the coil are set at a considerable distance, seem to dart in every possible direction as though the terminals were perfectly independent of each other. As the sparks would soon destroy the insulation it is necessary to prevent them. This is best done by immersing the coil in a good liquid insulator, such as boiled-out oil. Immersion in a liquid may be considered almost an absolute necessity for the continued and successful working of such a coil.

It is of course out of the question, in an experimental lecture, with only a few minutes at disposal for the performance of each experiment, to show these discharge phenomena to advantage, as to produce each phenomenon at its best a very careful adjustment is required. But even if imperfectly produced, as they are likely to be this evening, they are sufficiently striking to interest an intelligent audience.

Before showing some of these curious effects I must, for the sake of completeness, give a short description of the coil and other apparatus used in the experiments with the disruptive discharge this evening.

It is contained in a box *B* (Fig. 3) of thick boards of hard wood, covered on the outside with zinc sheet Z, which is carefully soldered all around. It might be advisable, in a strictly scientific investigation, when accuracy is of great importance, to do away with the metal cover, as it might introduce many errors, principally on account of its complex action upon the coil, as a condenser of very small capacity and as an electrostatic and electromagnetic screen. When the coil is used for such experiments as are here contemplated, the employment of the metal cover offers some practical advantages, but these are not of sufficient importance to be dwelt upon.

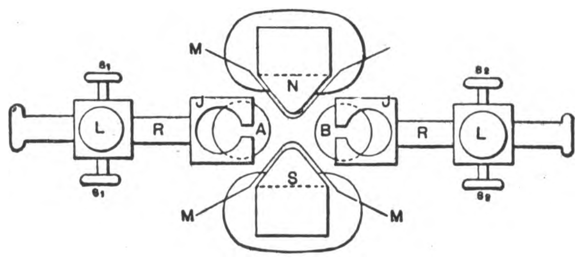


Fig. 4.

The coil should be placed symmetrically to the metal cover, and the space between should, of course, not be too small, certainly not less than, say, five centimetres, but much more if possible; especially the two sides of the zinc box, which are at right angles to the axis of the coil, should be sufficiently remote from the latter, as otherwise they might impair its action and be a source of loss.

The coil consists of two spools of hard rubber *R R,* held apart at a distance of 10 centimetres by bolts *c* and nuts *n,* likewise of hard rubber. Each spool comprises a tube *T* of approximately 8 centimetres inside diameter, and 3 millimetres thick, upon which are screwed two flanges *F F,* 24 centimetres square, the space between the flanges being about 3 centimetres. The secondary, *S S,* of the best gutta percha-covered wire, has 26 layers, 10 turns in each, giving for each half a total of 260 turns. The two halves are wound oppositely and connected in series, the connection between both being made over the primary. This disposition, besides being convenient, has the advantage that when the coil is well balanced — that is, when both of its terminals T_1 T_1 are connected to bodies or devices of equal capacity — there is not much danger of breaking through to the primary, and the insulation between the primary and the secondary need not be thick. In using the coil it is advisable to attach to *both* terminals devices of nearly equal capacity, as, when the capacity of the terminals is not equal, sparks will be apt to pass to the primary. To avoid this, the middle point of the secondary may be connected to the primary, but this is not always practicable.

The primary *P P* is wound in two parts, and oppositely, upon a wooden spool *W,* and the four ends are led out of the oil through hard rubber tubes *t t.* The ends of the secondary T_1 T_1 are also led out of the oil through rubber tubes t_1 t_1 of great thickness. The primary and secondary layers are insulated by cotton cloth, the thickness of the insulation, of course, bearing some proportion to the difference of potential between the turns of the different layers. Each half of the primary has four layers, 24 turns in each, this giving a total of 96 turns. When both the parts are connected in series, this gives a ratio of conversion of about 1:2.7, and with the primaries in multiple, 1:5,4; but in operating with very rapidly alternating currents this ratio does not convey even an approximate idea of the ratio of the E.M.Fs. in the primary and secondary circuits. The coil is held in position in the oil on wooden supports, there being about 5 centimetres thickness of oil all round. Where the oil is not specially needed, the space is filled with pieces of wood, and for this purpose principally the wooden box *B* surrounding the whole is used.

The construction here shown is, of course, not the best on general principles, but I believe it is a good and convenient one for the production of effects in which an excessive potential and a very small current are needed.

In connection with the coil I use either the ordinary form of discharger or a modified form. In the former I have introduced two changes which secure some advantages, and which are obvious. If they are mentioned, it is only in the hope that some experimenter may find them of use.

One of the changes is that the adjustable knobs *A* and *B* (Fig. 4), of the discharger are held in jaws of brass, *J J,* by spring pressure, this allowing of turning them successively into different positions, and so doing away with the tedious process of frequent polishing up.

The other change consists in the employment of a strong electromagnet *N S,* which is placed with its axis at right angles to the line joining the knobs *A* and *B,* and produces a strong magnetic field between them. The pole pieces of the magnet are movable and properly formed so as to protrude between the brass knobs, in order to make the field

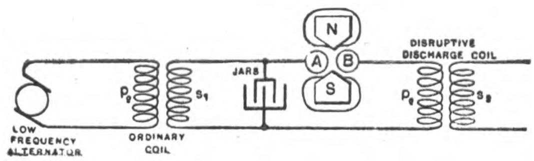


Fig. 5.

as intense as possible; but to prevent the discharge from jumping to the magnet the pole pieces are protected by a layer of mica, *M M,* of sufficient thickness, s_1 s_1 and s_2 s_2 are screws for fastening the wires. On each side one of the screws is for large and the other for small wires. *L L* are screws for fixing in position the rods *R R,* which support the knobs.

In another arrangement with the magnet I take the discharge between the rounded pole pieces themselves, which in such case are insulated and preferably provided with polished brass caps.

The employment of an intense magnetic field is of advantage principally when the induction coil or transformer which charges the condenser is operated by currents of very low frequency. In such a case the number of the fundamental discharges between the knobs may be so small as to render the currents produced in the secondary unsuitable for many experiments. The intense magnetic field than serves to blow out the arc between the knobs as soon as it is formed, and the fundamental discharges occur in quicker succession.

Instead of the magnet, a draught or blast of air may be employed with some advantage. In this case the arc is preferably established between the knobs *A B,* in Fig. 2 (the knobs *a b* being generally joined, or entirely done away with), as in this disposition the arc is long and unsteady, and is easily affected by the draught.

When a magnet is employed to break the arc, it is better to choose the connection indicated diagrammatically in Fig 5, as in this case the currents forming the arc are much more powerful, and the magnetic field exercises a greater influence. The use of the magnet permits, however, of the arc being replaced by a vacuum tube, but I have encountered great difficulties in working with an exhausted tube.

The other form of discharger used in these and similar experiments is indicated in Figs. 6 and 7. It consists of a number of brass pieces *c c* (Fig. 6), each of which comprises a spherical middle portion *m* with an extension *e* below — which is merely used to fasten the piece in a lathe when polishing up the discharging surface — and a column above, which consists of a knurled flange *f* surmounted by a threaded stem *l* carrying a nut *n,* by means of which a wire is fastened to the column. The flange *f*

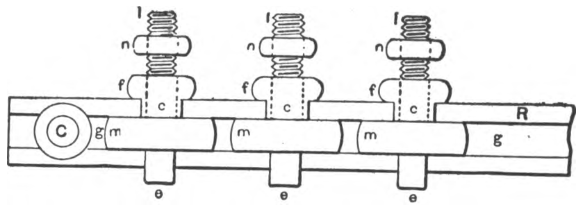


Fig. 6.

conveniently serves for holding the brass piece when fastening the wire, and also for turning it in any position when it becomes necessary to present a fresh discharging surface. Two stout strips of hard rubber *R R,* with planed grooves *g g* (Fig. 7) to fit the middle portion of the pieces *c c,* serve to clamp the latter and hold them firmly in position by means of two bolts *C C* (of which only one is shown) passing through the ends of the strips.

In the use of this kind of discharger I have found three principal advantages over the ordinary form. First, the dielectric strength of a given total width of air space is greater when a great many small air gaps are used instead of one, which permits of working with a smaller length of air gap, and that means smaller loss and less deterioration of the metal; secondly by reason of splitting the arc up into smaller arcs, the polished surfaces are made to last much longer; and, thirdly, the apparatus affords some gauge in the experiments. I usually set the pieces by putting between them sheets of uniform thickness at a certain very small distance which is known from the experiments of Sir William Thomson to require a certain electromotive force to be bridged by the spark.

It should, of course, be remembered that the sparking distance is much diminished as the frequency is increased. By taking any number of spaces the experimenter has a rough idea of the electromotive force, and he finds it easier to repeat an experiment, as he has not the trouble of setting the knobs again and again. With this kind of discharger I have been able to maintain an oscillating motion without any spark being visible with the naked eye between the knobs, and they would not show a very appreciable rise in temperature. This form of discharge also lends itself to many arrangements of condensers and circuits which are often very convenient and time-saving. I have used it preferably in a disposition similar to that indicated in Fig. 2, when the currents forming the arc are small.

I may here mention that I have also used dischargers with single or multiple air gaps, in which the discharge surfaces were rotated with great speed. No particular advantage was, however, gained by this method, except in cases where the currents from the condenser were large and the keeping cool of the surfaces was necessary, and in cases when, the discharge not being oscillating of itself, the arc as soon as established was broken by the air current, thus starting the vibration at intervals in rapid succession. I have also used mechanical interrupters in many ways. To avoid the difficulties with frictional contacts, the preferred plan adopted was to establish the arc and rotate through it at great speed a rim of mica provided with many holes and fastened to a steel plate.

It is understood, of course, that the employment of a magnet, air current, or other interrupter, produces an effect worth noticing, unless the self-induction, capacity and resistance are so related that there are oscillations set up upon each interruption.

I will now endeavor to show you some of the most noteworthy of these discharge phenomena.

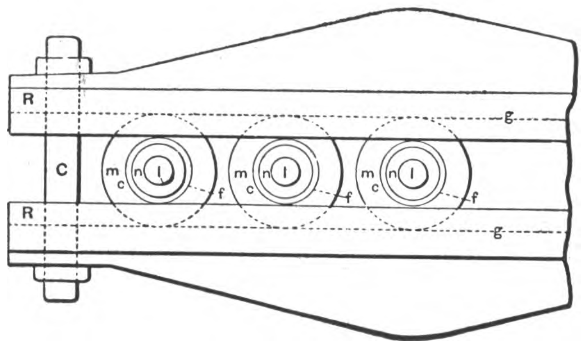


Fig. 7.

I have stretched across the room two ordinary cotton covered wires, each about 7 metres in length. They are supported on insulating cords at a distance of about 30 centimetres. I attach now to each of the terminals of the coil one of the wires and set the coil in action. Upon turning the lights off in the room you see the wires strongly illuminated by the streams issuing abundantly from their whole surface in spite of the cotton covering, which may even be very thick. When the experiment is performed under good conditions, the light from the wires is sufficiently intense to allow distinguishing the objects in a room. To produce the best result it is, of course, necessary to adjust carefully the capacity of the jars, the arc between the knobs and the length of the wires. My experience is that calculation of the length of the wires leads, in such case, to no result whatever. The experimenter will do best to take the wires at the start very long, and then adjust by cutting off first long pieces, and then smaller and smaller ones as he approaches the right length.

A convenient way is to use an oil condenser of very small capacity, consisting of two small adjustable metal plates, in connection with this and similar experiments. In such case I take wires rather short and set at the beginning the condenser plates at maximum distance. If the streams for the wires increase by approach of the plates, the length of the wires is about right; if they diminish the wires are too long for that frequency and potential. When a condenser is used in connection with experiments with such a coil, it should be an oil condenser by all means, as in using an air condenser considerable energy might be wasted. The wires leading to the plates in the oil should be very thin, heavily coated with some insulating compound, and provided with a conducting covering — this preferably extending under the surface of the oil. The conducting cover should not be too near the terminals, or ends, of the wire, as a spark would be apt to jump from the wire to it. The conducting coating is used to diminish the air losses, in virtue of its action as an electrostatic screen. As to the size of the vessel containing the oil, and the size of the plates, the experimenter gains at once an idea from a rough trial. The size of the plates *in oil* is, however, calculable, as the dielectric losses are very small.

In the preceding experiment it is of considerable interest to know what relation the quantity of the light emitted bears to the frequency and potential of the electric impulses. My opinion is that the heat as well as light effects produced should be proportionate, under otherwise equal conditions of test, to the product of frequency and square of potential, but the experimental verification of the law, whatever it may be, would be exceedingly difficult. One thing is certain, at any rate, and that is, that in augmenting the potential and frequency we rapidly intensify the streams; and, though it may be very sanguine, it is surely not altogether hopeless to expect that we may succeed in producing a practical illuminant on these lines. We would then be simply using burners or flames, in which there would be no chemical process, no consumption of material, but merely a transfer of energy, and which would, in all probability emit more light and less heat than ordinary flames.

The luminous intensity of the streams is, of course, considerably increased when they are focused upon a small surface. This may be shown by the following experiment:

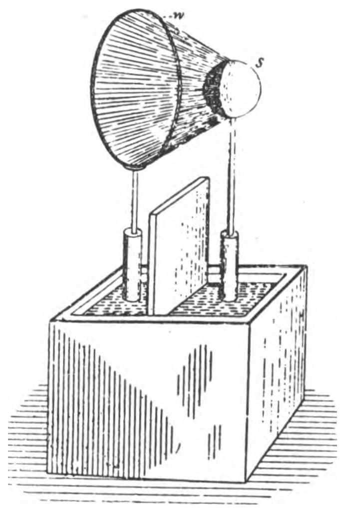


Fig. 8.

I attach to one of the terminals of the coil a wire *w* (Fig. 8), bent in a circle of about 30 centimetres in diameter, and to the other terminal I fasten a small brass sphere *s,* the surface of the wire being preferably equal to the surface of the sphere, and the centre of the latter being in a line at right angles to the plane of the wire circle and passing through its centre. When the discharge is established under proper conditions, a luminous hollow cone is formed, and in the dark one-half of the brass sphere is strongly illuminated, as shown in the cut.

By some artifice or other, it is easy to concentrate the streams upon small surfaces and to produce very strong light effects. Two thin wires may thus be rendered intensely luminous.

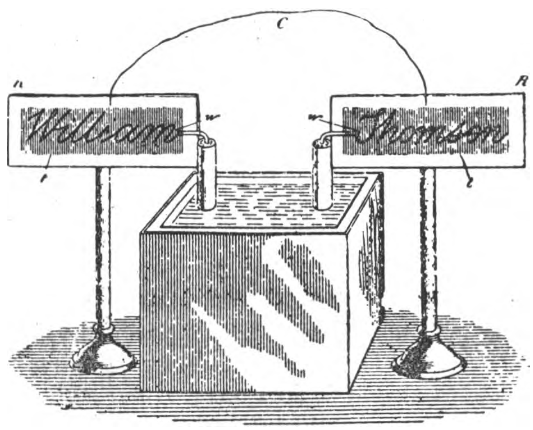
In order to intensify the streams the wires should be very thin and short; but as in this case their capacity would be generally too small for the coil — at least, for such a one as the present — it is necessary to augment the capacity to the required value, while, at the same time, the surface of the wires remains very small. This may be done in many ways.

Here, for instance, I have two plates *R R,* of hard rubber (Fig. 9), upon which I have glued two very thin wires *w w,* so as to form a name. The wires may be bare or covered with the best insulation — it is immaterial for the success of the experiment. Well insulated wires, if anything, are preferable. On the back of each plate, indicated by the shaded portion, is a tinfoil coating *t t.* The plates are placed in line at a sufficient distance to prevent a spark passing from one to the other wire. The two tinfoil coatings I have joined by a conductor *C,* and the two wires I presently connect to the terminals of the coil. It is now easy, by varying the strength and frequency of the currents through the primary, to find a point at which the capacity of the system is best suited to the conditions, and the wires become so strongly luminous that, when the light in the room is turned off the name formed by them appears in brilliant letters.

It is perhaps preferable to perform this experiment with a coil operated from an alternator of high frequency, as then, owing to the harmonic rise and fall, the streams are very uniform, though they are less abundant than when produced with such a coil as the present. This experiment, however, may be performed with low frequencies, but much less satisfactorily.

When two wires, attached to the terminals of the coil, are set at the proper distance, the streams between them may be so intense as to produce a continuous luminous sheet.

To show this phenomenon I have here two circles, *C* and *c* (Fig. 10), of rather stout wire, one being about 80 centimetres and the other 30 centimetres in diameter. To each of the terminals of the coil I attach one of the circles. The supporting wires are so bent that the circles may be placed in the same plane, coinciding as nearly as possible. When the light in the room is turned off and the coil set to work, you see the whole space between the wires uniformly filled with streams, forming a luminous disc, which could be seen from a considerable distance, such is the intensity of the streams. The outer circle could have been much larger than the present one; in fact, with this coil I have used much larger circles, and I have been able to produce a strongly luminous sheet, covering an area of more than one square metre, which is a remarkable effect with this very small coil. To avoid uncertainty, the circle has been taken smaller, and the area is how about 0,43 square metre.



Fig, 9.

The frequency of the vibration, and the quickness of succession of the sparks between the knobs, affect to a marked degree the appearance of the streams. When the frequency is very low, the air gives way in more or less the same manner, as by a steady difference of potential, and the streams consist of distinct threads, generally mingled with thin sparks, which probably correspond to the successive discharges occurring between the knobs. But when the frequency is extremely high, and the arc of the discharge produces a very *loud* but *smooth* sound — showing both that oscillation takes place and that the sparks succeed each other with great rapidity — then the luminous streams formed are perfectly uniform. To reach this result very small coils and jars of small capacity should be used. I take two tubes of thick Bohemian glass, about 5 centimetres in diameter and 20 centimetres long. In each of the tubes I slip a primary of very thick copper wire. On the top of each tube I wind a secondary of much thinner gutta-percha covered wire. The two secondaries I connect in series, the primaries preferably in multiple arc. The tubes are then placed in a large glass vessel, at a distance of 10 to 15 centimetres from each other, on insulating supports, and the vessel is filled with boiled out oil, the oil reaching about an inch above the tubes. The free ends of the secondary are lifted out of the oil and placed parallel to each other at a distance of about 10 centimetres. The ends which are scraped should be dipped in the oil. Two four-pint jars joined in series may be used to discharge through the primary. When the necessary adjustments in the length and distance of the wires above the oil and in the arc of discharge are made, a luminous sheet is produced between the wires which is perfectly smooth and textureless, like the ordinary discharge through a moderately exhausted tube.

I have purposely dwelt upon this apparently insignificant experiment. In trials of this kind the experimenter arrives at the startling conclusion that, to pass ordinary luminous discharges through gases, no particular degree of exhaustion is needed, but that the gas may be at ordinary or even greater pressure. To accomplish this, a very high frequency is essential; a high potential is likewise required, but this is a merely incidental necessity. These experiments teach us that, in endeavoring to discover novel methods of producing light by the agitation of atoms, or molecules, of a gas, we need not limit our research to the vacuum tube, but may look forward quite seriously to the possibility of obtaining the light effects without the use of any vessel whatever, with air at ordinary pressure.

Such discharges of very high frequency, which render luminous the air at ordinary pressures, we have probably often occasion to witness in Nature. I have no doubt that if, as many believe, the aurora borealis is produced by sudden cosmic disturbances, such as eruptions at the sun's surface, which set the electrostatic charge of the earth in an extremely rapid vibration, the red glow observed is not confined to the upper rarefied strata of the air, but the discharge traverses, by reason of its very high frequency, also the dense atmosphere in the form of a *glow,* such as we ordinarily produce in a slightly exhausted tube. If the frequency were very low, or even more so, if the charge were not at all vibrating, the dense air would break down as in a lightning discharge. Indications of such breaking down of the lower dense strata of the air have been repeatedly observed at the occurrence of this marvelous phenomenon; but if it does occur, it can only be attributed to the fundamental disturbances, which are few in number, for the vibration produced by them would be far too rapid to allow a disruptive break. It is the original and irregular impulses which affect the instruments; the superimposed vibrations probably pass unnoticed.

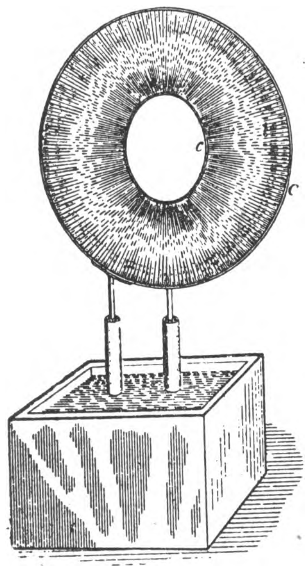


Fig. 10.

When an ordinary low frequency discharge is passed through moderately rarefied air, the air assumes a purplish hue. If by some means or other we increase the intensity of the molecular, or atomic, vibration, the gas changes to a white color. A similar change occurs at ordinary pressures with electric impulses of very high frequency. If the molecules of the air around a wire are moderately agitated, the brush formed is reddish or violet; if the vibration is rendered sufficiently intense, the streams become white. We may accomplish this in various ways. In the experiment before shown with the two wires across the room, I have endeavored to secure the result by pushing to a high value both the frequency and potential; in the experiment with the thin wires glued on the rubber plate I have concentrated the action upon a very small surface — in other words, I have worked with a great electric density.

A most curious form of discharge is observed with such a coil when the frequency and potential are pushed to the extreme limit. To perform the experiment, every part of the coil should be heavily insulated, and only two small spheres — or, better still, two sharp-edged metal discs *(d d,* Fig. 11) of no more than a few centimetres in diameter — should be exposed to the air. The coil here used is immersed in oil, and the ends of the secondary reaching out of the oil are covered with an air-tight cover of hard rubber of great thickness. All cracks, if there are any, should be carefully stopped up, so that the brush discharge cannot form anywhere except on the small spheres or plates which are exposed to the air. In this case, since there are no large plates or other bodies of capacity attached to the terminals, the coil is capable of an extremely rapid vibration. The potential may be raised by increasing, as far as the experimenter judges proper, the rate of change of the primary current. With a coil not widely differing from the present, it is best to connect the two primaries in multiple arc; but if the secondary should have a much greater number of turns the primaries should preferably be used in series, as otherwise the vibration might be too fast for the secondary. It occurs under these conditions that misty white streams break forth from the edges of the discs and spread out phantom-like into space. With this coil, when fairly well produced, they are about 25 to 30 centimetres long. When the hand is held against them no sensation is produced, and a spark, causing a shock, jumps from the terminal only upon the hand being brought much nearer. If the oscillation of the primary current is rendered intermittent by some means or other, there is a corresponding throbbing of the streams, and now the hand or other conducting object may be brought in still greater proximity to the terminal without a spark being caused to jump.

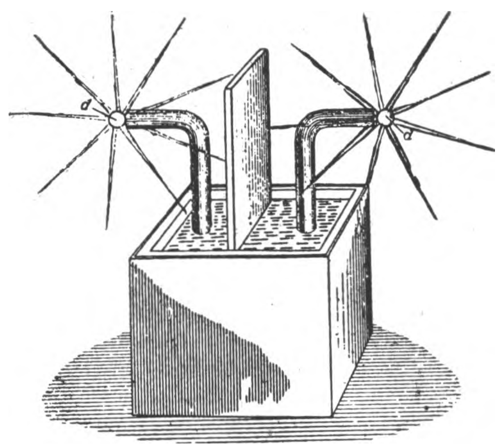


Fig. 11.

Among the many beautiful phenomena which may be produced with such a coil I have here selected only those which appear to possess some features of novelty, and lead us to some conclusions of interest. One will not find it at all difficult to produce in the laboratory, by means of it, many other phenomena which appeal to the eye even more than these here shown, but present no particular feature of novelty.

Early experimenters describe the display of sparks produced by an ordinary large induction coil upon an insulating plate separating the terminals. Quite recently Siemens performed some experiments in which fine effects were obtained, which were seen by many with interest. No doubt large coils, even if operated with currents of low frequencies, are capable of producing beautiful effects. But the largest coil ever made could not, by far, equal the magnificent display of streams and sparks obtained from such a disruptive discharge coil when properly adjusted. To give an idea, a coil such as the present one will cover easily a plate of 1 metre in diameter completely with the streams. The best way to perform such experiments is to take a very thin rubber or a glass plate and glue on one side of it a narrow ring of tinfoil of very large diameter, and on the other a circular washer, the centre of the latter coinciding with that of the ring, and the surfaces of both being preferably equal, so as to keep the coil well balanced. The washer and ring should be connected to the terminals by heavily insulated thin wires. It is easy in observing the effect of the capacity to produce a sheet of uniform streams, or a fine network of thin silvery threads, or a mass of loud brilliant sparks, which completely cover the plate.

Since I have advanced the idea of the conversion by means of the disruptive discharge, in my paper before the American Institute of Electrical Engineers at the beginning of the past year, the interest excited in it has been considerable. It affords us a means for producing any potentials by the aid of inexpensive coils operated from ordinary systems of distribution, and — what is perhaps more appreciated — it enables us to convert currents of any frequency into currents of any other lower or higher frequency. But its chief value will perhaps be found in the help which it will afford us in the investigations of the phenomena of phosphorescence, which a disruptive discharge coil is capable of exciting in innumerable cases where ordinary coils, even the largest, would utterly fail.

Considering its probable uses for many practical purposes, and its possible introduction into laboratories for scientific research, a few additional remarks as to the construction of such a coil will perhaps not be found superfluous.

It is, of course, absolutely necessary to employ in such a coil wires provided with the best insulation.

Good coils may be produced by employing wires covered with several layers of cotton, boiling the coil a long time in pure wax, and cooling under moderate pressure. The advantage of such a coil is that it can be easily handled, but it cannot probably give as satisfactory results as a coil immersed in pure oil. Besides, it seems that the presence of a large body of wax affects the coil disadvantageously, whereas this does not seem to be the case with oil. Perhaps it is because the dielectric losses in the liquid are smaller.

I have tried at first silk and cotton covered wires with oil immersion, but I have been gradually led to use gutta-percha covered wires, which proved most satisfactory. Gutta-percha insulation adds, of course, to the capacity of the coil, and this, especially if the coil be large, is a great disadvantage when extreme frequencies are desired; but, on the other hand, gutta-percha will withstand much more than an equal thickness of oil, and this advantage should be secured at any price. Once the coil has been immersed, it should never be taken out of the oil for more than a few hours, else the gutta-percha will crack up and the coil will not be worth half as much as before. Gutta-percha is probably slowly attacked by the oil, but after an immersion of eight to nine months I have found no ill effects.

I have obtained in commerce two kinds of gutta-percha wire: in one the insulation sticks tightly to the metal, in the other it does not. Unless a special method is followed to expel all air, it is much safer to use the first kind. I wind the coil within an oil tank so that all interstices are filled up with the oil. Between the layers I use cloth boiled out thoroughly in oil, calculating the thickness according to the difference of potential between the turns. There seems not to be a very great difference whatever kind of oil is used; I use paraffine or linseed oil.

To exclude more perfectly the air, an excellent way to proceed, and easily practicable with small coils, is the following: Construct a box of hard wood of very thick boards which have been for a long time boiled in oil. The boards should be so joined as to safely withstand the external air pressure. The coil being placed and fastened in position within the box, the latter is closed with a strong lid, and covered with closely fitting metal sheets, the joints of which are soldered very carefully. On the top two small holes are drilled, passing through the metal sheet and the wood, and in these holes two small glass tubes are inserted and the joints made air-tight. One of the tubes is connected to a vacuum pump, and the other with a vessel containing a sufficient quantity of boiled-out oil. The latter tube has a very small hole at the bottom, and is provided with a stopcock. When a fairly good vacuum has been obtained, the stopcock is opened and the oil slowly fed in. Proceeding in this manner, it is impossible that any big bubbles, which are the principal danger, should remain between the turns. The air is most completely excluded, probably better than by boiling out, which, however, when gutta-percha coated wires are used, is not practicable.

For the primaries I use ordinary line wire with a thick cotton coating. Strands of very thin insulated wires properly interlaced would, of course, be the best to employ for the primaries, but they are not to be had.

In an experimental coil the size of the wires is not of great importance. In the coil here used the primary is No. 12 and the secondary No. 24 Brown & Sharpe gauge wire; but the sections may be varied considerably. I would only imply different adjustments; the results aimed at would not be materially affected.

I have dwelt at some length upon the various forms of brush discharge because, in studying them, we not only observe phenomena which please our eye, but also afford us food for thought, and lead us to conclusions of practical importance. In the use of alternating currents of very high tension, too much precaution cannot be taken to prevent the brush discharge. In a main conveying such currents, in an induction coil or transformer, or in a condenser, the brush discharge is a source of great danger to the insulation. In a condenser especially the gaseous matter must be most carefully expelled, for in it the charged surfaces are near each other, and if the potentials are high, just as sure as a weight will fall if let go, so the insulation will give way if a single gaseous bubble of some size be present, whereas, if all gaseous matter were carefully excluded, the condenser would safely withstand a much higher difference of potential. A main conveying alternating currents of very high tension may be injured merely by a blow-hole or small crack in the insulation, the more so as a blowhole is apt to contain gas at low pressure; and as it appears almost impossible to completely obviate such little imperfections, I am led to believe that in our future distribution of electrical energy by currents of very high tension liquid insulation will be used. The cost is a great drawback, but if we employ an oil as an insulator the distribution of electrical energy with something like 100,000 volts, and even more, become, at least with higher frequencies, so easy that they could be hardly called engineering feats. With oil insulation and alternate current motors transmissions of power can be effected with safety and upon an industrial basis at distances of as much as a thousand miles.

A peculiar property of oils, and liquid insulation in general, when subjected to rapidly changing electric stresses, is to disperse any gaseous bubbles which may be present, and diffuse them through its mass, generally long before any injurious break can occur. This feature may be easily observed with an ordinary induction coil by taking the primary out, plugging up the end of the tube upon which the secondary is wound, and filling it with some fairly transparent insulator, such as paraffine oil. A primary of a diameter something like six millimetres smaller than the inside of the tube may be inserted in the oil. When the coil is set to work one may see, looking from the top through the oil, many luminous points — air bubbles which are caught by inserting the primary, and which are rendered luminous in consequence of the violent bombardment. The occluded air, by its impact against the oil, beats it; the oil begins to circulate, carrying some of the air along with it, until the bubbles are dispersed and the luminous points disappear. In this manner, unless large bubbles are occluded in such way that circulation is rendered impossible, a damaging break is averted, the only effect being a moderate warming up of the oil. If, instead of the liquid, a solid insulation, no matter how thick, were used, a breaking through and injury of the apparatus would be inevitable.

The exclusion of gaseous matter from any apparatus in which the dielectric is subjected to more or less rapidly changing electric forces is, however, not only desirable in order to avoid a possible injury of the apparatus, but also on account of economy. In a condenser, for instance, as long as only a solid or only a liquid dielectric is used, the loss is small; but if a gas under ordinary or small pressure be present the loss may be very great. Whatever the nature of the force acting in the dielectric may be, it seems that in a solid or liquid the molecular displacement produced by the force is small:

hence the product of force and displacement is insignificant, unless the force be very great; but in a gas the displacement, and therefore this product, is considerable; the molecules are free to move, they reach high speeds, and the energy of their impact is lost in heat or otherwise. If the gas be strongly compressed, the displacement due to the force is made smaller, and the losses are reduced.

In most of the succeeding experiments I prefer, chiefly on account of the regular and positive action, to employ the alternator before referred to. This is one of the several machines constructed by me for the purposes of these investigations. It has 384 pole projections, and is capable of giving currents of a frequency of about 10,000 per second. This machine has been illustrated and briefly described in my first paper before the American Institute of Electrical Engineers, May 20, 1891, to which I have already referred. A more detailed description, sufficient to enable any engineer to build a similar machine, will be found in several electrical journals of that period.

The induction coils operated from the machine are rather small, containing from 5,000 to 15,000 turns in the secondary. They are immersed in boiled-out linseed oil, contained in wooden boxes covered with zinc sheet.

I have found it advantageous to reverse the usual position of the wires, and to wind, in these coils, the primaries on the top; this allowing the use of a much bigger primary, which, of course, reduces the danger of overheating and increases the output of the coil. I make the primary on each side at least one centimetre shorter than the secondary, to prevent the breaking through on the ends, which would surely occur unless the insulation on the top of the secondary be very thick, and this, of course, would be disadvantageous.

When the primary is made movable, which is necessary in some experiments, and many times convenient for the purposes of adjustment, I cover the secondary with wax, and turn it off in a lathe to a diameter slightly smaller than the inside of the primary coil. The latter I provide with a handle reaching out of the oil, which serves to shift it in any position along the secondary.

I will now venture to make, in regard to the general manipulation of induction coils, a few observations bearing upon points which have not been fully appreciated in earlier experiments with such coils, and are even now often overlooked.

The secondary of the coil possesses usually such a high self-induction that the current through the wire is inappreciable, and may be so even when the terminals are joined by a conductor of small resistance. If capacity is added to the terminals, the self-induction is counteracted, and a stronger current is made to flow through the secondary, though its terminals are insulated from each other. To one entirely unacquainted with the properties of alternating currents nothing will look more puzzling. This feature was illustrated in the experiment performed at the beginning with the top plates of wire gauze attached to the terminals and the rubber plate. When the plates of wire gauze were close together, and a small arc passed between them, the arc *prevented* a strong current from passing through the secondary, because it did away with the capacity on the terminals; when the rubber plate was inserted between, the capacity of the condenser formed counteracted the self-induction of the secondary, a stronger current passed now, the coil performed more work, and the discharge was by far more powerful.

The first thing, then, in operating the induction coil is to combine capacity with the secondary to overcome the self-induction. If the frequencies and potentials are very high gaseous matter should be carefully kept away from the charged surfaces. If Leyden jars are used, they should be immersed in oil, as otherwise considerable dissipation may occur if the jars are greatly strained. When high frequencies are used, it is of equal importance to combine a condenser with the primary. One may use a condenser connected to the ends of the primary or to the terminals of the alternator, but the latter is not to be recommended, as the machine might be injured. The best way is undoubtedly to use the condenser in series with the primary and with the alternator, and to adjust its capacity so as to annul the self-induction of both the latter. The condenser should be adjustable by very small steps, and for a finer adjustment a small oil condenser with movable plates may be used conveniently.

I think it best at this juncture to bring before you a phenomenon, observed by me some time ago, which to the purely scientific investigator may perhaps appear more interesting than any of the results which I have the privilege to present to you this evening.

It may be quite properly ranked among the brush phenomena — in fact, it is a brush, formed at, or near, a single terminal in high vacuum.

In bulbs provided with a conducting terminal, though it be of aluminium, the brush has but an ephemeral existence, and cannot, unfortunately, be indefinitely preserved in its most sensitive state, even in a bulb devoid of any conducting electrode. In studying one phenomenon, by all means a bulb having no leading-in wire should be used. I have found it best to use bulbs constructed as indicated in Figs. 12 and 13.

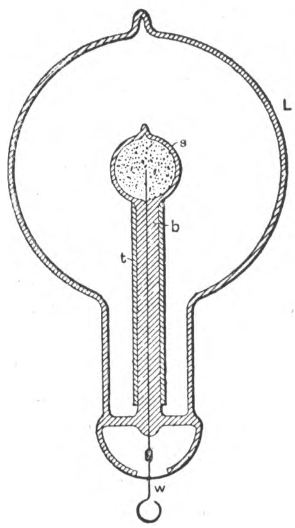


Fig. 12.

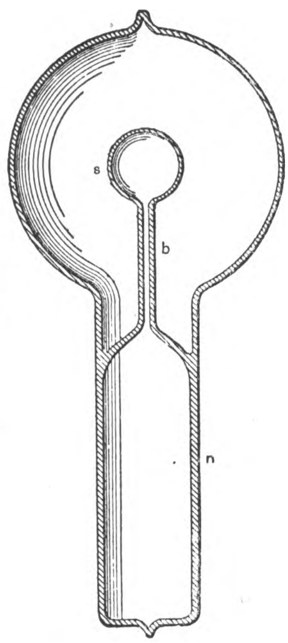


Fig. 13.

In Fig. 12 the bulb comprises an incandescent lamp globe *L,* in the neck of which is sealed a barometer tube *b,* the end of which is blown out to form a small sphere *s.* This sphere should be sealed as closely as possible in the centre of the large globe. Before sealing, a thin tube *t,* of aluminium sheet, may be slipped in the barometer tube, but it is not important to employ it.

The small hollow sphere *s* is filled with some conducting powder, and a wire *w* is cemented in the neck for the purpose of connecting the conducting powder with the generator.

The construction shown in Fig. 13 was chosen in order to remove from the brush any conducting body which might possibly affect it. The bulb consists in this case of a lamp globe *L,* which has a neck *n,* provided with a tube *b* and small sphere *s,* sealed to it, so that two entirely independent compartments are formed, as indicated in the drawing. When the bulb is in use, the neck *n* is provided with a tinfoil coating, which is connected to the generator and acts inductively upon the moderately rarefied and highly conducting gas inclosed in the neck. From there the current passes through the tube *b* into the small sphere *s,* to act by induction upon the gas contained in the globe *L.*

It is of advantage to make the tube *t* very thick, the hole through it very small, and to blow the sphere *s* very thin. It is of the greatest importance that the sphere *s* be placed in the centre of the globe *L.*

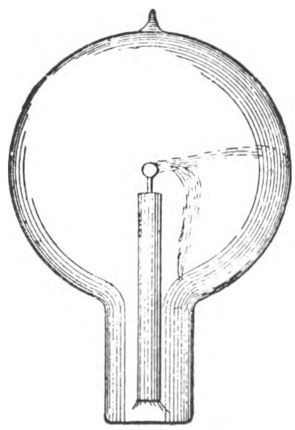


Fig. 14.

Figs. 14, 15 and 16 indicate different forms, or stages, of the brush. Fig. 14 shows the brush as it first appears in a bulb provided with a conducting terminal; but, as in such a bulb it very soon disappears — often after a few minutes — I will confine myself to the description of the phenomenon as seen in a bulb without conducting electrode. It is observed under the following conditions:

When the globe *L* (Figs. 12 and 13) is exhausted to a very high degree, generally the bulb is not excited upon connecting the wire *w* (Fig. 12) or the tinfoil coating of the bulb (Fig. 13) to the terminal of the induction coil. To excite it, it is usually sufficient to grasp the globe *L* with the hand. An intense phosphorescence then spreads at first over the globe, but soon gives place to a white, misty light. Shortly afterward one may notice that the luminosity is unevenly distributed in the globe, and after passing the current for some time the bulb appears as in Fig. 15. From this stage the phenomenon will gradually pass to that indicated in Fig. 16, after some minutes, hours, days or weeks, according as the bulb is worked. Warming the bulb or increasing the potential hastens the transit.

When the brush assumes the form indicated in Fig. 16, it may be brought to a state of extreme sensitiveness to electrostatic and magnetic influence. The bulb hanging straight down from a wire, and all objects being remote from it, the approach of the observer at a few paces from the bulb will cause the brush to fly to the opposite side, and if he walks around the bulb it will always keep on the opposite side. It may begin to spin around the terminal long before it reaches that sensitive stage. When it begins to turn around principally, but also before, it is affected by a magnet, and at a certain stage it is susceptible to magnetic influence to an astonishing degree. A small permanent magnet, with its poles at a distance of no more than two centimetres, will affect it visibly at a distance of two metres, slowing down or accelerating the rotation according to how it is held relatively to the brush. I think I have observed that at the stage when it is most sensitive to magnetic, it is not most sensitive to electrostatic, influence. My explanation is, that the electrostatic attraction between the brush and the glass of the bulb, which retards the rotation, grows much quicker than the magnetic influence when the intensity of the stream is increased.

When the bulb hangs with the globe *L* down, the rotation is always clockwise. In the southern hemisphere it would occur in the opposite direction and on the equator the brush should not turn at all. The rotation may be reversed by a magnet kept at some distance. The brush rotates best, seemingly, when it is at right angles to the lines of force of the earth. It very likely rotates, when at its maximum speed, in synchronism with the alternations, say 10,000 times a second. The rotation can be slowed down or accelerated by the approach or receding of the observer, or any conducting body, but it cannot be reversed by putting the bulb in any position. When it is in the state of the highest sensitiveness and the potential or frequency be varied the sensitiveness is rapidly diminished. Changing either of these but little will generally stop the rotation. The sensitiveness is likewise affected by the variations of temperature. To attain great sensitiveness it is necessary to have the small sphere *s* in the centre of the globe *L,* as otherwise the electrostatic action of the glass of the globe will tend to stop the rotation. The sphere *s* should be small and of uniform thickness; any dissymmetry of course has the effect to diminish the sensitiveness.

The fact that the brush rotates in a definite direction in a permanent magnetic field seems to show that in alternating currents of very high frequency the positive and negative impulses are not equal, but that one always preponderates over the other.

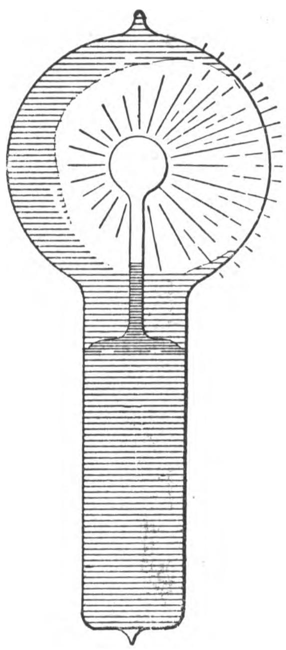


Fig. 15.

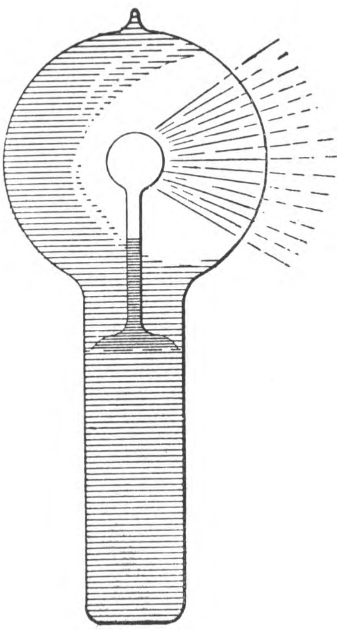


Fig. 16.

Of course, this rotation in one direction may be due to the action of two elements of the same current upon each other, or to the action of the field produced by one of the elements upon the other, as in a series motor, without necessarily one impulse being stronger than the other. The fact that the brush turns, as far as I could observe, in any position, would speak for this view. In such case it would turn at any point of the earth's surface. But, on the other hand, it is then hard to explain why a permanent magnet should reverse the rotation, and one must assume the preponderance of impulses of one kind.

As to the causes of the formation of the brush or stream, I think it is due to the electrostatic action of the globe and the dissymmetry of the parts. If the small bulb *s* and the globe *L* were perfect concentric spheres, and the glass throughout of the same thickness and quality, I think the brush would not form, as the tendency to pass would be equal on all sides. That the formation of the stream is due to an irregularity is apparent from the fact that it has the tendency to remain in one position, and rotation occurs most generally only when it is brought out of this position by electrostatic or magnetic influence. When in an extremely sensitive state it rests in one position, most curious experiments may be performed with it. For instance, the experimenter may, by selecting a proper position, approach the hand at a certain considerable distance to the bulb, and he may cause the brush to pass off by merely stiffening the muscles of the arm. When it begins to rotate slowly, and the hands are held at a proper distance, it is impossible to make even the slightest motion without producing a visible effect upon the brush. A metal plate connected to the other terminal of the coil affects it at a great distance, slowing down the rotation often to one turn a second.

I am firmly convinced that such a brush, when we learn how to produce it properly, will prove a valuable aid in the investigation of the nature of the forces acting in an electrostatic or magnetic field. If there is any motion which is measurable going on in the space, such a brush ought to reveal it. It is, so to speak, a beam of light, frictionless, devoid of inertia.

I think that it may find practical applications in telegraphy. With such a brush it would be possible to send dispatches across the Atlantic, for instance, with any speed, since its sensitiveness may be so great that the slightest changes will affect it. If it were possible to make the stream more intense and very narrow, its deflections could be easily photographed.

I have been interested to find whether there is a rotation of the stream itself, or whether there is simply a stress traveling around in the bulb. For this purpose I mounted a light mica fan so that its vanes were in the path of the brush. If the stream itself was rotating the fan would be spun around. I could produce no distinct rotation of the fan, although I tried the experiment repeatedly; but as the fan exerted a noticeable influence on the stream, and the apparent rotation of the latter was, in this case, never quite satisfactory, the experiment did not appear to be conclusive.

I have been unable to produce the phenomenon with the disruptive discharge coil, although every other of these phenomena can be well produced by it — many, in fact, much better than with coils operated from an alternator.

It may be possible to produce the brush by impulses of one direction, or even by a steady potential, in which case it would be still more sensitive to magnetic influence.

In operating an induction coil with rapidly alternating currents, we realize with astonishment, for the first time, the great importance of the relation of capacity, self-induction and frequency as regards the general result. The effects of capacity are the most striking, for in these experiments, since the self-induction and frequency both are high, the critical capacity is very small, and need be but slightly varied to produce a very considerable change. The experimenter may bring his body in contact with the terminals of the secondary of the coil, or attach to one or both terminals insulated bodies of very small bulk, such as bulbs, and he may produce a considerable rise or fall of potential, and greatly affect the flow of the current through the primary. In the experiment before shown, in which a brush appears at a wire attached to one terminal, and the wire is vibrated when the experimenter brings his insulated body in contact with the other terminal of the coil, the sudden rise of potential was made evident.

I may show you the behavior of the coil in another manner which possesses a feature of some interest. I have here a little light fan of aluminium sheet, fastened to a needle and arranged to rotate freely in a metal piece screwed to one of the terminals of the coil. When the coil is set to work, the molecules of the air are rhythmically attracted and repelled. As the force with which they are repelled is greater than that with which they are attracted, it results that there is a repulsion exerted on the surfaces of the fan. If the fan were made simply of a metal sheet, the repulsion would be equal on the opposite sides, and would produce no effect. But if one of the opposite surfaces is screened, or if, generally speaking, the bombardment on this side is weakened in some way or other, there remains the repulsion exerted upon the other, and the fan is set in rotation. The screening is best effected by fastening upon one of the opposing sides of the fan insulated conducting coatings, or, if the fan is made in the shape of an ordinary propeller screw, by fastening on one side, and close to it, an insulated metal plate. The static screen may however, be omitted and simply a thickness of insulating material fastened to one of the sides of the fan.

To show the behavior of the coil, the fan may be placed upon the terminal and it will readily rotate when the coil is operated by currents of very high frequency. With a steady potential, of course, and even with alternating currents of very low frequency, it would not turn, because of the very slow exchange of air and, consequently, smaller bombardment; but in the latter case it might turn if the potential were excessive. With a pin wheel, quite the opposite rule holds good; it rotates best with a steady potential, and the effort is the smaller the higher the frequency. Now, it is very easy to adjust the conditions so that the potential is normally not sufficient to turn the fan, but that by connecting the other terminal of the coil with an insulated body it rises to a much greater value, so as to rotate the fan, and it is likewise possible to stop the rotation by connecting to the terminal a body of different size, thereby diminishing the potential.

Instead of using the fan in this experiment, we may use the "electric" radiometer with similar effect. But in this case it will be found that the vanes will rotate only at high exhaustion or at ordinary pressures; they will not rotate at moderate pressures, when the air is highly conducting. This curious observation was made conjointly by Professor Crookes and myself. I attribute the result to the high conductivity of the air, the molecules of which then do not act as independent carriers of electric charges, but act all together as a single conducting body. In such case, of course, if there is any repulsion at all of the molecules from the vanes, it must be very small. It is possible, however, that the result is in part due to the fact that the greater part of the discharge passes from the leading-in wire through the highly conducting gas, instead of passing off from the conducting vanes.

In trying the preceding experiment with the electric radiometer the potential should not exceed a certain limit, as then the electrostatic attraction between the vanes and the glass of the bulb may be so great as to stop the rotation.

A most curious feature of alternate currents of high frequencies and potentials is that they enable us to perform many experiments by the use of one wire only. In many respects this feature is of great interest.

In a type of alternate current motor invented by me some years ago I produced rotation by inducing, by means of a single alternating current passed through a motor circuit, in the mass or other circuits of the motor, secondary currents, which, jointly with the primary or inducing current, created a moving field of force. A simple but crude form of such a motor is obtained by winding upon an iron core a primary, and close to it a secondary coil, joining the ends of the latter and placing a freely movable metal disc within the influence of the field produced by both. The iron core is employed for obvious reasons, but it is not essential to the operation. To improve the motor, the iron core is made to encircle the armature. Again to improve, the secondary coil is made to overlap partly the primary, so that it cannot free itself from a strong inductive action of the latter, repel its lines as it may. Once more to improve, the proper difference of phase is obtained between the primary and secondary currents by a condenser, self-induction, resistance or equivalent windings.

I had discovered, however, that rotation is produced by means of a single coil and core; my explanation of the phenomenon, and leading thought in trying the experiment, being that there must be a true time lag in the magnetization of the core. I remember the pleasure I had when, in the writings of Professor Ayrton, which came later to my hand, I found the idea of the time lag advocated. Whether there is a true time lag, or whether the retardation is due to eddy currents circulating in minute paths, must remain an open question, but the fact is that a coil wound upon an iron core and traversed by an alternating current creates a moving field of force, capable of setting an armature in rotation. It is of some interest, in conjunction with the historical Arago experiment, to mention that in lag or phase motors I have produced rotation in the opposite direction to the moving field, which means that in that experiment the magnet may not rotate, or may even rotate in the opposite direction to the moving disc. Here, then, is a motor (diagrammatically illustrated in Fig. 17), comprising a coil and iron core, and a freely movable copper disc in proximity to the latter.

To demonstrate a novel and interesting feature, I have, for a reason which I will explain, selected this type of motor. When the ends of the coil are connected to the terminals of an alternator the disc is set in rotation. But it is not this experiment, now well known, which I desire to perform. What I wish to show you is that this motor rotates with *one single* connection between it and the generator; that is to say, one terminal of the motor is connected to one terminal of the generator — in this case the secondary of a high-tension induction coil — the other terminals of motor and generator being insulated in space. To produce rotation it is generally (but not absolutely) necessary to connect the free end of the motor coil to an insulated body of some size. The experimenter's body is more than sufficient. If he touches the free terminal with an object held in the

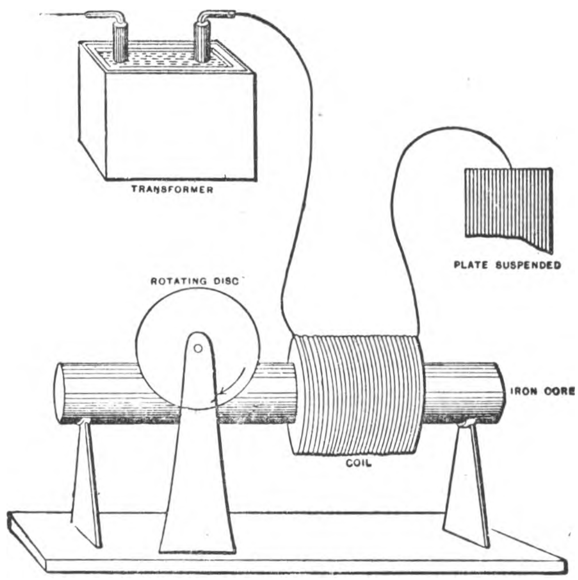


Fig. 17.

hand, a current passes through the coil and the copper disc is set in rotation. If an exhausted tube is put in series with the coil, the tube lights brilliantly, showing the passage of a strong current. Instead of the experimenter's body, a small metal sheet suspended on a cord may be used with the same result. In this case the plate acts as a condenser in series with the coil. It counteracts the self-induction of the latter and allows a strong current to pass. In such a combination, the greater the self-induction of the coil the smaller need be the plate, and this means that a lower frequency, or eventually a lower potential, is required to operate the motor. A single coil wound upon a core has a high self-induction; for this reason principally, this type of motor was chosen to perform the experiment. Were a secondary closed coil wound upon the core, it would tend to diminish the self-induction, and then it would be necessary to employ a much higher frequency and potential. Neither would be advisable, for a higher potential would endanger the insulation of the small primary coil, and a higher frequency would result in a materially diminished torque.

It should be remarked that when such a motor with a closed secondary is used, it is not at all easy to obtain rotation with excessive frequencies, as the secondary cuts off almost completely the lines of the primary — and this, of course, the more, the higher the frequency — and allows the passage of but a minute current. In such a case, unless the secondary is closed through a condenser, it is almost essential, in order to produce rotation, to make the primary and secondary coils overlap each other more or less.

But there is an additional feature of interest about this motor, namely, it is not necessary to have even a single connection between the motor and generator, except, perhaps, through the ground; for not only is an insulated plate capable of giving off energy into space, but it is likewise capable of deriving it from an alternating electrostatic field, though in the latter case the available energy is much smaller. In this instance one of the motor terminals is connected to the insulated plate or body located within the alternating electrostatic field, and the other terminal preferably to the ground.

It is quite possible, however, that such “no-wire” motors, as they might be called, could be operated by conduction through the rarefied air at considerable distances. Alternate currents, especially of high frequencies, pass with astonishing freedom through even slightly rarefied gases. The upper strata of the air are rarefied. To reach a number of miles out into space requires the overcoming of difficulties of a merely mechanical nature. There is no doubt that with the enormous potentials obtainable by the use of high frequencies and oil insulation luminous discharges might be passed through many miles of rarefied air, and that, by thus directing the energy of many hundreds or thousands of horse-power, motors or lamps might be operated at considerable distances from stationary sources. But such schemes are mentioned merely as possibilities. We shall have no need to *transmit* power at all. Ere many generations pass, our machinery will be driven by a power obtainable at any point of the universe. This idea is not novel. Men have been led to it long ago by instinct or reason. It has been expressed in many ways, and in many places, in the history of old and new. We find it in the delightful myth of Antheus, who derives power from the earth; we find it among the subtile speculations of one of your splendid mathematicians, and in many hints and statements of thinkers of the present time. Throughout space there is energy. Is this energy static or kinetic? If static our hopes are in vain; if kinetic — and this we know it is, for certain — then it is a mere question of time when men will succeed in attaching their machinery to the very wheelwork of nature. Of all, living or dead, Crookes came nearest to doing it. His radiometer will turn in the light of day and in the darkness of the night; it will turn everywhere where there is heat, and heat is everywhere. But, unfortunately, this beautiful little machine, while it goes down to posterity as the most interesting, must likewise be put on record as the most inefficient machine ever invented!

The preceding experiment is only one of many equally interesting experiments which may be performed by the use of only one wire with alternate currents of high potential and frequency. We may connect an insulated line to a source of such currents, we may pass an inappreciable current over the line, and on any point of the same we are able to obtain a heavy current, capable of fusing a thick copper wire. Or we may, by the help of some artifice, decompose a solution in any electrolytic cell by connecting only one pole of the cell to the line or source of energy. Or we may, by attaching to the line, or only bringing into its vicinity, light up an incandescent lamp, an exhausted tube, or a phosphorescent bulb.

However impracticable this plan of working may appear in many cases, it certainly seems practicable, and even recommendable, in the production of light. A perfected lamp would require but little energy, and if wires were used at all we ought to be able to supply that energy without a return wire.

It is now a fact that a body may be rendered incandescent or phosphorescent by bringing it either in single contact or merely in the vicinity of a source of electric impulses of the proper character, and that in this manner a quantity of light sufficient to afford a practical illuminant may be produced. It is, therefore, to say the least, worth while to attempt to determine the best conditions and to invent the best appliances for attaining this object.

Some experiences have already been gained in this direction, and I will dwell on them briefly, in the hope that they might prove useful.

The heating of a conducting body inclosed in a bulb, and connected to a source of rapidly alternating electric impulses, is dependent on so many things of a different nature, that it would be difficult to give a generally applicable rule under which the maximum heating occurs. As regards the size of the vessel, I have lately found that at ordinary or only slightly differing atmospheric pressures, when air is a good insulator, and hence practically the same amount of energy by a certain potential and frequency is given off from the body, whether the bulb be small or large, the body is brought to a higher temperature if inclosed in a small bulb, because of the better confinement of heat in this case.

At lower pressures, when air becomes more or less conducting, or if the air be sufficiently warmed as to become conducting, the body is rendered more intensely incandescent in a large bulb, obviously because, under otherwise equal conditions of test, more energy may be given off from the body when the bulb is large.

At very high degrees of exhaustion, when the matter in the bulb becomes “radiant”, a large bulb has still an advantage, but a comparatively slight one, over the small bulb.

Finally, at excessively high degrees of exhaustion, which cannot be reached except by the employment of special means, there seems to be, beyond a certain and rather small size of vessel, no perceptible difference in the heating.

These observations were the result of a number of experiments, of which one, showing the effect of the size of the bulb at a high degree of exhaustion, may be described and shown here, as it presents a feature of interest. Three spherical bulbs of 2 inches, 3 inches and 4 inches diameter were taken, and in the centre of each was mounted an equal length of an ordinary incandescent lamp filament of uniform thickness. In each bulb the piece of filament was fastened to the leading-in wire of platinum, contained in a glass stem sealed in the bulb; care being taken, of course, to make everything as nearly alike as possible. On each glass stem in the inside of the bulb was slipped a highly polished tube made of aluminium sheet, which fitted the stem and was held on it by spring pressure. The function of this aluminium tube will be explained subsequently. In each bulb an equal length of filament protruded above the metal tube. It is sufficient to say now that under these conditions equal lengths of filament of the same thickness — in other words, bodies of equal bulk — were brought to incandescence. The three bulbs were sealed to a glass tube, which was connected to a Sprengel pump. When a high vacuum had been reached, the glass tube carrying the bulbs was sealed off. A current was then turned on successively on each bulb, and it was found that the filaments came to about the same brightness, and, if anything, the smallest bulb, which was placed midway between the two larger ones, may have been slightly brighter. This result was expected, for when either of the bulbs was connected to the coil the luminosity spread through the other two, hence the three bulbs constituted really one vessel. When all the three bulbs were connected in multiple arc to the coil, in the largest of them the filament glowed brightest, in the next smaller it was a little less bright, and in the smallest it only came to redness. The bulbs were then sealed off and separately tried. The brightness of the filaments was now such as would have been expected on the supposition that the energy given off was proportionate to the surface of the bulb, this surface in each case representing one of the coatings of a condenser.

Accordingly, there was less difference between the largest and the middle sized than between the latter and the smallest bulb.

An interesting observation was made in this experiment. The three bulbs were suspended from a straight bare wire connected to a terminal of the coil, the largest bulb being placed at the end of the wire, at some distance from it the smallest bulb, and an equal distance from the latter the middle-sized one. The carbons glowed then in both the larger bulbs about as expected, but the smallest did not get its share by far. This observation led me to exchange the position of the bulbs, and I then observed that whichever of the bulbs was in the middle it was by far less bright than it was in any other position. This mystifying result was, of course, found to be due to the electrostatic action between the bulbs. When they were placed at a considerable distance, or when they were attached to the corners of an equilateral triangle of copper wire, they glowed about in the order determined by their surfaces.

As to the shape of the vessel, it is also of some importance, especially at high degrees of exhaustion. Of all the possible constructions, it seems that a spherical globe with the refractory body mounted in its centre is the best to employ. In experience it has been demonstrated that in such a globe a refractory body of a given bulk is more easily brought to incandescence than when otherwise shaped bulbs are used. There is also an advantage in giving to the incandescent body the shape of a sphere, for self-evident reasons. In any case the body should be mounted in the centre, where the atoms rebounding from the glass collide. This object is best attained in the spherical bulb; but it is also attained in a cylindrical vessel with one or two straight filaments coinciding with its axis, and possibly also in parabolical or spherical bulbs with the refractory body or bodies placed in the focus or foci of the same; though the latter is not probable, as the electrified, atoms should in all cases rebound normally from the surface they strike, unless the speed were excessive, in which case they *would* probably follow the general law of reflection. No matter what shape the vessel may have, if the exhaustion be low, a filament mounted in the globe is brought to the same degree of incandescence in all parts; but if the exhaustion be high and the bulb be spherical or pear-shaped, as usual, focal points form and the filament is heated to a higher degree at or near such points.

To illustrate the effect, I have here two small bulbs which are alike, only one is exhausted to a low and the other to a very high degree. When connected to the coil, the filament in the former glows uniformly throughout all its length; whereas in the latter, that portion of the filament which is in the centre of the bulb glows far more intensely than the rest. A curious point is that the phenomenon occurs even if two filaments are mounted in a bulb, each being connected to one terminal of the coil, and. what is still more curious, if they be very near together, provided the vacuum be very high. I noted in experiments with such bulbs that the filaments would give way usually at a certain point, and in the first trials I attributed it to a defect in the carbon. But when the phenomenon occurred many times in succession I recognized its real cause.

In order to bring a refractory body inclosed in a bulb to incandescence, it is desirable, on account of economy, that all the energy supplied to the bulb from the source should reach without loss the body to be heated; from there, and from nowhere else, it should be radiated. It is, of course, out of the question to reach this theoretical result, but it is possible by a proper construction of the illuminating device to approximate it more or less.

For many reasons, the refractory body is placed in the centre of the bulb and it is usually supported on a glass stem containing the leading-in wire. As the potential of this wire is alternated, the rarefied gas surrounding the stem is acted upon inductively, and the glass stem is violently bombarded and heated. In this manner by far the greater portion of the energy supplied to the bulb — especially when exceedingly high frequencies are used — may be lost for the purpose contemplated. To obviate this loss, or at least to reduce it to a minimum, I usually screen the rarefied gas surrounding the stem from the inductive action of the leading-in wire by providing the stem with a tube or coating of conducting material. It seems beyond doubt that the best among metals to employ for this purpose is aluminium, on account of its many remarkable properties. Its only fault is that it is easily fusible, and, therefore, its distance from the incandescing body should be properly estimated. Usually, a thin tube, of a diameter somewhat smaller than that of the glass stem, is made of the finest aluminium sheet, and slipped on the stem. The tube is conveniently prepared by wrapping around a rod fastened in a lathe a piece of aluminium sheet of the proper size, grasping the sheet firmly with clean chamois leather or blotting paper, and spinning the rod very fast. The sheet is wound tightly around the rod, and a highly polished tube of one or three layers of the sheet is obtained. When slipped on the stem, the pressure is generally sufficient to prevent it from slipping off, but, for safety, the lower edge of the sheet may be turned inside. The upper inside corner of the sheet — that is, the one which is nearest to the refractory incandescent body — should be cut out diagonally, as it often happens that, in consequence of the intense heat, this corner turns toward the inside and comes very near to, or in contact with, the wire, or filament, supporting the refractory body. The greater part of the energy supplied to the bulb is then used up in heating the metal tube, and the bulb is rendered useless for the purpose. The aluminium sheet should project above the glass stem more or less — one inch or so — or else, if the glass be too close to the incandescing body, it may be strongly heated and become more or less conducting, whereupon it may be ruptured, or may, by its conductivity, establish a good electrical connection between the metal tube and the leading-in wire, in which case, again, most of the energy will be lost in heating the former. Perhaps the best way is to make the top of the glass tube for about an inch, of a much smaller diameter. To still further reduce the danger arising from the heating of the glass stem, and also with the view of preventing an electrical connection between the metal tube and the electrode, I preferably wrap the stem with several layers of thin mica, which extends at least as far as the metal tube. In some bulbs I have also used an outside insulating cover.

The preceding remarks are only made to aid the experimenter in the first trials, for the difficulties which he encounters he may soon find means to overcome in his own way.

To illustrate the effect of the screen, and the advantage of using it, I have here two bulbs of the same size, with their stems, leading-in wires and incandescent lamp filaments tied to the latter, as nearly alike as possible. The stem of one bulb is provided with an aluminium tube, the stem of the other has none. Originally the two bulbs were joined by a tube which was connected to a Sprengel pump. When a high vacuum had been reached, first the connecting tube, and then the bulbs, were sealed off; they are therefore of the same degree of exhaustion. When they are separately connected to the coil giving a certain potential, the carbon filament in the bulb provided with the aluminium screen in rendered highly incandescent, while the filament in the other bulb may, with the same potential, not even come to redness, although in reality the latter bulb takes generally more energy than the former. When they are both connected together to the terminal, the difference is even more apparent, showing the importance of the screening. The metal tube placed on the stem containing the leading-in wire performs really two distinct functions: First; it acts more or less as an electrostatic screen, thus economizing the energy supplied to the bulb; and, second, to whatever extent it may fail to act electrostatically, it acts mechanically, preventing the bombardment, and consequently intense heating and possible deterioration of the slender support of the refractory incandescent body, or of the glass stem containing the leading-in wire. I say *slender* support, for it is evident that in order to confine the heat more completely to the incandescing body its support should be very thin, so as to carry away the smallest possible amount of heat by conduction. Of all the supports used I have found an ordinary incandescent lamp filament to be the best, principally because among conductors it can withstand the highest degrees of heat.

The effectiveness of the metal tube as an electrostatic screen depends largely on the degree of exhaustion.

At excessively high degrees of exhaustion — which are reached by using great care and special means in connection with the Sprengel pump — when the matter in the globe is in the ultra-radiant state, it acts most perfectly. The shadow of the upper edge of the tube is then sharply defined upon the bulb.

At a somewhat lower degree of exhaustion, which is about the ordinary "non-striking" vacuum, and generally as long as the matter moves predominantly in straight lines, the screen still does well. In elucidation of the preceding remark it is necessary to state that what is a "non-striking" vacuum for a coil operated, as ordinarily, by impulses, or currents, of low frequency, is not, by far, so when the coil is operated by currents of very high frequency. In such case the discharge may pass with great freedom through the rarefied gas through which a low-frequency discharge may not pass, even though the potential be much higher. At ordinary atmospheric pressures just the reverse rule holds good: the higher the frequency, the less the spark discharge is able to jump between the terminals, especially if they are knobs or spheres of some size.

Finally, at very low degrees of exhaustion, when the gas is well conducting, the metal tube not only does not act as an electrostatic screen, but even is a drawback, aiding to a considerable extent the dissipation of the energy laterally from the leading-in wire. This, of course, is to be expected. In this case, namely, the metal tube is in good electrical connection with the leading-in wire, and most of the bombardment is directed upon the tube. As long as the electrical connection is not good, the conducting tube is always of some advantage, for although it may not greatly economize energy, still it protects the support of the refractory button, and is a means for concentrating more energy upon the same.

To whatever extent the aluminium tube performs the function of a screen, its usefulness is therefore limited to very high degrees of exhaustion when it is insulated from the electrode — that is, when the gas as a whole is non-conducting, and the molecules, or atoms, act as independent carriers of electric charges.

In addition to acting as a more or less effective screen, in the true meaning of the word, the conducting tube or coating may also act, by reason of its conductivity, as a sort of equalizer or dampener of the bombardment against the stem. To be explicit, I assume the action as follows: Suppose a rhythmical bombardment to occur against the conducting tube by reason of its imperfect action as a screen, it certainly must happen that some molecules, or atoms, strike the tube sooner than others. Those which come first in contact with it give up their superfluous charge, and the tube is electrified, the electrification instantly spreading over its surface. But this must diminish the energy lost in the bombardment for two reasons: first, the charge given up by the atoms spreads over a great area, and hence the electric density at any point is small, and the atoms are repelled with less energy than they would be if they would strike against a good insulator; secondly, as the tube is electrified by the atoms which first come in contact with it, the progress of the following atoms against the tube is more or less checked by the repulsion which the electrified tube must exert upon the similarly electrified atoms. This repulsion may perhaps be sufficient to prevent a large portion of the atoms from striking the tube, but at any rate it must diminish the energy of their impact. It is clear that when the exhaustion is very low, and the rarefied gas well conducting, neither of the above effects can occur, and, on the other hand, the fewer the atoms, with the greater freedom they move; in other words, the higher the degree of exhaustion, up to a limit, the more telling will be both the effects.

What I have just said may afford an explanation of the phenomenon observed by Prof. Crookes, namely, that a discharge through a bulb is established with much greater facility when an insulator than when a conductor is present in the same. In my opinion, the conductor acts as a dampener of the motion of the atoms in the two ways pointed out; hence, to cause a visible discharge to pass through the bulb, a much higher potential is needed if a conductor, especially of much surface, be present.

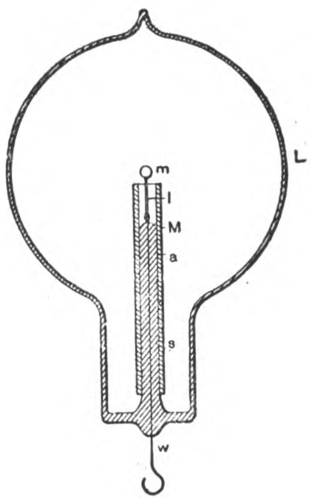


Fig. 18.

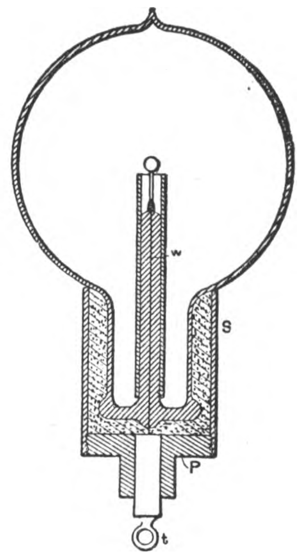


Fig. 19.

For the sake of clearness of some of the remarks before made, I must now refer to Figs. 18, 19 and 20, which illustrate various arrangements with a type of bulb most generally used.

Fig. 18 is a section through a spherical bulb *L,* with the glass stem *s,* containing the leading-in wire *w,* which has a lamp filament *l* fastened to it, serving to support the refractory button *m* in the centre. *M* is a sheet of thin mica wound in several layers around the stem *s,* and *a* is the aluminium tube.

Fig. 19 illustrates such a bulb in a somewhat more advanced stage of perfection. A metallic tube 5 is fastened by means of some cement to the neck of the tube. In the tube is screwed a plug *P,* of insulating material, in the centre of which is fastened a metallic terminal *t,* for the connection to the leading-in wire *w.* This terminal must be well insulated from the metal tube *S,* therefore, if the cement used is conducting — and most generally it is sufficiently so — the space between the plug *P* and the neck of the bulb should be filled with some good insulating material, as mica powder.

Fig. 20 shows a bulb made for experimental purposes. In this bulb the aluminium tube is provided with an external connection, which serves to investigate the effect of the tube under various conditions. It is referred to chiefly to suggest a line of experiment followed.

Since the bombardment against the stem containing the leading-in wire is due to the inductive action of the latter upon the rarefied gas, it is of advantage to reduce this action as far as practicable by employing a very thin wire, surrounded by a very thick insulation of glass or other material, and by making the wire passing through the rarefied gas as short as practicable. To combine these features I employ a large tube *T* (Fig. 21), which protrudes into the bulb to some distance, and carries on the top a very short glass stem *s,* into which is sealed the leading-in wire *w,* and I protect the top of the glass stem against the heat by a small, aluminium tube *a* and a layer of mica underneath the same, as usual. The wire *w,* passing through the large tube to the outside of the bulb, should be well insulated — with a glass tube, for instance — and the space between ought to be filled out with some excellent insulator. Among many insulating powders I have tried, I have found that mica powder is the best to employ. If this precaution is not taken, the tube *T,* protruding into the bulb, will surely be cracked in consequence of the heating by the brushes which are apt to form in the upper part of the tube, near the exhausted globe, especially if the vacuum be excellent, and therefore the potential necessary to operate the lamp very high.

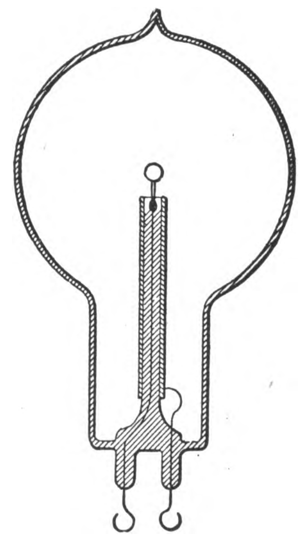


Fig. 20.

Fig. 22 illustrates a similar arrangement, with a large tube *T* protruding into the part of the bulb containing the refractory button *m.* In this case the wire leading from the outside into the bulb is omitted, the energy required being supplied through condenser coatings *C C.* The insulating packing *P* should in this construction be tightly fitting to the glass, and rather wide, or otherwise the discharge might avoid passing through the wire *w,* which connects the inside condenser coating to the incandescent button *m.*

The molecular bombardment against the glass stem in the bulb is a source of great trouble. As illustration I will cite a phenomenon only too frequently and unwillingly observed. A bulb, preferably a large one, may be taken, and a good conducting body, such as a piece of carbon, may be mounted in it upon a platinum wire sealed in the glass stem. The bulb may be exhausted to a fairly high degree, nearly to the point when phosphorescence begins to appear. When the bulb is connected with the coil, the piece of carbon, if small, may become highly incandescent at first, but its brightness immediately diminishes, and then the discharge may break through the glass somewhere in the middle of the stem, in the form of bright sparks, in spite of the fact that the platinum wire is in good electrical connection with the rarefied gas through the piece of carbon or metal at the top. The first sparks are singularly bright, recalling those drawn from a clear surface of mercury. But, as they heat the glass rapidly, they, of course, lose their brightness, and cease when the glass at the ruptured place becomes incandescent, or generally sufficiently hot to conduct. When observed for the first time the phenomenon must appear very curious, and shows in a striking manner how radically different alternate currents, or impulses, of high frequency behave, as compared with steady currents, or currents of low frequency. With such currents — namely, the latter — the phenomenon would of course not occur. When frequencies such as are obtained by mechanical means are used, I think that the rupture of the glass is more or less the consequence of the bombardment, which warms it up and impairs its insulating power, but with frequencies obtainable with condensers I have no doubt that the glass may give way without previous heating. Although this appears most singular at first, it is in reality what we might expect to occur. The energy supplied to the wire leading into the bulb is given off partly by direct action through the carbon button, and partly by inductive action through the glass surrounding the wire. The case is thus analogous to that in which a condenser shunted by a conductor of low resistance is connected to a source of alternating currents. As long as the frequencies are low, the conductor gets the most, and the condenser is perfectly safe; but when the frequency becomes excessive, the *role* of the conductor may become quite insignificant. In the latter case the difference of potential at the terminals of the condenser may become so great as to rupture the dielectric, notwithstanding the fact that the terminals are joined by a conductor of low resistance.

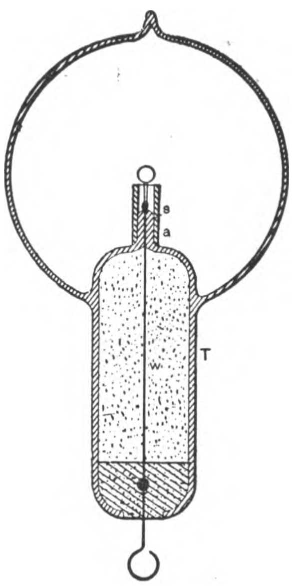


Fig. 21.

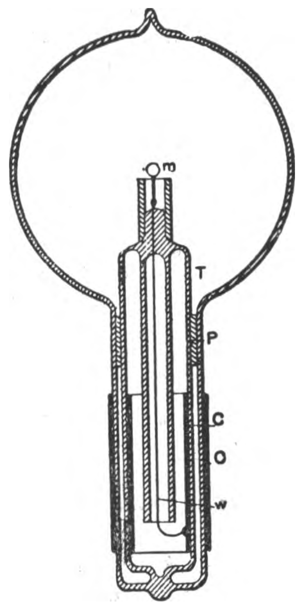


Fig. 22.

It is, of course, not necessary, when it is desired to produce the incandescence of a body inclosed in a bulb by means of these currents, that the body should be a conductor, for even a perfect non-conductor may be quite as readily heated. For this purpose it is sufficient to surround a conducting electrode with a non-conducting material, as, for instance, in the bulb described before in Fig. 21, in which a thin incandescent lamp filament is coated with a non-conductor, and supports a button of the same material On the top. At the start the bombardment goes on by inductive action through the non-conductor, until the same is sufficiently heated to become conducting, when the bombardment continues in the ordinary way.

A different arrangement used in some of the bulbs constructed is illustrated in Fig. 23. In this instance a non-conductor *m* is mounted in a piece of common arc light carbon so as to project some small distance above the latter. The carbon piece is connected to the leading-in wire passing through a glass stem, which is wrapped with several layers of mica. An aluminium tube *a* is employed as usual for screening. It is so arranged that it reaches very nearly as high as the carbon and only the non-conductor *m* projects a little above it. The bombardment goes at first against the upper surface of carbon, the lower parts being protected by the aluminium tube. As soon, however, as the non-conductor *m* is heated it is rendered good conducting, and then it becomes the centre of the bombardment, being most exposed to the same.

I have also constructed during these experiments many such single-wire bulbs with or without internal electrode, in which the radiant matter was projected against, or focused upon, the body to be rendered incandescent. Fig. 24 illustrates one of the bulbs used. It consists of a spherical globe *L,* provided with a long neck *n,* on the top, for increasing the action in some cases by the application of an external conducting coating. The globe *L* is blown out on the bottom into a very small bulb *b,* which serves to hold it firmly in a socket *S,* of insulating material into which it is cemented. A fine lamp filament *f,* supported on a wire *w* passes through the centre of the globe *L.* The filament is rendered incandescent in the middle portion, where the bombardment proceeding from the lower inside surface of the globe is most intense. The lower portion of the globe, as far as the socket *S* reaches, is rendered conducting, either by a tinfoil coating or otherwise, and the external electrode is connected to a terminal of the coil.

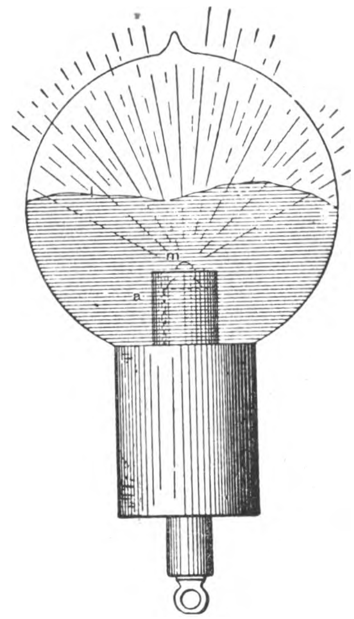


Fig. 23.

The arrangement diagrammatically indicated in Fig. 24 was found to be an inferior one when it was desired to render incandescent a filament or button supported in the centre of the globe, but it was convenient when the object was to excite phosphorescence.

In many experiments in which bodies of a different kind were mounted in the bulb as, for instance, indicated in Fig. 23, some observations of interest were made.

It was found, among other things, that in such cases, no matter where the bombardment began, just as soon as a high temperature was reached there was generally one of the bodies which seemed to take most of the bombardment upon itself, the other, or others, being thereby relieved. This quality appeared to depend principally on the point of fusion, and on the facility with which the body was "evaporated", or, generally speaking, disintegrated — meaning by the latter term not only the throwing off of atoms, but likewise of larger lumps. The observation made was in accordance with generally accepted notions. In a highly exhausted bulb electricity is carried off from the electrode by independent carriers, which are partly the atoms, or molecules, of the residual atmosphere, and partly the atoms, molecules, or lumps thrown off from the electrode. If the electrode is composed of bodies of different character, and if one of these is more easily disintegrated than the others, most of the electricity supplied is carried off from that body, which is then brought to a higher temperature than the others, and this the more, as upon an increase of the temperature the body is still more easily disintegrated.

It seems to me quite probable that a similar process takes place in the bulb even with a homogenous electrode, and I think it to be the principal cause of the disintegration. There is bound to be some irregularity, even if the surface is highly polished, which, of course, is impossible with most of the refractory bodies employed as electrodes. Assume that a point of the electrode gets hotter, instantly most of the discharge passes through that point, and a minute patch is probably fused and evaporated. It is now possible that in consequence of the violent disintegration the spot attacked sinks in temperature, or that a counter force is created, as in an arc; at any rate, the local tearing off meets with the limitations incident to the experiment, whereupon the same process occurs on another place. To the eye the electrode appears uniformly brilliant, but there are upon it points constantly shifting and wandering around, of a temperature far above the mean, and this materially hastens the process of deterioration. That some such thing occurs, at least when the electrode is at a lower temperature, sufficient experimental evidence can be obtained in the following manner: Exhaust a bulb to a very high degree, so that with a fairly high potential the discharge cannot pass — that is, not a *luminous* one, for a weak invisible discharge occurs always, in all probability. Now raise slowly and carefully the potential, leaving the primary current on no more than for an instant. At a certain point, two, three, or half a dozen phosphorescent spots will appear on the globe. These places of the glass are evidently more violently bombarded than others, this being due to the unevenly distributed electric density, necessitated, of course, by sharp projections, or, generally speaking, irregularities of the electrode. But the luminous patches are constantly changing in position, which is especially well observable if one manages to produce very few, and this indicates that the configuration of the electrode is rapidly changing.

From experiences of this kind I am led to infer that, in order to be most durable, the refractory button in the bulb should be in the form of a sphere with a highly polished surface. Such a small sphere could be manufactured from a diamond or some other crystal, but a better way would be to fuse, by the employment of extreme degrees of temperature, some oxide — as, for instance, zirconia — into a small drop, and then keep it in the bulb at a temperature somewhat below its point of fusion.

Interesting and useful results can no doubt be reached in the direction of extreme degrees of heat. How can such high temperatures be arrived at? How are the highest degrees of heat reached in nature? By the impact of stars, by high speeds and collisions. In a collision any rate of heat generation may be attained. In a chemical process we are limited. When oxygen and hydrogen combine, they fall, metaphorically speaking, from a definite height. We cannot go very far with a blast, nor by confining heat in a furnace, but in an exhausted bulb we can concentrate any amount of energy upon a minute button. Leaving practicability out of consideration, this, then, would be the means which, in my opinion, would enable us to reach the highest temperature. But a great difficulty when proceeding in this way is encountered, namely, in most cases the body is carried off before it can fuse and form a drop. This difficulty exists principally with an oxide such as zirconia, because it cannot be compressed in so hard a cake that it would not be carried off quickly. I endeavored repeatedly to fuse zirconia, placing it in a cup or arc light carbon as indicated in Fig. 23. It glowed with a most intense light, and the stream of the particles projected out of the carbon cup was of a vivid white; but whether it was compressed in a cake or made into a paste with carbon, it was carried off before it could be fused. The carbon cup containing the zirconia had to be mounted very low in the neck of a large bulb, as the heating of the glass by the projected particles of the oxide was so rapid that in the first trial the bulb was cracked almost in an instant when the current was turned on. The heating of the glass by the projected particles was found to be always greater when the carbon cup contained a body which was rapidly carried off — I presume because in such cases, with the same potential, higher speeds were reached, and also because, per unit of time, more matter was projected — that is, more particles would strike the glass.

The before mentioned difficulty did not exist, however, when the body mounted in the carbon cup offered great resistance to deterioration. For instance, when an oxide was first fused in an oxygen blast and then mounted in the bulb, it melted very readily into a drop.

Generally during the process of fusion magnificent light effects were noted, of which it would be difficult to give an adequate idea. Fig. 23 is intended to illustrate the effect observed with a ruby drop. At first one may see a narrow funnel of white light projected against the top of the globe, where it produces an irregularly outlined phosphorescent patch. When the point of the ruby fuses the phosphorescence becomes very powerful; but as the atoms are projected with much greater speed from the surface of the drop, soon the glass gets hot and "tired", and now only the outer edge of the patch glows. In this manner an intensely phosphorescent, sharply defined line, *l,* corresponding to the outline of the drop, is produced, which spreads slowly over the globe as the drop gets larger. When the mass begins to boil, small bubbles and cavities are formed, which cause dark colored spots to sweep across the globe. The bulb may be turned downward without fear of the drop falling off, as the mass possesses considerable viscosity.

I may mention here another feature of some interest, which I believe to have noted in the course of these experiments, though the observations do not amount to a certitude. It *appeared* that under the molecular impact caused by the rapidly alternating potential the body was fused and maintained in that state at a lower temperature in a highly exhausted bulb than was the case at normal pressure and application of heat in the ordinary way — that is, at least, judging from the quantity of the light emitted. One of the experiments performed may be mentioned here by way of illustration. A small piece of pumice stone was stuck on a platinum wire, and first melted to it in a gas burner. The wire was next placed between two pieces of charcoal and a burner applied so as to produce an intense heat, sufficient to melt down the pumice stone into a small glass-like button. The platinum wire had to be taken of sufficient thickness to prevent its melting in the fire. While in the charcoal fire, or when held in a burner to get a better idea of the degree of heat, the button glowed with great brilliancy. The wire with the button was then mounted in a bulb, and upon exhausting the same to a high degree, the current was turned on slowly so as to prevent the cracking of the button. The button was heated to the point of fusion, and when it melted it did not, apparently, glow with the same brilliancy as before, and this would indicate a lower temperature. Leaving out of consideration the observer's possible, and even probable, error, the question is, can a body under these conditions be brought from a solid to a liquid state with evolution of *less* light?

When the potential of a body is rapidly alternated it is certain that the structure is jarred. When the potential is very high, although the vibrations may be few — say 20,000 per second — the effect upon the structure may be considerable. Suppose, for example, that a ruby is melted into a drop by a steady application of energy. When it forms a drop it will emit visible and invisible waves, which will be in a definite ratio, and to the eye the drop will appear to be of a certain brilliancy. Next, suppose we diminish to any degree we choose the energy steadily supplied, and, instead, supply energy which rises and falls according to a certain law. Now, when the drop is formed, there will be emitted from it three different kinds of vibrations — the ordinary visible, and two kinds of invisible waves: that is, the ordinary dark waves of all lengths, and, in addition, waves of a well defined character. The latter would not exist by a steady supply of the energy; still they help to jar and loosen the structure. If this really be the case, then the ruby drop will emit relatively less visible and more invisible waves than before. Thus it would seem that when a platinum wire, for instance, is fused by currents alternating with extreme rapidity, it emits at the point of fusion less light and more invisible radiation than it does when melted by a steady current, though the total energy used up in the process of fusion is the same in both cases. Or, to cite another example, a lamp filament is not capable of withstanding as long with currents of extreme frequency as it does with steady currents, assuming that it be worked at the same luminous intensity. This means that for rapidly alternating currents the filament should be shorter and thicker. The higher the frequency — that is, the greater the departure from the steady flow — the worse it would be for the filament. But if the truth of this remark were demonstrated, it would be erroneous to conclude that such a refractory button as used in these bulbs would be deteriorated quicker by currents of extremely high frequency than by steady or low frequency currents. From experience I may say that just the opposite holds good: the button withstands the bombardment better with currents of very high frequency. But this is due to the fact that a high frequency discharge passes through a rarefied gas with much greater freedom than a steady or low frequency discharge, and this will say that with the former we can work with a lower potential or with a less violent impact. As long, then, as the gas is of no consequence, a steady or low frequency current is better; but as soon as the action of the gas is desired and important, high frequencies are preferable.

In the course of these experiments a great many trials were made with all kinds of carbon buttons. Electrodes made of ordinary carbon buttons were decidedly more durable when the buttons were obtained by the application of enormous pressure. Electrodes prepared by depositing carbon in well known ways did not show up well; they blackened the globe very quickly. From many experiences I conclude that lamp filaments obtained in this manner can be advantageously used only with low potentials and low frequency currents. Some kinds of carbon withstand so well that, in order to bring them to the point of fusion, it is necessary to employ very small buttons. In this case the observation is rendered very difficult on account of the intense heat produced. Nevertheless there can be no doubt that all kinds of carbon are fused under the molecular bombardment, but the liquid state must be one of great instability. Of all the bodies tried there were two which withstood best — diamond and carborundum. These two showed up about equally, but the latter was preferable, for many reasons. As it is mors than likely that this body is not yet generally known, I will venture to call your attention to it.

It has been recently produced by Mr. E. G. Acheson, of Monongahela City, Pa., U. S. A. It is intended to replace ordinary diamond powder for polishing precious stones, etc., and I have been informed that it accomplishes this object quite successfully. I do not know why the name “carborundum” has been given to it, unless there is something in the process of its manufacture which justifies this selection. Through the kindness of the inventor, I obtained a short while ago some samples which I desired to test in regard to their qualities of phosphorescence and capability of withstanding high degrees of heat.

Carborundum can be obtained in two forms — in the form of “crystals” and of powder. The former appear to the naked eye dark colored, but are very brilliant; the latter is of nearly the same color as ordinary diamond powder, but very much finer. When viewed under a microscope the samples of crystals given to me did not appear to have any definite form, but rather resembled pieces of broken up egg coal of fine quality. The majority were opaque, but there were some which were transparent and colored. The crystals are a kind of carbon containing some impurities; they are extremely hard, and withstand for a long time even an oxygen blast. When the blast is directed against them they at first form a cake of some compactness, probably in consequence of the fusion of impurities they contain. The mass withstands for a very long time the blast without further fusion; but a slow carrying off, or burning, occurs, and, finally, a small quantity of a glass-like residue is left, which, I suppose, is melted alumina. When compressed strongly they conduct very well, but not as well as ordinary carbon. The powder, which is obtained from the crystals in some way, is practically non-conducting. It affords a magnificent polishing material for stones.

The time has been too short to make a satisfactory study of the properties of this product, but enough experience has been gained in a few weeks I have experimented upon it to say that it does possess some remarkable properties in many respects. It withstands excessively high degrees of heat, it is little deteriorated by molecular bombardment, and it does not blacken the globe as ordinary carbon does. The only difficulty which I have found in its use in connection with these experiments was to find some binding material which would resist the heat and the effect of the bombardment as successfully as carborundum itself does.

I have here a number of bulbs which I have provided with buttons of carborundum To make such a button of carborundum crystals I proceed in the following manner: I take an ordinary lamp filament and dip its point in tar, or some other thick substance or paint which may be readily carbonized. I next pass the point of the filament through the crystals, and then hold it vertically over a hot plate. The tar softens and forms a drop on the point of the filament, the crystals adhering to the surface of the drop. By regulating the distance from the plate the tar is slowly dried out and the button becomes solid. I then once more dip the button in tar and hold it again over a plate until the tar is evaporated, leaving only a hard mass which firmly binds the crystals. When a larger button is required I repeat the process several times, and I generally also cover the filament a certain distance below the button with crystals. The button being mounted in a bulb, when a good vacuum has been reached, first a weak and then a strong discharge is passed through the bulb to carbonize the tar and expel all gases, and later it is brought to a very intense incandescence.

When the powder is used I have found it best to proceed as follows: I make a thick paint of carborundum and tar, and pass a lamp filament through the paint. Taking then most of the paint off by rubbing the filament against a piece of chamois leather, I hold it over a hot plate until the tar evaporates and the coating becomes firm. I repeat this process as many times as it is necessary to obtain a certain thickness of coating. On the point of the coated filament I form a button in the same manner.

There is no doubt that such a button — properly prepared under great pressure — of carborundum, especially of powder of the best quality, will withstand the effect of the bombardment fully as well as anything we know. The difficulty is that the binding material gives way, and the carborundum is slowly thrown off after some time. As it does not seem to blacken the globe in the least, it might be found useful for coating the filaments of ordinary incandescent lamps, and I think that it is even possible to produce thin threads or sticks of carborundum which will replace the ordinary filaments in an incandescent lamp. A carborundum coating seems to be more durable than other coatings, not only because the carborundum can withstand high degrees of heat, but also because it seems to unite with the carbon better than any other material I have tried. A coating of zirconia or any other oxide, for instance, is far more quickly destroyed. I prepared buttons of diamond dust in the same manner as of carborundum, and these came in durability nearest to those prepared of carborundum, but the binding paste gave way much more quickly in the diamond buttons: this, however, I attributed to the size and irregularity of the grains of the diamond.

It was of interest to find whether carborundum possesses the quality of phosphorescence. One is, of course, prepared to encounter two difficulties: first, as regards the rough product, the "crystals", they are good conducting, and it is a fact that conductors do not phosphoresce; second, the powder, being exceedingly fine, would not be apt to exhibit very prominently this quality, since we know that when crystals, even such as diamond or ruby, are finely powdered, they lose the property of phosphorescence to a considerable degree.

The question presents itself here, can a conductor phosphoresce? What is there in such a body as a metal, for instance, that would deprive it of the quality of phosphorescence, unless it is that property which characterizes it as a conductor? for it is a fact that most of the phosphorescent bodies lose that quality when they are sufficiently heated to become more or less conducting. Then, if a metal be in a large measure, or perhaps entirely, deprived of that property, it should be capable of phosphorescence. Therefore it is quite possible that at some extremely high frequency, when behaving practically as a non-conductor, a metal or any other conductor might exhibit the quality of phosphorescence, even though it be entirely incapable of phosphorescing under the impact of a low-frequency discharge. There is, however, another possible way how a conductor might at least *appear* to phosphoresce.

Considerable doubt still exists as to what really is phosphorescence, and as to whether the various phenomena comprised under this head are due to the same causes. Suppose that in an exhausted bulb, under the molecular impact, the surface of a piece of metal or other conductor is rendered strongly luminous, but at the same time it *is* found that it remains comparatively cool, would not this luminosity be called phosphorescence? Now such a result, theoretically at least, is possible, for it is a mere question of potential or speed. Assume the potential of the electrode, and consequently the speed of the projected atoms, to be sufficiently high, the surface of the metal piece against which the atoms are projected would be rendered highly incandescent, since the process of heat generation would be incomparably faster than that of radiating or conducting away from the surface of the collision. In the eye of the observer a single impact of the atoms would cause an instantaneous flash, but if the impacts were repeated with sufficient rapidity they would produce a continuous impression upon his retina. To him then the surface of the metal would appear continuously incandescent and of constant luminous intensity, while in reality the light would be either intermittent or at least changing periodically in intensity. The metal piece would rise in temperature until equilibrium was attained — that is, until the energy continuously radiated would equal that intermittently supplied. But the supplied energy might under such conditions not be sufficient to bring the body to any more than a very moderate mean temperature, especially if the frequency of the atomic impacts be very low — just enough that the fluctuation of the intensity of the light emitted could not be detected by the eye. The body would now, owing to the manner in which the energy is supplied, emit a strong light, and yet be at a comparatively very low mean temperature. How could the observer call the luminosity thus produced? Even if the analysis of the light would teach him something definite, still he would probably rank it under the phenomena of phosphorescence. It is conceivable that in such a way both conducting and non-conducting bodies may be maintained at a certain luminous intensity, but the energy required would very greatly vary with the nature and properties of the bodies.

These and some foregoing remarks of a speculative nature were made merely to bring out curious features of alternate currents or electric impulses. By their help we may cause a body to emit *more* light, while at a certain mean temperature, than it would emit if brought to that temperature by a steady supply; and, again, we may bring a body to the point of fusion, and cause it to emit *less* light than when fused by the application of energy in ordinary ways. It all depends on how we supply the energy, and what kind of vibrations we set up: in one case the vibrations are more, in the other less, adapted to affect our sense of vision.

Some effects, which I had not observed before, obtained with carborundum in the first trials, I attributed to phosphorescence, but in subsequent experiments it appeared that it was devoid of that quality. The crystals possess a noteworthy feature. In a bulb provided with a single electrode in the shape of a small circular metal disc, for instance, at a certain degree of exhaustion the electrode is covered with a milky film, which is separated by a dark space from the glow filling the bulb. When the metal disc is covered with carborundum crystals, the film is far more intense, and snow-white. This I found later to be merely an effect of the bright surface of the crystals, for when an aluminium electrode was highly polished it exhibited more or less the same phenomenon. I made a number of experiments with the samples of crystals obtained, principally because it would have been of special interest to find that they are capable of phosphorescence, on account of their being conducting. I could not produce phosphorescence distinctly, but I must remark that a decisive opinion cannot be formed until other experimenters have gone over the same ground.

The powder behaved in some experiments as though it contained alumina, but it did not exhibit with sufficient distinctness the red of the latter. Its dead color brightens considerably under the molecular impact, but I am now convinced it does not phosphoresce. Still, the tests with the powder are not conclusive, because powdered carborundum probably does not behave like a phosphorescent sulphide, for example, which could be finely powdered without impairing the phosphorescence, but rather like powdered ruby or diamond, and therefore it would be necessary, in order to make a decisive test, to obtain it in a large lump and polish up the surface.

If the carborundum proves useful in connection with these and similar experiments, its chief value will be found in the production of coatings, thin conductors, buttons, or other electrodes capable of withstanding extremely high degrees of heat.

The production of a small electrode capable of withstanding enormous temperatures I regard as of the greatest importance in the manufacture of light. It would enable us to obtain, by means of currents of very high frequencies, certainly 20 times, if not more, the quantity of light which is obtained in the present incandescent lamp by the same expenditure of energy. This estimate may appear to many exaggerated, but in reality I think it is far from being so. As this statement might be misunderstood I think it necessary to expose clearly the problem with which in this line of work we are confronted, and the manner in which, in my opinion, a solution will be arrived at.

Any one who begins a study of the problem will be apt to think that what is wanted in a lamp with an electrode is a very high degree of incandescence of the electrode. There he will be mistaken. The high incandescence of the button is a necessary evil, but what is really wanted is the high incandescence of the gas surrounding the button. In other words, the problem in such a lamp is to bring a mass of gas to the highest possible incandescence. The higher the incandescence, the quicker the mean vibration, the greater is the economy of the light production. But to maintain a mass of gas at a high degree of incandescence in a glass vessel, it will always be necessary to keep the incandescent mass away from the glass; that is, to confine it as much as possible to the central portion of the globe.

In one of the experiments this evening a brush was produced at the end of a wire. This brush was a flame, a source of heat and light. It did not emit much perceptible heat, nor did it glow with an intense light; but is it the less a flame because it does not scorch my hand? Is it the less a flame because it does not hurt my eye by its brilliancy? The problem is precisely to produce in the bulb such a flame, much smaller in size, but incomparably more powerful. Were there means at hand for producing electric impulses of a sufficiently high frequency, and for transmitting them, the bulb could be done away with, unless it were used to protect the electrode, or to economize the energy by confining the heat. But as such means are not at disposal, it becomes necessary to place the terminal in a bulb and rarefy the air in the same. This is done merely to enable the apparatus to perform the work which it is not capable of performing at ordinary air pressure. In the bulb we are able to intensify the action to any degree — so far that the brush emits a powerful light.

The intensity of the light emitted depends principally on the frequency and potential of the impulses, and on the electric density on the surface of the electrode. It is of the greatest importance to employ the smallest possible button, in order to push the density very far. Under the violent impact of the molecules of the gas surrounding it, the small electrode is of course brought to an extremely high temperature, but around it is a mass of highly incandescent gas, a flame photosphere, many hundred times the volume of the electrode. With a diamond, carborundum or zirconia button the photosphere can be as much as one thousand times the volume of the button. Without much reflecting one would think that in pushing so far the incandescence of the electrode it would be instantly volatilized. But after a careful consideration he would find that, theoretically, it should not occur, and in this fact — which, however, is experimentally demonstrated — lies principally the future value of such a lamp.

At first, when the bombardment begins, most of the work is performed on the surface of the button, but when a highly conducting photosphere is formed the button is comparatively relieved. The higher the incandescence of the photosphere the more it approaches in conductivity to that of the electrode, and the more, therefore, the solid and the gas form one conducting body. The consequence is that the further is forced the incandescence the more work, comparatively, is performed on the gas, and the less on the electrode. The formation of a powerful photosphere is consequently the very means for protecting the electrode. This protection, of course, is a relative one, and it should not be thought that by pushing the incandescence higher the electrode is actually less deteriorated. Still, theoretically, with extreme frequencies, this result must be reached, but probably at a temperature too high for most of the refractory bodies known. Given, then, an electrode which can withstand to a very high limit the effect of the bombardment and outward strain, it would be safe no matter how much it is forced beyond that limit. In an incandescent lamp quite different considerations apply. There the gas is not at all concerned: the whole of the work is performed on the filament; and the life of the lamp diminishes so rapidly with the increase of the degree of incandescence that economical reasons compel us to work it at a low incandescence. But if an incandescent lamp is operated with currents of very high frequency, the action of the gas cannot be neglected, and the rules for the most economical working must be considerably modified.

In order to bring such a lamp with one or two electrodes to a great perfection, it is necessary to employ impulses of very high frequency. The high frequency secures, among others, two chief advantages, which have a most important bearing upon the economy of the light production. First, the deterioration of the electrode is reduced by reason of the fact that we employ a great many small impacts, instead of a few violent ones, which shatter quickly the structure; secondly, the formation of a large photosphere is facilitated.

In order to reduce the deterioration of the electrode to the minimum, it is desirable that the vibration be harmonic, for any suddenness hastens the process of destruction. An electrode lasts much longer when kept at incandescence by currents, or impulses, obtained from a high-frequency alternator, which rise and fall more or less harmonically, than by impulses obtained from a disruptive discharge coil. In the latter case there is no doubt that most of the damage is done by the fundamental sudden discharges.

One of the elements of loss in such a lamp is the bombardment of the globe. As the potential is very high, the molecules are projected with great speed; they strike the glass, and usually excite a strong phosphorescence. The effect produced is very pretty, but for economical reasons it would be perhaps preferable to prevent, or at least reduce to the minimum, the bombardment against the globe, as in such case it is, as a rule, not the object to excite phosphorescence, and as some loss of energy results from the bombardment. This loss in the bulb is principally dependent on the potential of the impulses and on the electric density on the surface of the electrode. In employing very high frequencies the loss of energy by the bombardment is greatly reduced, for, first, the potential needed to perform a given amount of work is much smaller; and, secondly, by producing a highly conducting photosphere around the electrode, the same result is obtained as though the electrode were much larger, which is equivalent to a smaller electric density. But be it by the diminution of the maximum potential or of the density, the gain is effected in the same manner, namely, by avoiding violent shocks, which strain the glass much beyond its limit of elasticity. If the frequency could be brought high enough, the loss due to the imperfect elasticity of the glass would be entirely negligible. The loss due to bombardment of the globe may, however, be reduced by using two electrodes instead of one. In such case each of the electrodes may be connected to one of the terminals; or else, if it is preferable to use only one wire, one electrode may be connected to one terminal and the other to the ground or to an insulated body of some surface, as, for instance, a shade on the lamp. In the latter case, unless some judgment is used, one of the electrodes might glow more intensely than the other.

But on the whole I find it preferable when using such high frequencies to employ only one electrode and one connecting wire. I am convinced that the illuminating device of the near future will not require for its operation more than one lead, and, at any rate, it will have no leading-in wire, since the energy required can be as well transmitted through the glass. In experimental bulbs the leading-in wire is most generally used on account of convenience, as in employing condenser coatings in the manner indicated in Fig. 22, for example, there is some difficulty in fitting the parts, but these difficulties would not exist if a great many bulbs were manufactured; otherwise the energy can be conveyed through the glass as well as through a wire, and with these high frequencies the losses are very small. Such illuminating devices will necessarily involve the use of very high potentials, and this, in the eyes of practical men, might be an objectionable feature. Yet, in reality, high potentials are not objectionable — certainly not in the least as far as the safety of the devices is concerned.

There are two ways of rendering an electric appliance safe. One is to use low potentials, the other is to determine the dimensions of the apparatus so that it is safe no matter how high a potential is used. Of the two the latter seems to me the better way, for then the safety is absolute, unaffected by any possible combination of circumstances which might render even a low-potential appliance dangerous to life and property. But the practical conditions require not only the judicious determination of the dimensions of the apparatus; they likewise necessitate the employment of energy of the proper kind. It is easy, for instance, to construct a transformer capable of giving, when operated from an ordinary alternate current machine of low tension, say 50,000 volts, which might be required to light a highly exhausted phosphorescent tube, so that, in spite of the high potential, it is perfectly safe, the shock from it producing no inconvenience. Still, such a transformer would be expensive, and in itself inefficient; and, besides, what energy was obtained from it would not be economically used for the production of light. The economy demands the employment of energy in the form of extremely rapid vibrations. The problem of producing light has been likened to that of maintaining a certain high-pitch note by means of a bell. It should be said a *barely audible* note; and even these words would not express it, so wonderful is the sensitiveness of the eye. We may deliver powerful blows at long intervals, waste a good deal of energy, and still not get what we want; or we may keep up the note by delivering frequent gentle taps, and get nearer to the object sought by the expenditure of much less energy. In the production of light, as fas as the illuminating device is concerned, there can be only one rule — that is, to use as high frequencies as can be obtained; but the means for the production and conveyance of impulses of such character impose, at present at least, great limitations. Once it is decided to use very high frequencies, the return wire becomes unnecessary, and all the appliances are simplified. By the use of obvious means the same result is obtained as though the return wire were used. It is sufficient for this purpose to bring in contact with the bulb, or merely in the vicinity of the same, an insulated body of some surface. The surface need, of course, be the smaller, the higher the frequency and potential used, and necessarily, also, the higher the economy of the lamp or other device, This plan of working has been resorted to on several occasions this evening. So, for instance, when the incandescence of a button was produced by grasping the bulb with the hand, the body of the experimenter merely served to intensify the action. The bulb used was similar to that illustrated in Fig. 19, and the coil was excited to a small potential, not sufficient to bring the button to incandescence when the bulb was hanging from the wire; and incidentally, in order to perform the experiment in a more suitable manner, the button was taken so large that a perceptible time had to elapse before,

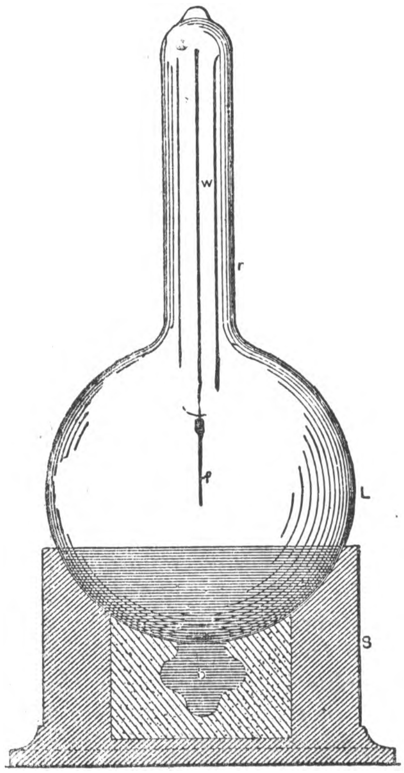


Fig. 24.

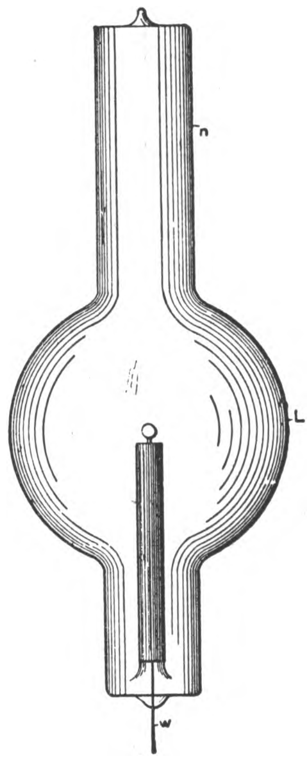


Fig. 25.

upon grasping the bulb, it could be rendered incandescent. The contact with the bulb was, of course, quite unnecessary. It is easy, by using a rather large bulb with an exceedingly small electrode, to adjust the conditions so that the latter is brought to bright incandescence by the mere approach of the experimenter within a few feet of the bulb, and that the incandescence subsides upon his receding.

In another experiment, when phosphorescence was excited, a similar bulb was used. Here again, originally, the potential was not sufficient to excite phosphorescence until the action was intensified — in this case, however, to present a different feature, by touching the socket with a metallic object held in the hand. The electrode in the bulb was a carbon button so large that it could not be brought to incandescence, and thereby spoil the effect produced by phosphorescence.

Again, in another of the early experiments, a bulb was used as illustrated in Fig. 12. In this instance, by touching the bulb with one or two fingers, one or two shadows of the stem inside were projected against the glass, the touch of the finger producing the same result as the application of an external negative electrode under ordinary circumstances.

In all these experiments the action was intensified by augmenting the capacity at the end of the lead connected to the terminal. As a rule, it is not necessary to resort to such means, and would be quite unnecessary with still higher frequencies; but when it *is* desired, the bulb, or tube, can be easily adapted to the purpose.

In Fig. 24, for example, an experimental bulb *L* is shown, which is provided with a neck *n* on the top for the application of an external tinfoil coating, which may be connected to a body of larger surface. Such a lamp as illustrated in Fig. 25 may also be lighted by connecting the tinfoil coating on the neck *n* to the terminal, and the leading-in wire *w* to an insulated plate. If the bulb stands in a socket upright, as shown in the cut, a shade of conducting material may be slipped in the neck *n,* and the action thus magnified.

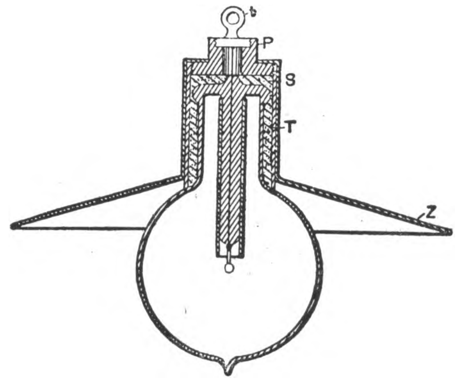


Fig. 26.

A more perfected arrangement used in some of these bulbs is illustrated in Fig. 26. In this case the construction of the bulb is as shown and described before, when reference was made to Fig. 19. A zinc sheet Z, with a tubular extension *T,* is slipped over the metallic socket *S.* The bulb hangs downward from the terminal *t,* the zinc sheet *Z,* performing the double office of intensifier and reflector. The reflector is separated from the terminal *t* by an extension of the insulating plug *P*.

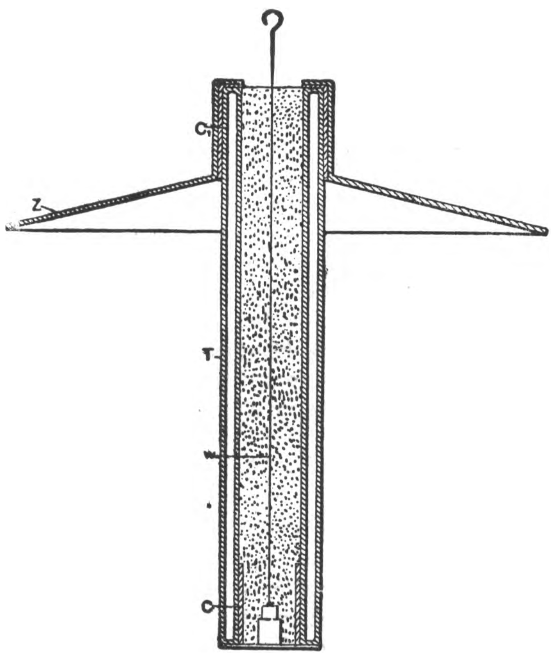


Fig. 27.

A similar disposition with a phosphorescent tube is illustrated in Fig. 27. The tube *T* is prepared from two short tubes of a different diameter, which are sealed on the ends. On the lower end is placed an outside conducting coating *C,* which connects to the wire *w.* The wire has a hook on the upper end for suspension, and passes through the centre of the inside tube, which is filled with some good and tightly packed insulator. On the outside of the upper end of the tube T is another conducting coating C_1, upon which is slipped a metallic reflector *Z,* which should be separated by a thick insulation from the end of wire *w*.

The economical use of such a reflector or intensifier would require that all energy supplied to an air condenser should be recoverable, or, in other words, that there should not be any losses, neither in the gaseous medium nor through its action elsewhere. This is far from being so, but, fortunately, the losses may be reduced to anything desired.

A few remarks are necessary on this subject, in order to make the experiences gathered in the course of these investigations perfectly clear.

Suppose a small helix with many well insulated turns, as in experiment Fig. 17, has one of its ends connected to one of the terminals of the induction coil, and the other to a metal plate, or, for the sake of simplicity, a sphere, insulated in space. When the coil is set to work, the potential of the sphere is alternated, and the small helix now behaves as though its free end were connected to the other terminal of the induction coil. If an iron rod be held within the small helix it is quickly brought to a high temperature, indicating the passage of a strong current through the helix; How does the insulated sphere act in this case? It can be a condenser, storing and returning the energy supplied to it, or it can be a mere sink of energy, and the conditions of the experiment determine whether it is more one or the other. The sphere being charged to a high potential, it acts inductively upon the surrounding air, or whatever gaseous medium there might be. The molecules, or atoms, which are near the sphere are of course more attracted, and move through a greater distance than the farther ones. When the nearest molecules strike the sphere they are repelled, and collisions occur at all distances within the inductive action of the sphere. It is now clear that, if the potential be steady, but little loss of energy can be caused in this way, for the molecules which are nearest to the sphere, having had an additional charge imparted to them by contact, are not attracted until they have parted, if not with all, at least with most of the additional charge, which can be accomplished only after a great many collisions. From the fact that with a steady potential there is but little loss in dry air, one must come to such a conclusion. When the potential of the sphere, instead of being steady, is alternating, the conditions are entirely different. In this case a rhythmical bombardment occurs, no matter whether the molecules after coming in contact with the sphere lose the imparted charge or not; what is more, if the charge is not lost, the impacts are only the more violent. Still if the frequency of the impulses be very small, the loss caused by the impacts and collisions would not be serious unless the potential were excessive. But when extremely high frequencies and more or less high potentials are used, the loss may be very great. The total energy lost per unit of time is proportionate to the product of the number of impacts per second, or the frequency and the energy lost in each impact. But the energy of an impact must be proportionate to the square of the electric density of the sphere, since the charge imparted to the molecule is proportionate to that density. I conclude from this that the total energy lost must be proportionate to the product of the frequency and the square of the electric density; but this law needs experimental confirmation. Assuming the preceding considerations to be true, then, by rapidly alternating the potential of a body immersed in an insulating gaseous medium, any amount of energy may be dissipated into space. Most of that energy then, I believe, is not dissipated in the form of long ether waves, propagated to considerable distance, as is thought most generally, but is consumed — in the case of an insulated sphere, for example — in impact and collisional losses — that is, heat vibrations — on the surface and in the vicinity of the sphere. To reduce the dissipation it is necessary to work with a small electric density — the smaller the higher the frequency.

But since, on the assumption before made, the loss is diminished with the square of the density, and since currents of very high frequencies involve considerable waste when transmitted through conductors, it follows that, on the whole, it is better to employ one wire than two. Therefore, if motors, lamps, or devices of any kind are perfected, capable of being advantageously operated by currents of extremely high frequency, economical reasons will make it advisable to use only one wire, especially if the distances are great.

When energy is absorbed in a condenser the same behaves as though its capacity were increased. Absorption always exists more or less, but generally it is small and of no consequence as long as the frequencies are not very great. In using extremely high frequencies, and, necessarily in such case, also high potentials, the absorption — or, what is here meant more particularly by this term, the loss of energy due to the presence of a gaseous medium — is an important factor to be considered, as the energy absorbed in the air condenser may be any fraction of the supplied energy. This would seem to make it very difficult to tell from the measured or computed capacity of an air condenser its actual capacity or vibration period, especially if the condenser is of very small surface and is charged to a very high potential. As many important results are dependent upon the correctness of the estimation of the vibration period, this subject demands the most careful scrutiny of other investigators. To reduce the probable error as much as possible in experiments of the kind alluded to, it is advisable to use spheres or plates of large surface, so as to make the density exceedingly small. Otherwise, when it is practicable, an oil condenser should be used in preference. In oil or other liquid dielectrics there are seemingly no such losses as in gaseous media. It being impossible to exclude entirely the gas in condensers with solid dielectrics, such condensers should be immersed in oil, for economical reasons if nothing else; they can then be strained to the utmost and will remain cool. In Leyden jars the loss due to air is comparatively small, as the tinfoil coatings are large, close together, and the charged surfaces not directly exposed; but when the potentials are very high, the loss may be more or less considerable at, or near, the upper edge of the foil, where the air is principally acted upon. If the jar be immersed in boiled-out oil, it will be capable of performing four times the amount of work which it can for any length of time when used in the ordinary way, and the loss will be inappreciable.

It should not be thought that the loss in heat in an air condenser is necessarily associated with the formation of *visible* streams or brushes. If a small electrode, inclosed in an unexhausted bulb, is connected to one of the terminals of the coil, streams can be seen to issue from the electrode and the air in the bulb is heated; if, instead of a small electrode, a large sphere is inclosed in the bulb, no streams are observed, still the air is heated.

Nor should it be thought that the temperature of an air condenser would give even an approximate idea of the loss in heat incurred, as in such case heat must be given off much more quickly, since there is, in addition to the ordinary radiation, a very active carrying away of heat by independent carriers going on, and since not only the apparatus, but the air at some distance from it is heated in consequence of the collisions which must occur.

Owing to this, in experiments with such a coil, a rise of temperature can be distinctly observed only when the body connected to the coil is very small. But with apparatus on a larger scale, even a body of considerable bulk would be heated, as, for instance, the body of a person; and I think that skilled physicians might make observations of utility in such experiments, which, if the apparatus were judiciously designed, would not present the slightest danger.

A question of some interest, principally to meteorologists, presents itself here. How does the earth behave? The earth is an air condenser, but is it a perfect or a very imperfect one — a mere sink of energy? There can be little doubt that to such small disturbance as might be caused in an experiment the earth behaves as an almost perfect condenser. But it might be different when its charge is set in vibration by some sudden disturbance occurring in the heavens. In such case, as before stated, probably only little of the energy of the vibrations set up would be lost into space in the form of long ether radiations, but most of the energy, I think, would spend itself in molecular impacts and collisions, and pass off into space in the form of short heat, and possibly light, waves. As both the frequency of the vibrations of the charge and the potential are in all probability excessive, the energy converted into heat may be considerable. Since the density must be unevenly distributed, either in consequence of the irregularity of the earth's surface, or on account of the condition of the atmosphere in various places, the effect produced would accordingly vary from place to place. Considerable variations in the temperature and pressure of the atmosphere may in this manner be caused at any point of the surface of the earth. The variations may be gradual or very sudden, according to the nature of the general disturbance, and may produce rain and storms, or locally modify the weather in any way.

From the remarks before made one may see what an important factor of loss the air in the neighborhood of a charged surface becomes when the electric density is great and the frequency of the impulses excessive. But the action as explained implies that the air is insulating — that is, that it is composed of independent carriers immersed in an insulating medium. This is the case only when the air is at something like ordinary or greater, or at extremely small, pressure. When the air is slightly rarefied and conducting, then true conduction losses occur also. In such case, of course, considerable energy may be dissipated into space even with a steady potential, or with impulses of low frequency, if the density is very great.

When the gas is at very low pressure, an electrode is heated more because higher speeds can be reached. If the gas around the electrode is strongly compressed, the displacements, and consequently the speeds, are very small, and the heating is insignificant. But if in such case the frequency could be sufficiently increased, the electrode would be brought to a high temperature as well as if the gas were at very low pressure; in fact, exhausting the bulb is only necessary because we cannot produce (and possibly not convey) currents of the required frequency.

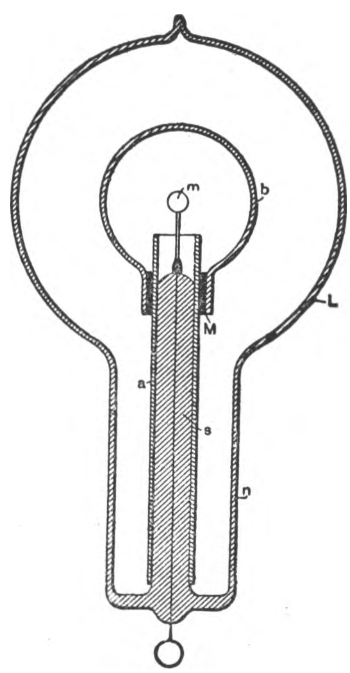


Fig. 28.

Returning to the subject of electrode lamps, it is obviously of advantage in such a lamp to confine as much as possible the heat to the electrode by preventing the circulation of the gas in the bulb. If a very small bulb be taken, it would confine the heat better than a large one, but it might not be of sufficient capacity to be operated from the coil, or, if so, the glass might get too hot. A simple way to improve in this direction is to employ a globe of the required size, but to place a small bulb, the diameter of which is properly estimated, over the refractory button contained in the globe. This arrangement is illustrated in Fig. 28.

The globe *L* has in this case a large neck *n,* allowing the small bulb *b* to slip through. Otherwise the construction is the same as shown in Fig. 18, for example. The small bulb is conveniently supported upon the stem *s,* carrying the refractory button *m.* It is separated from the aluminium tube a by several layers of mica *M,* in order to prevent the cracking of the neck by the rapid heating of the aluminium tube upon a sudden turning on of the current. The inside bulb should be as small as possible when it is desired to obtain light only by incandescence of the electrode. If it is desired to produce phosphorescence, the bulb should be larger, else it would be apt to get too hot, and the phosphorescence would cease. In this arrangement usually only the small bulb shows phosphorescence, as there is practically no bombardment against the outer globe. In some of these bulbs constructed as illustrated in Fig. 28 the small tube was coated with phosphorescent paint, and beautiful effects were obtained. Instead of making the inside bulb large, in order to avoid undue heating, it answers the purpose to make the electrode *m* larger. In this case the bombardment is weakened by reason of the smaller electric density.

Many bulbs were constructed on the plan illustrated in Fig. 29. Here a small bulb *b,* containing the refractory button *m,* upon being exhausted to a very high degree was sealed in a large globe *L,* which was then moderately exhausted and sealed off. The principal advantage of this construction was that it allowed of reaching extremely high vacua, and, at the same time use a large bulb. It was found, in the course of experiences with bulbs such as illustrated in Fig. 29, that it was well to make the stem s near the seal at *e* very thick, and the leading-in wire *w* thin, as it occurred sometimes that the stem at e was heated and the bulb was cracked. Often the outer globe *L* was exhausted only just enough to allow the discharge to pass through, and the space between the bulbs appeared crimson, producing a curious effect. In some cases, when the exhaustion in globe *L* was very low, and the air good conducting, it was found necessary, in order to bring the button *m* to high incandescence, to place, preferably on the upper part of the neck of the globe, a tinfoil coating which was connected to an insulated body, to the ground, or to the other terminal of the coil, as the highly conducting air weakened the effect somewhat, probably by being acted upon inductively from the wire *w,* where it entered the bulb at *e.* Another difficulty — which, however, is always present when the refractory button is mounted in a very small bulb — existed in the construction illustrated in Fig. 29, namely, the vacuum in the bulb *b* would be impaired in a comparatively short time.

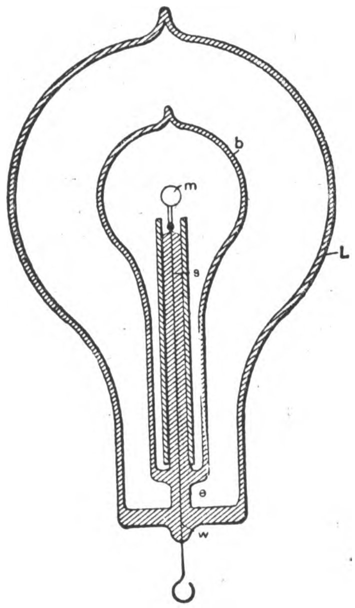


Fig. 29

The chief idea in the two last described constructions was to confine the heat to the central portion of the globe by preventing the exchange of air. An advantage is secured, but owing to the heating of the inside bulb and slow evaporation of the glass the vacuum is hard to maintain, even if the construction illustrated in Fig. 28 be chosen, in which both bulbs communicate.

But by far the better way — the ideal way — would be to reach sufficiently high frequencies. The higher the frequency the slower would be the exchange of the air, and I think that a frequency may be reached at which there would be no exchange whatever of the air molecules around the terminal. We would then produce a flame in which there would be no carrying away of material, and a queer flame it would be, for it would be rigid! With such high frequencies the inertia of the particles would come into play. As the brush, or flame, would gain rigidity in virtue of the inertia of the particles, the exchange of the latter would be prevented. This would necessarily occur, for, the number of the impulses being augmented, the potential energy of each would diminish, so that finally only atomic vibrations could be set up, and the motion of translation through measurable space would cease. Thus an ordinary gas burner connected to a source of rapidly alternating potential might have its efficiency augmented to a certain limit, and this for two reasons — because of the additional vibration imparted, and because of a slowing down of the process of carrying off. But the renewal being rendered difficult, and renewal being necessary to maintain the *burner,* a continued increase of the frequency of the impulses, assuming they could be transmitted to and impressed upon the flame, would result in the "extinction" of the latter, meaning by this term only the cessation of the chemical process.

I think, however, that in the case of an electrode immersed in a fluid insulating medium, and surrounded by independent carriers of electric charges, which can be acted upon inductively, a sufficiently high frequency of the impulses would probably result in a gravitation of the gas all around toward the electrode. For this it would be only necessary to assume that the independent bodies are irregularly shaped; they would then turn toward the electrode their side of the greatest electric density, and this would be a position in which the fluid resistance to approach would be smaller than that offered to the receding.

The general opinion, I do not doubt, is that it is out of the question to reach any such frequencies as might — assuming some of the views before expressed to be true — produce any of the results which I have pointed out as mere possibilities. This may be so, but in the course of these investigations, from the observation of many phenomena I have gained the conviction that these frequencies would be much lower than one is apt to estimate at first. In a flame we set up light vibrations by causing molecules, or atoms, to collide. But what is the ratio of the frequency of the collisions and that of the vibrations set up? Certainly it must be incomparably smaller than that of the knocks of the bell and the sound vibrations, or that of the discharges and the oscillations of the condenser. We may cause the molecules of the gas to collide by the use of alternate electric impulses of high frequency, and so we may imitate the process in a flame; and from experiments with frequencies which we are now able to obtain, I think that the result is producible with impulses which are transmissible through a conductor.

In connection with thoughts of a similar nature, it appeared to me of great interest to demonstrate the rigidity of a vibrating gaseous column. Although with such low frequencies as, say 10,000 per second, which I was able to obtain without difficulty from a specially constructed alternator, the task looked discouraging at first, I made a series of experiments. The trials with air at ordinary pressure led to no result, but with air moderately rarefied I obtain what I think to be an unmistakable experimental evidence of the property sought for. As a result of this kind might lead able investigators to conclusions of importance I will describe one of the experiments performed.

It is well known that when a tube is slightly exhausted the discharge may be passed through it in the form of a thin luminous thread. When produced with currents of low frequency, obtained from a coil operated as usual, this thread is inert. If a magnet be approached to it, the part near the same is attracted or repelled, according to the direction of the lines of force of the magnet. It occurred to me that if such a thread would be produced with currents of very high frequency, it should be more or less rigid, and as it was visible it could be easily studied. Accordingly I prepared a tube about 1 inch in diameter and 1 metre long, with outside coating at each end. The tube was exhausted to a point at which by a little working the thread discharge could be obtained. It must be remarked here that the general aspect of the tube, and the degree of exhaustion, are quite different than when ordinary low frequency currents are used. As it was found preferable to work with one terminal, the tube prepared was suspended from the end of a wire connected to the terminal, the tinfoil coating being connected to the wire, and to the lower coating sometimes a small insulated plate was attached. When the thread was formed it extended through the upper part of the tube and lost itself in the lower end. If it possessed rigidity it resembled, not exactly an elastic cord stretched tight between two supports, but a cord suspended from a height with a small weight attached at the end. When the finger or a magnet was approached to the upper end of the luminous thread, it could be brought locally out of position by electrostatic or magnetic action; and when the disturbing object was very quickly removed, an analogous result was produced, as though a suspended cord would be displaced and quickly released near the point of suspension. In doing this the luminous thread was set in vibration, and two very sharply marked nodes, and a third indistinct one, were formed. The vibration, once set up, continued for fully eight minutes, dying gradually out. The speed of the vibration often varied perceptibly, and it could be observed that the electrostatic attraction of the glass affected the vibrating thread; but it was clear that the electrostatic action was not the cause of the vibration, for the thread was most generally stationary, and could always be set in vibration by passing the finger quickly near the upper part of the tube. With a magnet the thread could be split in two and both parts vibrated. By approaching the hand to the lower coating of the tube, or insulated plate if attached, the vibration was quickened; also, as far as I could see, by raising the potential or frequency. Thus, either increasing the frequency or passing a stronger discharge of the same frequency corresponded to a tightening of the cord. I did not obtain any experimental evidence with condenser discharges. A luminous band excited in a bulb by repeated discharges of a Leyden jar must possess rigidity, and if deformed and suddenly released should vibrate. But probably the amount of vibrating matter is so small that in spite of the extreme speed the inertia cannot prominently assert itself. Besides, the observation in such a case is rendered extremely difficult on account of the fundamental vibration.

The demonstration of the fact — which still needs better experimental confirmation — that a vibrating gaseous column possesses rigidity, might greatly modify the views of thinkers. When with low frequencies and insignificant potentials indications of that property may be noted, how must a gaseous medium behave under the influence of enormous electrostatic stresses which may be active in the interstellar space, and which may alternate with inconceivable rapidity? The existence of such an electrostatic, rhythmically throbbing force — of a vibrating electrostatic field — would show *a* possible way how solids might have formed from the ultra-gaseous uterus, and how transverse and all kinds of vibrations may be transmitted through a gaseous medium filling all space. Then, ether might be a true fluid, devoid of rigidity, and at rest, it being merely necessary as a connecting link to enable interaction. What determines the rigidity of a body? It must be the speed and the amount of moving matter. In a gas the speed may be considerable, but the density is exceedingly small; in a liquid the speed would be likely to be small, though the density may be considerable; and in both cases the inertia resistance offered to displacement is practically *nil.* But place a gaseous (or liquid) column in an intense, rapidly alternating electrostatic field, set the particles vibrating with enormous speeds, then the inertia resistance asserts itself. A body might move with more or less freedom through the vibrating mass, but as a whole it would be rigid.

There is a subject which I must mention in connection with these experiments: it is that of high vacua. This is a subject the study of which is not only interesting, but useful, for it may lead to results of great practical importance. In commercial apparatus, such as incandescent lamps, operated from ordinary systems of distribution, a much higher vacuum than obtained at present would not secure a very great advantage. In such a case the work is performed on the filament and the gas is little concerned; the improvement, therefore, would be but trifling. But when we begin to use very high frequencies and potentials, the action of the gas becomes all important, and the degree of exhaustion materially modifies the results. As long as ordinary coils, even very large ones, were used, the study of the subject was limited, because just at a point when it became most interesting it had to be interrupted on account of the "non-striking" vacuum being reached. But presently we are able to obtain from a small disruptive discharge coil potentials much higher than even the largest coil was capable of giving, and, what is more, we can make the potential alternate with great rapidity. Both of these results enable us now to pass a luminous discharge through almost any vacua obtainable, and the field of our investigations is greatly extended. Think we as we may, of all the possible directions to develop a practical illuminant, the line of high vacua seems to be the most promising at present. But to reach extreme vacua the appliances must be much more improved, and ultimate perfection will not be attained until we shall have discarded the mechanical and perfected an *electrical* vacuum pump. Molecules and atoms can be thrown out of a bulb under the action of an enormous potential: *this* will be the principle of the vacuum pump of the future. For the present, we must secure the best results we can with mechanical appliances. In this respect, it might not be out of the way to say a few words about the method of, and apparatus for, producing excessively high degrees of exhaustion of which I have availed myself in the course of these investigations. It is very probable that other experimenters have used similar arrangements; but as it is possible that there may be an item of interest in their description, a few remarks, which will render this investigation more complete, might be permitted.

The apparatus is illustrated in a drawing shown in Fig. 30. *S* represents a Sprengel pump, which has been specially constructed to better suit the work required. The stopcock which is usually employed has been omitted, and instead of it a hollow stopper *s* has been fitted in the neck of the reservoir *R*. This stopper has a small hole *h,* through which the mercury descends; the size of the outlet *o* being properly determined with respect to the section of the fall tube *t,* which is sealed to the reservoir instead of being connected to it in the usual manner. This arrangement overcomes the imperfections and troubles which often arise from the use of the stopcock on the reservoir and the connection of the latter with the fall tube.

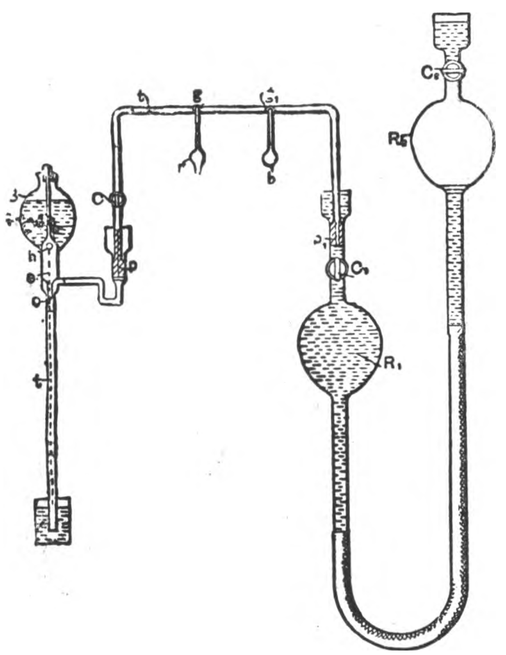


Fig. 30.

The pump is connected through a U-shaped tube *t* to a very large reservoir R_1. Especial care was taken in fitting the grinding surfaces of the stoppers *p* and p_1, and both of these and the mercury caps above them were made exceptionally long. After the U-shaped tube was fitted and put in place, it was heated, so as to soften and take off the strain resulting from imperfect fitting. The U-shaped tube was provided with a stopcock *C,* and two ground connections *g* and g_1 — one for a small bulb *b,* usually containing caustic potash, and the other for the receiver *r,* to be exhausted.

The reservoir R_1 was connected by means of a rubber tube to a slightly larger reservoir R_2, each of the two reservoirs being provided with a stopcock C_1 and C_2, respectively. The reservoir R_2 could be raised and lowered by a wheel and rack, and the range of its motion was so determined that when it was filled with mercury and the stopcock C_2 closed, so as to form a Torricellian vacuum in it when raised, it could be lifted so high that the mercury in reservoir R_1, would stand a little above stopcock C_1: and when this stopcock was closed and the reservoir R_2 descended, so as to form a Torricellian vacuum in reservoir R_1 it could be lowered so far as to completely empty the latter, the mercury filling the reservoir R_2 up to a little above stopcock C_2.

The capacity of the pump and of the connections was taken as small as possible relatively to the volume of reservoir, R_1, since, of course, the degree of exhaustion depended upon the ratio of these quantities.

With this apparatus I combined the usual means indicated by former experiments for the production of very high vacua. In most of the experiments it was convenient to use caustic potash. I may venture to say, in regard to its use, that much time is saved and a more perfect action of the pump insured by fusing and boiling the potash as soon as, or even before, the pump settles down. If this course is not followed the sticks, as ordinarily employed, may give moisture off at a certain very slow rate, and the pump may work for many hours without reaching a very high vacuum. The potash was heated either by a spirit lamp or by passing a discharge through it, or by passing a current through a wire contained in it. The advantage in the latter case was that the heating could be more rapidly repeated.

Generally the process of exhaustion was the following: — At the start, the stopcocks C and C_1 being open, and all other connections closed, the reservoir R_2 was raised so far that the mercury filled the reservoir R_1 and a part of the narrow connecting U-shaped tube. When the pump was set to work, the mercury would, of course, quickly rise in the tube, and reservoir R_2 was lowered, the experimenter keeping the mercury at about the same level. The reservoir R_2 was balanced by a long spring which facilitated the operation, and the friction of the parts was generally sufficient to keep it almost in any position. When the Sprengel pump had done its work, the reservoir R_2 was further lowered and the mercury descended in R_1 and filled R_2, whereupon stopcock C_2 was closed. The air adhering to the walls of R_1 and that absorbed by the mercury was carried off, and to free the mercury of all air the reservoir R_2 was for a long time worked up and down. During this process some air, which would gather below stopcock C_2, was expelled from R_2 by lowering it far enough and opening the stopcock, closing the latter again before raising the reservoir. When all the air had been expelled from the mercury, and no air would gather in R_2 when it was lowered, the caustic potash was resorted to. The reservoir R_2 was now again raised until the mercury in R_1 stood above stopcock C_1. The caustic potash was fused and boiled, and the moisture partly carried off by the pump and partly re-absorbed; and this process of heating and cooling was repeated many times, and each time, upon the moisture being absorbed or carried off, the reservoir R_2 was for a long time raised and lowered. In this manner all the moisture was carried off from the mercury, and both the reservoirs were in proper condition to be used. The reservoir R_2 was then again raised to the top, and the pump was kept working for a long time. When the highest vacuum obtainable with the pump had been reached the potash bulb was usually wrapped with cotton which was sprinkled with ether so as to keep the potash at a very low temperature, then the reservoir R_2 was lowered, and upon reservoir R_1 being emptied the receiver r was quickly sealed up.

When a new bulb was put on, the mercury was always raised above stopcock C_1, which was closed, so as to always keep the mercury and both the reservoirs in fine condition, and the mercury was never withdrawn from R_1 except when the pump had reached the highest degree of exhaustion. It is necessary to observe this rule if it is desired to use the apparatus to advantage.

By means of this arrangement I was able to proceed very quickly, and when the apparatus was in perfect order it was possible to reach the phosphorescent stage in a small bulb in less than 15 minutes, which is certainly very quick work for a small laboratory arrangement requiring all in all about 100 pounds of mercury. With ordinary small bulbs the ratio of the capacity of the pump, receiver, and connections, and that of reservoir *R* was about 1—20, and the degrees of exhaustion reached were necessarily very high, though I am unable to make a precise and reliable statement how far the exhaustion was carried.

What impresses the investigator most in the course of these experiences is the behavior of gases when subjected to great rapidly alternating electrostatic stresses. But he must remain in doubt as to whether the effects observed are due wholly to the molecules, or atoms, of the gas which chemical analysis discloses to us, or whether there enters into play another medium of a gaseous nature, comprising atoms, or molecules, immersed in a fluid pervading the space. Such a medium surely must exist, and I am convinced that, for instance, even if air were absent, the surface and neighborhood of a body in space would be heated by rapidly alternating the potential of the body; but no such heating of the surface or neighborhood could occur if all free atoms were removed and only a homogeneous, incompressible, and elastic fluid — such as ether is supposed to be — would remain, for then there would be no impacts, no collisions. In such a case, as far as the body itself is concerned, only frictional losses in the inside could occur.

It is a striking fact that the discharge through a gas is established with ever increasing freedom as the frequency of the impulses is augmented. It behaves in this respect quite contrarily to a metallic conductor. In the latter the impedance enters prominently into play as the frequency is increased, but the gas acts much as a series of condensers would: the facility with which the discharge passes through seems to depend on the rate of change of potential. If it act so, then in a vacuum tube even of great length, and no matter how strong the current, self-induction could not assert itself to any appreciable degree. We have, then, as far as we can now see, in the gas a conductor which is capable of transmitting electric impulses of any frequency which we may be able to produce. Could the frequency be brought high enough, then a queer system of electric distribution, which would be likely to interest gas companies, might be realized: metal pipes filled with gas — the metal being the insulator, the gas the conductor — supplying phosphorescent bulbs, or perhaps devices as yet uninvented. It is certainly possible to take a hollow core of copper, rarefy the gas in the same, and by passing impulses of sufficiently high frequency through a circuit around it, bring the gas inside to a high degree of incandescence; but as to the nature of the forces there would be considerable uncertainty, for it would be doubtful whether with such impulses the copper core would act as a static screen. Such paradoxes and apparent impossibilities we encounter at every step in this line of work, and therein lies, to a great extent, the charm of the study.

I have here a short and wide tube which is exhausted to a high degree and covered with a substantial coating of bronze, the coating allowing barely the light to shine through. A metallic clasp, with a hook for suspending the tube, is fastened around the middle portion of the latter, the clasp being in contact with the bronze coating. I now want to light the gas inside by suspending the tube on a wire connected to the coil. Any one who would try the experiment for the first time, not having any previous experience, would probably take care to be quite alone when making the trial, for fear that he might become the joke of his assistants. Still, the bulb lights in spite of the metal coating, and the light can be distinctly perceived through the latter. A long tube covered with aluminium bronze lights when held in one hand — the other touching the terminal of the coil — quite powerfully. It might be objected that the coatings are not sufficiently conducting; still, even if they were highly resistant, they ought to screen the gas. They certainly screen it perfectly in a condition of rest, but not by far perfectly when the charge is surging in the coating. But the loss of energy which occurs within the tube, notwithstanding the screen, is occasioned principally by the presence of the gas. Were we to take a large hollow metallic sphere and fill it with a perfect incompressible fluid dielectric, there would be no loss inside of the sphere, and consequently the inside might be considered as perfectly screened, though the potential be very rapidly alternating. Even were the sphere filled with oil, the loss would be incomparably smaller than when the fluid is replaced by a gas, for in the latter case the force produces displacements; that means impact and collisions in the inside.

No matter what the pressure of the gas may be, it becomes an important factor in the heating of a conductor when the electric density is great and the frequency very high. That in the heating of conductors by lightning discharges air is an element of great importance, is almost as certain as an experimental fact. I may illustrate the action of the air by the following experiment: I take a short tube which is exhausted to a moderate degree and has a platinum wire running through the middle from one end to the other. I pass a steady or low frequency current through the wire, and it is heated uniformly in all parts. The heating here is due to conduction, or frictional losses, and the gas around the wire has — as far as we can see — no function to perform. But now let me pass sudden discharges, or a high frequency current, through the wire. Again the wire is heated, this time principally on the ends and least in the middle portion; and if the frequency of the impulses, or the rate of change, is high enough, the wire might as well be cut in the middle as not, for practically all the heating is due to the rarefied gas. Here the gas might only act as a conductor of no impedance diverting the current from the wire as the impedance of the latter is enormously increased, and merely heating the ends of the wire by reason of their resistance to the passage of the discharge. But it is not at all necessary that the gas in the tube should be conducting; it might be at an extremely low pressure, still the ends of the wire would be heated — as, however, is ascertained by experience — only the two ends would in such case not be electrically connected through the gaseous medium. Now what with these frequencies and potentials occurs in an exhausted tube occurs in the lightning discharges at ordinary pressure. We only need remember one of the facts arrived at in the course of these investigations, namely, that to impulses of very high frequency the gas at ordinary pressure behaves much in the same manner as though it were at moderately low pressure. I think that in lightning discharges frequently wires or conducting objects are volatilized merely because air is present, and that, were the conductor immersed in an insulating liquid, it would be safe, for then the energy would have to spend itself somewhere else. From the behavior of gases to sudden impulses of high potential I am led to conclude that there can be no surer way of diverting a lightning discharge than by affording it a passage through a volume of gas, if such a thing can be done in a practical manner.

There are two more features upon which I think it necessary to dwell in connection with these experiments — the "radiant state" and the "non-striking vacuum".

Any one who has studied Crookes' work must have received the impression that the "radiant state" is a property of the gas inseparably connected with an extremely high degree of exhaustion. But it should be remembered that the phenomena observed in an exhausted vessel are limited to the character and capacity of the apparatus which is made use of. I think that in a bulb a molecule, or atom, does not precisely move in a straight line because it meets no obstacle, but because the velocity imparted to it is sufficient to propel it in a sensibly straight line. The mean free path is one thing, but the velocity — the energy associated with the moving body — is another, and under ordinary circumstances I believe that it is a mere question of potential or speed. A disruptive discharge coil, when the potential is pushed very far, excites phosphorescence and projects shadows, at comparatively low degrees of exhaustion. In a lightning discharge, matter moves in straight lines at ordinary pressure when the mean free path is exceedingly small, and frequently images of wires or other metallic objects have been produced by the particles thrown off in straight lines.

I have prepared a bulb to illustrate by an experiment the correctness of these assertions. In a globe *L* (Fig. 31), I have mounted upon a lamp filament *f* a piece of lime l. The lamp filament is connected with a wire which leads into the bulb, and the general construction of the latter is as indicated in Fig. 19, before described. The bulb being suspend ed from a wire connected to the terminal of the coil, and the latter being set to work, the lime piece l and the projecting parts of the filament f are bombarded. The degree of exhaustion is just such that with the potential the coil is capable of giving phosphorescence of the glass is produced, but disappears as soon as the vacuum is impaired. The lime containing moisture, and moisture being given off as soon as heating occurs, the phosphorescence lasts only for a few moments. When the lime has been sufficiently heated, enough moisture has been given off to impair materially the vacuum of the bulb. As the bombardment goes on, one point of the lime piece is more heated than other points, and the result is that finally practically all the discharge passes through that point which is intensely heated, and a white stream of lime particles (Fig. 31) then breaks forth from that point. This stream is composed of "radiant" matter, yet the degree of exhaustion is low. But the particles move in straight lines because the velocity imparted to them is great, and this is due to three causes — to the great electric density, the high temperature of the small point, and the fact that the particles of the lime are easily torn and thrown off — far more easily than those of carbon. With frequencies such as we are able to obtain, the particles are bodily thrown off and projected to a considerable distance, but with sufficiently high frequencies no such thing would occur: in such case only a stress would spread or a vibration would be propagated through the bulb. It would be out of the question to reach any such frequency on the assumption that the atoms move with the speed of light; but I believe that such a thing is impossible; for this an enormous potential would be required. With potentials which we are able to obtain, even with a disruptive discharge coil, the speed must be quite insignificant.

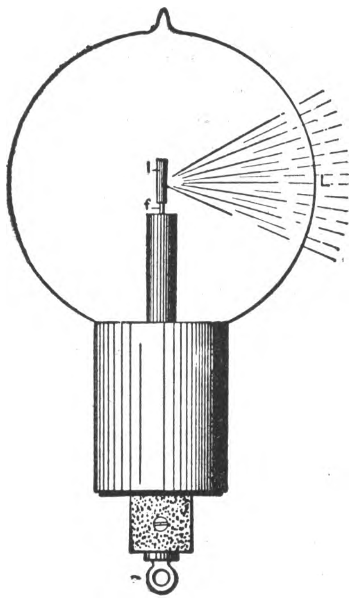


Fig. 31.

As to the "non-striking vacuum", the point to be noted is that it can occur only with low frequency impulses, and it is necessitated by the impossibility of carrying oft enough energy with such impulses in high vacuum since the few atoms which are around the terminal upon coming in contact with the same are repelled and kept at a distance for a comparatively long period of time, and not enough work can be performed to render the effect perceptible to the eye. If the difference of potential between the terminals is raised, the dielectric breaks down. But with very high frequency impulses there is no necessity for such breaking down, since any amount of work can be performed by continually agitating the atoms in the exhausted vessel, provided the frequency is high enough. It is easy to reach — even with frequencies obtained from an alternator as here used — a stage at which the discharge does not pass between two electrodes in a narrow tube, each of these being connected to one of the terminals of the coil, but it is difficult to reach a point at which a luminous discharge would not occur around each electrode.

A thought which naturally presents itself in connection with high frequency currents, is to make use of their powerful electro-dynamic inductive action to produce light effects in a sealed glass globe. The leading-in wire is one of the defects of the present incandescent lamp, and if no other improvement were made, that imperfection at least should be done away with. Following this thought, I have carried on experiments in various directions, of which some were indicated in my former paper. I may here mention one or two more lines of experiment which have been followed up.

Many bulbs were constructed as shown in Fig. 32 and Fig. 33.

In Fig. 32 a wide tube *T* was sealed to a smaller W-shaped tube *U,* of phosphorescent glass. In the tube *T* was placed a coil *C* of aluminium wire, the ends of which were provided with small spheres *t* and t_1 of aluminium, and reached into the *U* tube. The tube *T* was slipped into a socket containing a primary coil through which usually the discharges of Leyden jars were directed, and the rarefied gas in the small *U* tube was excited to strong luminosity by the high-tension currents induced in the

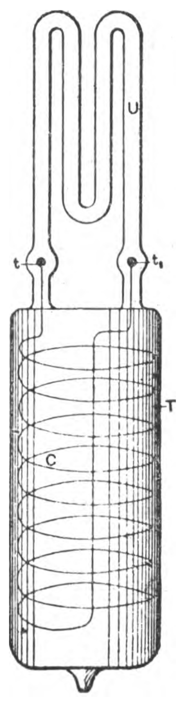


Fig. 32.

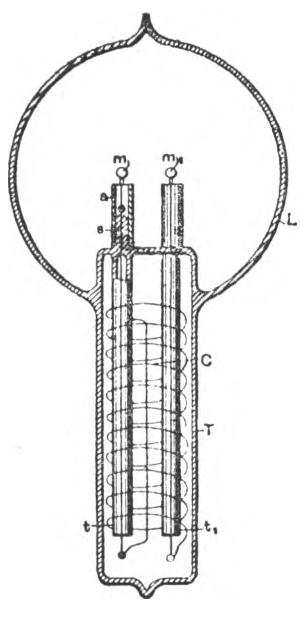


Fig. 33.

coil *C.* When Leyden jar discharges were used to induce currents in the coil *C,* it was found necessary to pack the tube *T* tightly with insulating powder, as a discharge would occur frequently between the turns of the coil, especially when the primary was thick and the air gap, through which the jars discharged, large, and no little trouble was experienced in this way.

In Fig. 33 is illustrated another form of the bulb constructed. In this case a tube T is sealed to a globe *L.* The tube contains a coil *C,* the ends of which pass through two small glass tubes *t* and t_1 which are sealed to the tube T. Two refractory buttons m and m_1 are mounted on lamp filaments which are fastened to the ends of the wires passing through the glass tubes *t and* t_1 Generally in bulbs made on this plan the globe *L* communicated with the tube *T*. For this purpose the ends of the small tubes *t* and t_1 were just a trifle heated in the burner, merely to hold the wires, but not to interfere with the communication. The tube *T,* with the small tubes, wires through the same, and the refractory buttons *m* and m_1 was first prepared, and then sealed to globe *L*, whereupon the coil *C* was slipped in and the connections made to its ends. The tube was then packed with insulating powder, jamming the latter as tight as possible up to very nearly the end, then it was closed and only a small hole left through which the remainder of the powder was introduced, and finally the end of the tube was closed. Usually in bulbs constructed as shown in Fig. 33 an aluminium tube *a* was fastened to the upper end *s* of each of the tubes *t* and t_1, in order to protect that end against the heat. The buttons *m* and m_1 could be brought to any degree of incandescence by passing the discharges of Leyden jars around the coil *C.* In such bulbs with two buttons a very curious effect is produced by the formation of the shadows of each of the two buttons.

Another line of experiment, which has been assiduously followed, was to induce by electro-dynamic induction a current or luminous discharge in an exhausted tube or bulb. This matter has received such able treatment at the hands of Prof. J. J. Thomson that I could add but little to what he has made known, even had I made it the special subject of this lecture. Still, since experiences in this line have gradually led me to the present views and results, a few words must be devoted here to this subject.

It has occurred, no doubt, to many that as a vacuum tube is made longer the electromotive force per unit length of the tube, necessary to pass a luminous discharge through the latter, gets continually smaller; therefore, if the exhausted tube be made long enough, even with low frequencies a luminous discharge could be induced in such a tube closed upon itself. Such a tube might be placed around a hall or on a ceiling, and at once a simple appliance capable of giving considerable light would be obtained. But this would be an appliance hard to manufacture and extremely unmanageable. It would not do to make the tube up of small lengths, because there would be with ordinary frequencies considerable loss in the coatings, and besides, if coatings were used, it would be better to supply the current directly to the tube by connecting the coatings to a transformer. But even if all objections of such nature were removed, still, with low frequencies the light conversion itself would be inefficient, as I have before stated. In using extremely high frequencies the length of the secondary — in other words, the size of the vessel — can be reduced as far as desired, and the efficiency of the light conversion is increased, provided that means are invented for efficiently obtaining such high frequencies. Thus one is led, from theoretical and practical considerations, to the use of high frequencies, and this means high electromotive forces and small currents in the primary. When he works with condenser charges — and they are the only means up to the present known for reaching these extreme frequencies — he gets to electromotive forces of several thousands of volts per turn of the primary. He cannot multiply the electro-dynamic inductive effect by taking more turns in the primary, for he arrives at the conclusion that the best way is to work with one single turn — though he must sometimes depart from this rule — and he must get along with whatever inductive effect he can obtain with one turn. But before he has long experimented with the extreme frequencies required to set up in a small bulb an electromotive force of several thousands of volts he realizes the great importance of electrostatic effects, and these effects grow relatively to the electro-dynamic in significance as the frequency is increased.

Now, if anything is desirable in this case, it is to increase the frequency, and this would make it still worse for the electro-dynamic effects. On the other hand, it is easy to exalt the electrostatic action as far as one likes by taking more turns on the secondary, or combining self-induction and capacity to raise the potential. It should also be remembered that, in reducing the current to the smallest value and increasing the potential, the electric impulses of high frequency can be more easily transmitted through a conductor.

These and similar thoughts determined me to devote more attention to the electrostatic phenomena, and to endeavor to produce potentials as high as possible, and alternating as fast as they could be made to alternate. I then found that I could excite vacuum tubes at considerable distance from a conductor connected to a properly constructed coil, and that I could, by converting the oscillatory current of a condenser to a higher potential, establish electrostatic alternating fields which acted through the whole extent of a room, lighting up a tube no matter where it was held in space. I thought I recognized that I had made a step in advance, and I have persevered in this line; but I wish to. say that I share with all lovers of science and progress the one and only desire — to reach a result of utility to men in any direction to which thought or experiment may lead me. I think that this departure is the right one, for I cannot see, from the observation of the phenomena, which manifest themselves as the frequency is increased, what there would remain to act between two. circuits conveying, for instance, impulses of several hundred millions per second, except electrostatic forces. Even with such trifling frequencies the energy would be practically all potential, and my conviction has grown strong that, to whatever kind of motion light may be due, it is produced by tremendous electrostatic stresses vibrating with extreme rapidity.

Of all these phenomena observed with currents, or electric impulses, of high frequency, the most fascinating for an audience are certainly those which are noted in an electrostatic field acting through considerable distance, and the best an unskilled lecturer can do is to begin and finish with the exhibition of these singular effects. I take a tube in the hand and move it about, and it is lighted wherever I may hold it; throughout space the invisible forces act. But I may take another tube and it might not light, the vacuum being very high. I excite it by means of a disruptive discharge coil, and now it will light in the electrostatic field. I may put it away for a few weeks or months, still it retains the faculty of being excited. What change have I produced in the tube in the act of exciting it? If a motion imparted to the atoms, it is difficult to perceive how it can persist so long without being arrested by frictional losses; and if a strain exerted in the dielectric, such as a simple electrification would produce, it is easy to see how it may persist indefinitely but very difficult to understand why such a condition should aid the excitation when we have to deal with potentials which are rapidly alternating.

Since I have exhibited these phenomena for the first time, I have obtained some other interesting effects. For instance, I have produced the incandescence of a button, filament, or wire enclosed in a tube. To get to this result it was necessary to economize the energy which is obtained from the field and direct most of it on the small body to be rendered incandescent. At the beginning the task appeared difficult, but the experiences gathered permitted me to reach the result easily. In Fig. 34 and Fig. 35 two such tubes are illustrated which are prepared for the occasion. In Fig. 34 a short tube T_1, sealed to another long tube *T,* is provided with a stem *s,* with a platinum wire sealed in the latter. A very thin lamp filament *l* is fastened to this wire, and connection to the outside is made through a thin copper wire *w.* The tube is provided with outside and inside coatings, *C* and C_1 respectively, and is filled as far as the coatings reach with conducting, and the space above with insulating powder. These coatings are merely used to enable me to perform two experiments with the tube — namely, to produce the effect desired either by direct connection of the body of the experimenter or of another body to the wire *w,* or by acting inductively through the glass. The stem *s* is provided with an aluminium tube *a,* for purposes before explained, and only a small part of the filament reaches out of this tube. By holding the tube T_1 anywhere in the electrostatic field the filament is rendered incandescent.

A more interesting piece of apparatus is illustrated in Fig. 35. The construction is the same as before, only instead of the lamp filament a small platinum wire *p,* sealed in a stem *s,* and bent above it in a circle, is connected to the. copper wire *w,* which is joined to an inside coating *C.* A small stem is provided with a needle, on the point of which is arranged to rotate very freely a very light fan of mica *v.* To prevent the fan from falling out, a thin stem of glass *g* is bent properly and fastened to the aluminium tube. When the glass tube is held anywhere in the electrostatic field the platinum wire becomes incandescent, and the mica vanes are rotated very fast.

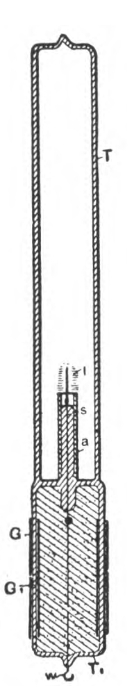


Fig. 34.

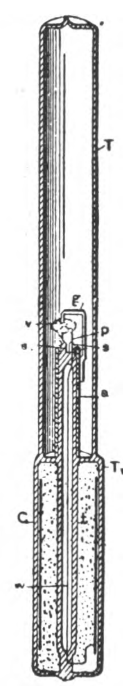


Fig. 35.

Intense phosphorescence may be excited in a bulb by merely connecting it to a plate within the field, and the plate need not be any larger than an ordinary lamp shade. The phosphorescence excited with these currents is incomparably more powerful than with ordinary apparatus. A small phosphorescent bulb, when attached to a wire connected to a coil, emits sufficient light to allow reading ordinary print at a distance of five to six paces. It was of interest to see how some of the phosphorescent bulbs of Professor Crookes would behave with these currents, and he has had the kindness to lend me a few for the occasion. The effects produced are magnificent, especially by the sulphide of calcium and sulphide of zinc. From the disruptive discharge coil they glow intensely merely by holding them in the hand and connecting the body to the terminal of the coil.

To whatever results investigations of this kind may lead, their chief interest lies for the present in the possibilities they offer for the production of an efficient illuminating device. In no branch of electric industry is an advance more desired than in the manufacture of light. Every thinker, when considering the barbarous methods employed, the deplorable losses incurred in our best systems of light production, must have asked himself, What is likely to be the light of the future? Is it to be an incandescent solid, as in the present lamp, or an incandescent gas, or a phosphorescent body, or something like a burner, but incomparably more efficient?

There is little chance to perfect a gas burner; not, perhaps, because human ingenuity has been bent upon that problem for centuries without a radical departure having been made — though this argument is not devoid of force — but because in a burner the higher vibrations can never be reached except by passing through all the low ones. For how is a flame produced unless by a fall of lifted weights? Such process cannot be maintained without renewal, and renewal is repeated passing from low to high vibrations. One way only seems to be open to improve a burner, and that is by trying to reach higher degrees of incandescence. Higher incandescence is equivalent to a quicker vibration; that means more light from the same material, and that, again, means more economy. In this direction some improvements have been made, but the progress is hampered by many limitations. Discarding, then, the burner, there remain the three ways first mentioned, which are essentially electrical.

Suppose the light of the immediate future to be a solid rendered incandescent by electricity. Would it not seem that it is better to employ a small button than a frail filament? From many considerations it certainly must be concluded that a button is capable of a higher economy, assuming, of course, the difficulties connected with the operation of such a lamp to be effectively overcome. But to light such a lamp we require a high potential; and to get this economically we must use high frequencies.

Such considerations apply even more to the production of light by the incandescence of a gas, or by phosphorescence. In all cases we require high frequencies and high potentials. These thoughts occurred to me a long time ago.

Incidentally we gain, by the use of very high frequencies, many advantages, such as a higher economy in the light production, the possibility of working with one lead, the possibility of doing away with the leading-in wire, etc.

The question is, how far can we go with frequencies? Ordinary conductors rapidly lose the facility of transmitting electric impulses when the frequency is greatly increased. Assume the means for the production of impulses of very great frequency brought to the utmost perfection, every one will naturally ask how to transmit them when the necessity arises. In transmitting such impulses through conductors we must remember that we have to deal with *pressure* and *flow,* in the ordinary interpretation of these terms. Let the pressure increase to an enormous value, and let the flow correspondingly diminish, then such impulses — variations merely of pressure, as it were — can no doubt be transmitted through a wire even if their frequency be many hundreds of millions per second. It would, of course, be out of question to transmit such impulses through a wire immersed in a gaseous medium, even if the wire were provided with a thick and excellent insulation for most of the energy would be lost in molecular bombardment and consequent heating. The end of the wire connected to the source would be heated, and the remote end would receive but a trifling part of the energy supplied. The prime necessity, then, if such electric impulses are to be used, is to find means to reduce as much as possible the dissipation.

The first thought is, employ the thinnest possible wire surrounded by the thickest practicable insulation. The next thought is to employ electrostatic screens. The insulation of the wire may be covered with a thin conducting coating and the latter connected to the ground. But this would not do, as then all the energy would pass through the conducting coating to the ground and nothing would get to the end of the wire. If a ground connection is made it can only be made through a conductor offering an enormous impedance, or through a condenser of extremely small capacity. This, however, does not do away with other difficulties.

If the wave length of the impulses is much smaller than the length of the wire, then corresponding short waves will be sent up in the conducting coating, and it will be more or less the same as though the coating were directly connected to earth. It is therefore necessary to cut up the coating in sections much shorter than the wave length. Such an arrangement does not still afford a perfect screen, but it is ten thousand times better than none. I think it preferable to cut up the conducting coating in small sections, even if the current waves be much longer than the coating.

If a wire were provided with a perfect electrostatic screen, it would be the same as though all objects were removed from it at infinite distance. The capacity would then be reduced to the capacity of the wire itself, which would be very small. It would then be possible to send over the wire current vibrations of very high frequencies at enormous distance without affecting greatly the character of the vibrations. A perfect screen is of course out of the question, but I believe that with a screen such as I have just described telephony could be rendered practicable across the Atlantic. According to my ideas, the gutta-percha covered wire should be provided with a third conducting coating subdivided in sections. On the top of this should be again placed a layer of gutta-percha and other insulation, and on the top of the whole the armor. But such cables will not be constructed, for ere long intelligence — transmitted without wires — will throb through the earth like a pulse through a living organism. The wonder is that, with the present state of knowledge and the experiences gained, no attempt is being made to disturb the electrostatic or magnetic condition of the earth, and transmit, if nothing else, intelligence.

It has been my chief aim in presenting these results to point out phenomena or features of novelty, and to advance ideas which I am hopeful will serve as starting points of new departures. It has been my chief desire this evening to entertain you with some novel experiments. Your applause, so frequently and generously accorded, has told me that I have succeeded.

In conclusion, let me thank you most heartily for your kindness and attention, and assure you that the honor I have had in addressing such a distinguished audience, the pleasure I have had in presenting these results to a gathering of so many able men — and among them also some of those in whose work for many years past I have found enlightenment and constant pleasure — I shall never forget.

4

ON LIGHT AND OTHER HIGH FREQUENCY PHENOMENA *

INTRODUCTORY — SOME THOUGHTS ON THE EYE

When we look at the world around us, on Nature, we are impressed with its beauty and grandeur. Each thing we perceive, though it may be vanishingly small, is in itself a world, that is, like the whole of the universe, matter and force governed by law, — a world, the contemplation of which fills us with feelings of wonder and irresistibly urges us to ceaseless thought and inquiry. But in all this vast world, of all objects our senses reveal to us, the most marvelous, the most appealing to our imagination, appears no doubt a highly developed organism, a thinking being. If there is anything fitted to make us admire Nature's handiwork, it is certainly this inconceivable structure, which performs its innumerable motions of obedience to external influence. To understand its workings, to get a deeper insight into this Nature's masterpiece, has ever been for thinkers a fascinating aim, and after many centuries of arduous research men have arrived at a fair understanding of the functions of its organs and senses. Again, in all the perfect harmony of its parts, of the parts which constitute the material or tangible of our being, of all its organs and senses, the eye is the most wonderful. It is the most precious, the most indispensable of our perceptive or directive organs, it is the great gateway through which all knowledge enters the mind. Of all our organs, it is the one, which is in the most intimate relation with that which we call intellect. So intimate is this relation, that it is often said, the very soul shows itself in the eye.

It can be taken as a fact, which the theory of the action of the eye implies, that for each external impression, that is, for each image produced upon the retina, the ends of the visual nerves, concerned in the conveyance of the impression to the mind, must be under a peculiar stress or in a vibratory state. It now does not seem improbable that, when by the power of thought an image is evoked, a distinct reflex action, no matter how weak, is exerted upon certain ends of the visual nerves, and therefore upon the retina. Will it ever be within human power to analyze the condition of the retina when disturbed by thought or reflex action, by the help of some optical or other means of such sensitiveness, that a clear idea of its state might be gained at any time? If this were possible, then the problem of reading one's thoughts with precision, like the characters of an open book, might be much easier to solve than many problems belonging to the domain of positive physical science, in the solution of which many, if not the majority, of scientific men implicitly believe. Helmholtz has shown that the fundi of the eye are themselves, luminous, and he was able to *see,* in total darkness, the movement of his arm by the light of his own eyes. This is one of the most remarkable experiments recorded in the history of science, and probably only a few men could satisfactorily

* A lecture delivered before the Franklin Institute, Philadelphia, February, 1893, and before the National Electric Light Association, St. Louis, March, 1893.

repeat it, for it is very likely, that the luminosity of the eyes is associated with uncommon activity of the brain and great imaginative power. It is fluorescence of brain action, as it were.

Another fact having a bearing on this subject which has probably been noted by many, since it is stated in popular expressions, but which I cannot recollect to have found chronicled as a positive result of observation is, that at times, when a sudden idea or image presents itself to the intellect, there is a distinct and sometimes painful sensation of luminosity produced in the eye, observable even in broad daylight.

The saying then, that the soul shows itself in the eye, is deeply founded, and we feel that it expresses a great truth. It has a profound meaning even for one who, like a poet or artist, only following his inborn instinct or love for Nature, finds delight in aimless thoughts and in the mere contemplation of natural phenomena, but a still more profound meaning for one who, in the spirit of positive scientific investigation, seeks to ascertain the causes of the effects. It is principally the natural philosopher, the physicist, for whom the eye is the subject of the most intense admiration.

Two facts about the eye must forcibly impress the mind of the physicist, notwithstanding he may think or say that it is an imperfect optical instrument, forgetting, that the very conception of that which is perfect or seems so to him, has been gained through this same instrument. First, the eye is, as far as our positive knowledge goes, the only organ which is *directly* affected by that subtile medium, which as science teaches us, must fill all space; secondly, it is the most sensitive of our organs, incomparably more sensitive to external impressions than any other.

The organ of hearing implies the impact of ponderable bodies, the organ of smell the transference of detached material particles, and the organs of taste, and of touch or force, the direct contact, or at least some interference of ponderable matter, and this is true even in those instances of animal organisms, in which some of these organs are developed to a degree of truly marvelous perfection. This being so, it seems wonderful that the organ of sight solely should be capable of being stirred by that, which all our other organs are powerless to detect, yet which plays an essential part in all natural phenomena, which transmits all energy and sustains all motion and, that most intricate of all, life, but which has properties such that even a scientifically trained mind cannot help drawing a distinction between it and all that is called matter. Considering merely this, and the fact that the eye, by its marvelous power, widens our otherwise very narrow range of perception far beyond the limits of the small world which is our own, to embrace myriads of other worlds, suns and stars in the infinite depths of the universe, would make it justifiable to assert, that it is an organ of a higher order. Its performances are beyond comprehension. Nature as far as we know never produced anything more wonderful. We can get barely a faint idea of its prodigious power by analyzing what it does and by comparing. When ether waves impinge upon the human body, they produce the sensations of warmth or cold, pleasure or pain, or perhaps other sensations of which we are not aware, and any degree or intensity of these sensations, which degrees are infinite in number, hence an infinite number of distinct sensations. But our sense of touch, or our sense of force, cannot reveal to us these differences in degree or intensity, unless they are very great. Now we can readily conceive how an organism, such as the human, in the eternal process of evolution, or more philosophically speaking, adaptation to Nature, being constrained to the use of only the sense of touch or force, for instance, might develop this sense to such a degree of sensitiveness or perfection, that it would be capable of distinguishing the minutest differences in the temperature of a body even at some distance, to a hundredth, or thousandth, or millionth part of a degree. Yet, even this apparently impossible performance would not begin to compare with that of the eye, which is capable of distinguishing and conveying to the mind in a single instant innumerable peculiarities of the body, be it in form, or color, or other respects. This power of the eye rests upon two things, namely, the rectilinear propagation of the disturbance by which it is effected, and upon its sensitiveness. To say that the eye is sensitive is not saying anything. Compared with it, all other organs are monstrously crude. The organ of smell which guides a dog on the trail of a deer, the organ of touch or force which guides an insect in its wanderings, the organ of hearing, which is affected by the slightest disturbances of the air, are sensitive organs, to be sure, but what are they compared with the human eye! No doubt it responds to the faintest echoes or reverberations of the medium; no doubt, it brings us tidings from other worlds, infinitely remote, but in a language we cannot as yet always understand. And why not? Because we live in a medium filled with air and other gases, vapors and a dense mass of solid particles flying about. These play an important part in many phenomena; they fritter away the energy of the vibrations before they can reach the eye; they too, are the carriers of germs of destruction, they get into our lungs and other organs, clog up the channels and imperceptibly, yet inevitably, arrest the stream of life. Could we but do away with all ponderable matter in the line of sight of the telescope, it would reveal to us undreamt of marvels. Even the unaided eye, I think, would be capable of distinguishing in the pure medium, small objects at distances measured probably by hundreds or perhaps thousands of miles.

But there is something else about the eye which impresses us still more than these wonderful features which we observed, viewing it from the standpoint of a physicist, merely as an optical instrument, — something which appeals to us more than its marvelous faculty of being directly affected by the vibrations of the medium, without interference of gross matter, and more than its inconceivable sensitiveness and discerning power. It is its significance in the processes of life. No matter what one's views on nature and life may be, he must stand amazed when, for the first time in his thoughts, he realizes the importance of the eye in the physical processes and mental performances of the human organism. And how could it be otherwise, when he realizes, that the eye is the means through which the human race has acquired the entire knowledge it possesses, that it controls all our motions, more still, and our actions.

There is no way of acquiring knowledge except through the eye. What is the foundation of all philosophical systems of ancient and modern times, in fact, of all the philosophy of man? *I am, I think; I think, therefore I am.* But how could I think and how would I know that I exist, if I had not the eye? For knowledge involves consciousness; consciousness involves ideas, conceptions; conceptions involve pictures or images, and images the sense of vision, and therefore the organ of sight. But how about blind men, will be asked? Yes, a blind man may depict in magnificent poems, forms and scenes from real life, from a world he physically does not see. A blind man may touch the keys of an instrument with unerring precision, may model the fastest boat, may discover and invent, calculate and construct, may do still greater wonders — but all the blind men who have done such things have descended from those who had seeing eyes. Nature may reach the same result in many ways. Like a wave in the physical world, in the infinite ocean of the medium which pervades all, so in the world of organisms, in life, an impulse started proceeds onward, at times, may be, with the speed of light, at times, again, so slowly that for ages and ages it seems to stay, passing through processes of a complexity inconceivable to men, but in all its forms, in all its stages, its energy ever and ever integrally present. A single ray of light from a distant star falling upon the eye of a tyrant in by-gone times, may have altered the course of his life, may have changed the destiny of nations, may have transformed the surface of the globe, so intricate, so inconceivably complex are the processes in Nature. In no way can we get such an overwhelming idea of the grandeur of Nature, as when we consider, that in accordance with the law of the conservation of energy, throughout the infinite, the forces are in a perfect balance, and hence the energy of a single thought may determine the motion of a Universe. It is not necessary that every individual, not even that every generation or many generations, should have the physical instrument of sight, in order to be able to form images and to think, that is, form ideas or conceptions; but sometime or other, during the process of evolution, the eye certainly must have existed, else thought, as we understand it, would be impossible; else conceptions, like spirit, intellect, mind, call it as you may, could not exist. It is conceivable, that in some other world, in some other beings, the eye is replaced by a different organ, equally or more perfect, but these beings cannot be men.

Now what prompts us all to voluntary motions and actions of any kind? Again the eye. If I am conscious of the motion, I must have an idea or conception, that is, an image, therefore the eye. If I am not precisely conscious of the motion, it is, because the images are vague or indistinct, being blurred by the superimposition of many. But when I perform the motion, does the impulse which prompts me to the action come from within or from without? The greatest physicists have not disdained to endeavor to answer this and similar questions and have at times abandoned themselves to the delights of pure and unrestrained thought. Such questions are generally considered not to belong to the realm of positive physical science, but will before long be annexed to its domain. Helmholtz has probably thought more on life than any modern scientist. Lord Kelvin expressed his belief that life's process is electrical and that there is a force inherent to the organism and determining its motions. Just as much as I am convinced of any physical truth I am convinced that the motive impulse must come from the outside. For, consider the lowest organism we know — and there are probably many lower ones — an aggregation of a few cells only. If it is capable of voluntary motion it can perform an infinite number of motions, all definite and precise. But now a mechanism consisting of a finite number of parts and few at that, cannot perform an infinite number of definite motions, hence the impulses which govern, its movements must come from the environment. So, the atom, the ulterior element of the Universe's structure, is tossed about in space eternally, a play to external influences, like a boat in a troubled sea. Were it to stop its motion *it would die.* Matter at rest, if such a thing could exist, would be matter dead. Death of matter! Never has a sentence of deeper philosophical meaning been uttered. This is the way in which Prof. Dewar forcibly expresses it in the description of his admirable experiments, in which liquid oxygen is handled as one handles water, and air at ordinary pressure is made to condense and even to solidify by the intense cold. Experiments, which serve to illustrate, in his language, the last feeble manifestations of life, the last quiverings of matter about to die. But human eyes shall not witness such death. There is no death of matter, for throughout the infinite universe, all has to move, to vibrate, that is, to live.

I have made the preceding statements at the peril of treading upon metaphysical ground, in my desire to introduce the subject of this lecture in a manner not altogether uninteresting, I may hope, to an audience such as I have the honor to address. But now, then, returning to the subject, this divine organ of sight, this indispensable instrument for thought and all intellectual enjoyment, which lays open to us the marvels of this universe, through which we have acquired what knowledge we possess, and which prompts us to, and controls, all our physical and mental activity. By what is it affected? By light! What is light?

We have witnessed the great strides which have been made in all departments of science in recent years. So great have been the advances that we cannot refrain from asking ourselves, Is this all true, or is it but a dream? Centuries ago men have lived, have thought, discovered, invented, and have believed that they were soaring, while they were merely proceeding at a snail's pace. So we too may be mistaken. But taking the truth of the observed events as one of the implied facts of science, we must rejoice in the immense progress already made and still more in the anticipation of what must come, judging from the possibilities opened up by modern research. There is, however, an advance which we have been witnessing, which must be particularly gratifying to every lover of progress. It is not a discovery, or an invention, or an achievement in any particular direction. It is an advance in all directions of scientific thought and experiment. I mean the generalization of the natural forces and phenomena, the looming up of a certain broad idea on the scientific horizon. It is this idea which has, however, long ago taken possession of the most advanced minds, to which I desire to call your attention, and which I intend to illustrate in a general way, in these experiments, as the first step in answering the question "What is light?" and to realize the modern meaning of this word.

It is beyond the scope of my lecture to dwell upon the subject of light in general, my object being merely to bring presently to your notice a certain class of light effects and a number of phenomena observed in pursuing the study of these effects. But to be consistent in my remarks it is necessary to state that, according to that idea, now accepted by the majority of scientific men as a positive result of theoretical and experimental investigation, the various forms or manifestations of energy which were generally designated as "electric" or more precisely "electromagnetic" are energy manifestations of the same nature as those of radiant heat and light. Therefore the phenomena of light and heat and others besides these, may be called electrical phenomena. Thus electrical science has become the mother science of all and its study has become all important. The day when we shall know exactly what "electricity" is, will chronicle an event probably greater, more important than any other recorded in the history of the human race. The time will come when the comfort, the very existence, perhaps, of man will depend upon that wonderful agent. For our existence and comfort we require heat, light and mechanical power. How do we now get all these? We get them from fuel, we get them by consuming material. What will man do when the forests disappear, when the coal fields are exhausted? Only one thing, according to our present knowledge will remain; that is, to transmit power at great distances. Men will go to the waterfalls, to the tides, which are the stores of an infinitesimal part of Nature's immeasurable energy. There will they harness the energy and transmit the same to their settlements, to warm their homes by, to give them light, and to keep their obedient slaves, the machines, toiling. But how will they transmit this energy if not by electricity? Judge then, if the comfort, nay, the very existence, of man will not depend on electricity. I am aware that this view is not that of a practical engineer, but neither is it that of an illusionist, for it is certain, that power transmission, which at present is merely a stimulus to enterprise, will some day be a dire necessity.

It is more important for the student, who takes up the study of light phenomena, to make himself thoroughly acquainted with certain modern views, than to peruse entire books on the subject of light itself, as disconnected from these views. Were I therefore to make these demonstrations before students seeking information — and for the sake of the few of those who may be present, give me leave to so assume — it would be my principal endeavor to impress these views upon their minds in this series of experiments.

It might be sufficient for this purpose to perform a simple and well-known experiment. I might take a familiar appliance, a Leyden jar, charge it from a frictional machine, and then discharge it. In explaining to you its permanent state when charged, and its transitory condition when discharging, calling your attention to the forces which enter into play and to the various phenomena they produce, and pointing out the relation of the forces and phenomena, I might fully succeed in illustrating that modern idea. No doubt, to the thinker, this simple experiment would appeal as much as the most magnificent display. But this is to be an experimental demonstration, and one which should possess, besides instructive, also entertaining features and as such, a simple experiment, such as the one cited, would not go very far towards the attainment of the lecturer's aim. I must therefore choose another way of illustrating, more spectacular certainly, but perhaps also more instructive. Instead of the frictional machine and Leyden jar, I shall avail myself in these experiments, of an induction coil of peculiar properties, which was described in detail by me in a lecture before the London Institution of Electrical Engineers, in Feb., 1892. This induction coil is capable of yielding currents of enormous potential differences, alternating with extreme rapidity. With this apparatus I shall endeavor to show you three distinct classes of effects, or phenomena, and it is my desire that each experiment, while serving for the purposes of illustration, should at the same time teach us some novel truth, or show us some novel aspect of this fascinating science. But before doing this, it seems proper and useful to dwell upon the apparatus employed, and method of obtaining the high potentials and high-frequency currents which are made use of in these experiments.

ON THE APPARATUS AND METHOD OF CONVERSION.

These high-frequency currents are obtained in a peculiar manner. The method employed was advanced by me about two years ago in an experimental lecture before the American Institute of Electrical Engineers. A number of ways, as practiced in the

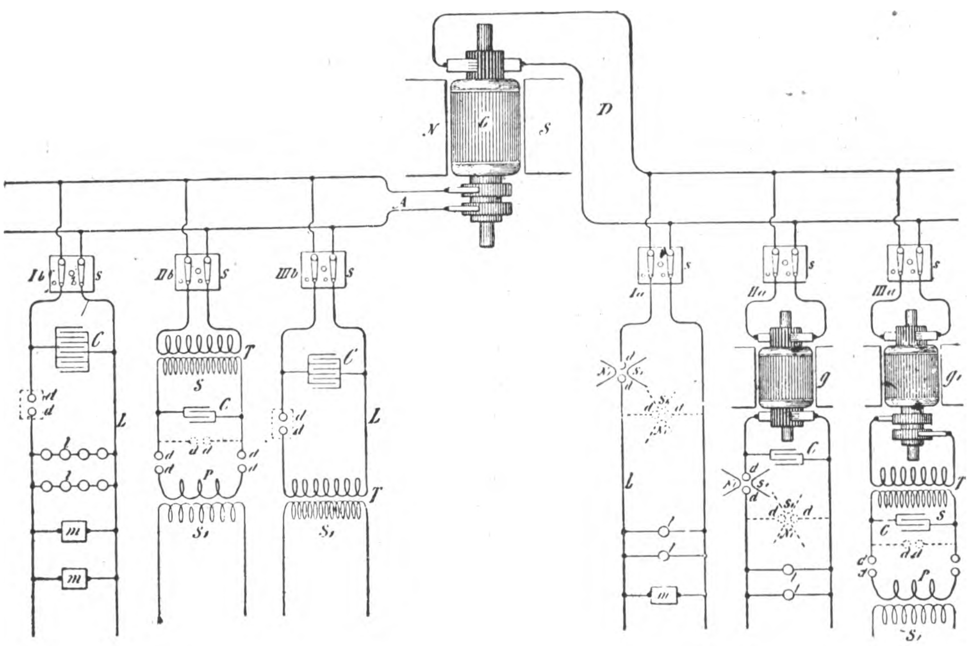


Fig. 1.

laboratory, of obtaining these currents either from continuous or low frequency alternating currents, is diagrammatically indicated in Fig. 1, which will be later described in detail. The general plan is to charge condensers, from a direct or alternate-current source, preferably of high-tension, and to discharge them disruptively while observing well-known conditions necessary to maintain the oscillations of the current. In view of the general interest taken in high-frequency currents and effects producible by them, it seems to me advisable to dwell at some length upon this method of conversion. In order to give you a clear idea of the action, I will suppose that a continuous-current generator is employed, which is often very convenient. It is desirable that the generator should possess such high tension as to be able to break through a small air space. If this is not the case, then auxiliary means have to be resorted to, some of which will be indicated subsequently. When the condensers are charged to a certain potential, the air, or insulating space, gives way and a disruptive discharge occurs. There is then a sudden rush of current and generally a large portion of accumulated electrical energy spends itself. The condensers are thereupon quickly charged and the same process is repeated in more or less rapid succession. To produce such sudden rushes of current it is necessary to observe certain conditions. If the rate at which the condensers are discharged is the same as that at which they are charged, then, clearly, in the assumed case the condensers do not come into play. If the rate of discharge be smaller than the rate of charging, then, again, the condensers cannot play an important part. But if, on the contrary, the rate of discharging is greater than that of charging, then a succession of rashes of current is obtained. It is evident that, if the rate at which the energy is dissipated by the discharge is very much greater than the rate of supply to the condensers, the sudden rushes will be comparatively few, with long-time intervals between. This always occurs when a condenser of considerable capacity is charged by means of a comparatively small machine. If the rates of supply and dissipation are not widely different, then the rushes of current will be in quicker succession, and this the more, the more nearly equal both the rates are, until limitations incident to each case and depending upon a number of causes are reached. Thus we are able to obtain from a continuous-current generator as, rapid a succession of discharges as we like. Of course, the higher the tension of the generator, the smaller need be the capacity of the condensers, and for this reason, principally, it is of advantage to employ a generator of very high tension. Besides, such a generator permits the attaining of greater rates of vibration.

The rushes of current may be of the same direction under the conditions before assumed, but most generally there is an oscillation superimposed upon the fundamental vibration of the current. When the conditions are so determined that there are no oscillations, the current impulses are unidirectional and thus a means is provided of transforming a continuous current of high tension, into a direct current of lower tension, which I think may find employment in the arts.

This method of conversion is exceedingly interesting and I was much impressed by its beauty when I first conceived it. It is ideal in certain respects. It involves the employment of no mechanical devices of any kind, and it allows of obtaining currents of any desired frequency from an ordinary circuit, direct or alternating. The frequency of the fundamental discharges depending on the relative rates of supply and dissipation can be readily varied within wide limits, by simple adjustments of these quantities, and the frequency of the superimposed vibration by the determination of the capacity, self-induction and resistance of the circuit. The potential of the currents, again, may be raised as high as any insulation is capable of withstanding safely by combining capacity and self-induction or by induction in a secondary, which need have but comparatively few turns.

As the conditions are often such that the intermittence or oscillation does not readily establish itself, especially when a direct current source is employed, it is of advantage to associate an interrupter with the arc, as I have, some time ago, indicated the use of an air-blast or magnet, or other such device readily at hand. The magnet is employed with special advantage in the conversion of direct currents, as it is then very effective. If the primary source is an alternate current generator, it is desirable, as I have stated on another occasion, that the frequency should be low, and that the current forming the arc be large, in order to render the magnet more effective.

A form of such discharger with a magnet which has been found convenient, and adopted after some trials, in the conversion of direct currents particularly, is illustrated in Fig. 2. N S are the pole pieces of a very strong magnet which is excited by a coil c. The pole pieces are slotted for adjustment and can be fastened in any position by screws s s_1. The discharge rods d d_1, thinned down on the ends in order to allow a closer approach of the magnetic pole pieces, pass through the columns of brass b b_1 and are fastened in position by screws s_2 s_2. Springs r and collars c c_1 are slipped on the rods, the latter serving to set the points of the rods at a certain suitable distance by

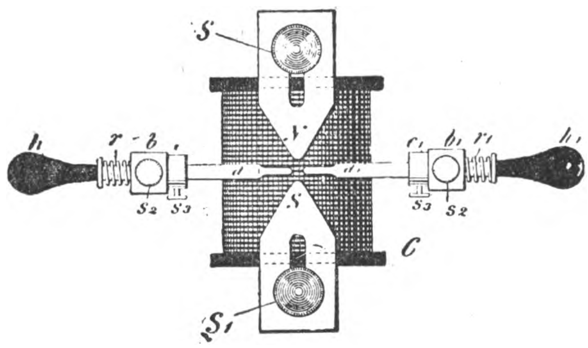


Fig. 2.

means of screws s_3 s_3, and the former to draw the points apart. When it is desired to start the arc, one of the large rubber handles h h_1 is tapped quickly with the hand, whereby the points of the rods are brought in contact but are instantly separated by the springs r r_1 Such an arrangement has been found to be often necessary, namely in cases when the E. M. F. was not large enough to cause the discharge to break through the gap, and also when it was desirable to avoid short circuiting of the generator by the metallic contact of the rods. The rapidity of the interruptions of the current with a magnet depends on the intensity of the magnetic field and on the potential difference at the end of the arc. The interruptions are generally in such quick succession as to produce a musical sound. Years ago it was observed that when a powerful induction coil is discharged between the poles of a strong magnet, the discharge produces a loud noise not unlike a small pistol shot. It was vaguely stated that the spark was intensified by the presence of the magnetic field. It is now clear that the discharge current, flowing for some time, was interrupted a great number of times by the magnet, thus producing the sound. The phenomenon is especially marked when the field circuit of a large magnet or dynamo is broken in a powerful magnetic field.

When the current through the gap is comparatively large, it is of advantage to slip on the points of the discharge rods pieces of very hard carbon and let the arc play between the carbon pieces. This preserves the rods, and besides has the advantage of keeping the air space hotter, as the heat is not conducted away as quickly through the carbons, and the result is that a smaller E. M. F. in the arc gap is required to maintain a succession of discharges.

Another form of discharger, which may be employed with advantage in some cases, is illustrated in Fig. 3. In this form the discharge rods d d_1 pass through perforations in a wooden box B, which is thickly coated with mica on the inside, as indicated by the heavy lines. The perforations are provided with mica tubes m m_1 of some thickness, which are preferably not in contact with the rods d d_1 The box has a cover c which is a little larger and descends on the outside of the box. The spark gap is warmed by a small lamp l contained in the box. A plate p above the lamp allows the draught to pass only through the chimney *e* of the lamp, the air entering through holes *o o* in or near the bottom of the box and following the path indicated by the arrows. When the discharger is in operation, the door of the box is closed so that the light of the arc is not visible outside. It is desirable to exclude the light as perfectly as possible, as it interferes with some experiments. This form of discharger is simple and very effective when properly manipulated. The air being warmed to a certain temperature, has its insulating power impaired; it becomes dielectrically weak, as it were, and the consequence is that the arc can be established at much greater distance. The arc should, of course, be sufficiently insulating to allow the discharge to pass through the gap *disruptively.* The arc formed under such conditions, when long, may be made extremely sensitive, and the weak draught through the lamp chimney *c* is quite sufficient to produce rapid interruptions. The adjustment is made by regulating the temperature and velocity of the draught. Instead of using the lamp, it answers the purpose to provide for a draught of warm air in other ways. A very simple way which has been practiced is to enclose the arc in a long vertical tube, with plates on the top and bottom for regulating the temperature and velocity of the air current. Some provision had to be made for deadening the sound.

The air may be rendered dielectrically weak also by rarefaction. Dischargers of this kind have likewise been used by me in connection with a magnet. A large tube is for this purpose provided with heavy electrodes of carbon or metal, between which the discharge is made to pass, the tube being placed in a powerful magnetic field. The exhaustion of the tube is carried to a point at which the discharge breaks through easily,

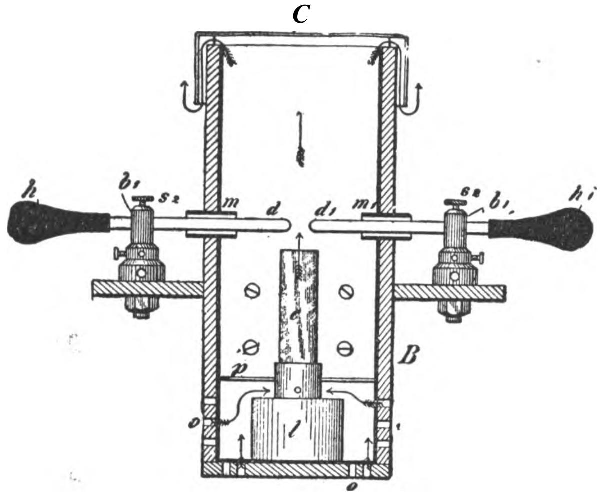


Fig 3.

but the pressure should be more than 75 millimetres, at which the ordinary thread discharge occurs. In another form of discharger, combining the features before mentioned, the discharge was made to pass between two adjustable magnetic pole pieces, the space between them being kept at an elevated temperature.

It should be remarked here that when such, or interrupting devices of any kind, are used and the currents are passed through the primary of a disruptive discharge coil, it is not, as a rule, of advantage to produce a number of interruptions of the current per second greater than the natural frequency of vibration of the dynamo supply circuit, which is ordinarily small. It should also be pointed out here, that while the devices mentioned in connection with the disruptive discharge are advantageous under certain conditions, they may be sometimes a source of trouble, as they produce intermittences and other irregularities in the vibration which it would be very desirable to overcome.

There is, I regret to say, in this beautiful method of conversion a defect, which fortunately is not vital, and which I have been gradually overcoming. I will best call attention to this defect and indicate a fruitful line of work, by comparing the electrical process with its mechanical analogue. The process may be illustrated in this manner. Imagine a tank with a wide opening at the bottom, which is kept closed by spring pressure, but so that it snaps off *suddenly* when the liquid in the tank has reached a certain height. Let the fluid be supplied to the tank by means of a pipe feeding at a certain rate. When the critical height of the liquid is reached, the spring gives way and the bottom of the tank drops out. Instantly the liquid falls through the wide opening, and the spring, reasserting itself, closes the bottom again. The tank is now filled, and after a certain time interval the same process is repeated. It is clear, that if the pipe feeds the fluid quicker than the bottom outlet is capable of letting it pass through, the bottom will remain off and the tank will still overflow. If the rates of supply are exactly equal, then the bottom lid will remain partially open and no vibration of the same and of the liquid column will generally occur, though it might, if started by some means. But if the inlet pipe does not feed the fluid fast enough for the outlet, then there will be always vibration. Again, in such case, each time the bottom flaps up or down, the spring and the liquid column, if the pliability of the spring and the inertia of the moving parts are properly chosen, will perform independent vibrations. In this analogue the fluid may be likened to electricity or electrical energy, the tank to the condenser, the spring to the dielectric, and the pipe to the conductor through which electricity is supplied to the condenser. To make this analogy quite complete it is necessary to make the assumption, that the bottom, each time it gives way, is knocked violently against a non-elastic stop, this impact involving some loss of energy; and that, besides, some dissipation of energy results due to frictional losses. In the preceding analogue the liquid is supposed to be under a steady pressure. If the presence of the fluid be assumed to vary rhythmically, this may be taken as corresponding to the case of an alternating current. The process is then not quite as simple to consider, but the action is the same in principle.

It is desirable, in order to maintain the vibration economically, to reduce the impact and frictional losses as much as possible. As regards the latter, which in the electrical analogue correspond to the losses due to the resistance of the circuits, it is impossible to obviate them entirely, but they can be reduced to a minimum by a proper selection of the dimensions of the circuits and by the employment of thin conductors in the form of strands. But the loss of energy caused by the first breaking through of the dielectric — which in the above example corresponds to the violent knock of the bottom against the inelastic stop — would be more important to overcome. At the moment of the breaking through, the air space has a very high resistance, which is probably reduced to a very small value when the current has reached some strength, and the space is brought to a high temperature. It would materially diminish the loss of energy if the space were always kept at an extremely high temperature, but then there would be no disruptive break. By warming the space moderately by means of a lamp or otherwise, the economy as far as the arc is concerned is sensibly increased. But the magnet or other interrupting device does not diminish the loss in the arc. Likewise, a jet of air only facilitates the carrying off of the energy. Air, or a gas in general, behaves curiously in this respect. When two bodies charged to a very high potential, discharge disruptively through an air space, any amount of energy may be carried off by the air. This energy is evidently dissipated by bodily carriers, in impact and collisional losses of the molecules. The exchange of the molecules in the space occurs with inconceivable rapidity. A powerful discharge taking place between two electrodes, they may remain entirely cool, and yet the loss in the air may represent any amount of energy. It is perfectly practicable, with very great potential differences in the gap, to dissipate several horse-power in the arc of the discharge without even noticing a small increase in the temperature of the electrodes. All the frictional losses occur then practically in the air. If the exchange of the air molecules is prevented, as by enclosing the air hermetically, the gas inside of the vessel is brought quickly to a high temperature, even with a very small discharge. It is difficult to estimate how much of the energy is lost in sound waves, audible or not, in a powerful discharge. When the currents through the gap are large, the electrodes may become rapidly heated, but this is not a reliable measure of the energy wasted in the arc, as the loss through the gap itself may be comparatively small. The air or a gas in general is, at ordinary pressure at least, clearly not the best medium through which a disruptive discharge should occur. Air or other gas under great pressure is of course a much more suitable medium for the discharge gap. I have carried on long-continued experiments in this direction, unfortunately less practicable on account of the difficulties and expense in getting air under great pressure. But even if the medium in the discharge space is solid or liquid, still the same losses take place, though they are generally smaller, for just as soon as the arc is established, the solid or liquid is volatilized. Indeed, there is no body known which would not be disintegrated by the arc, and it is an open question among scientific men, whether an arc discharge could occur at all in the air itself without the particles of the electrodes being torn off. When the current through the gap is very small and the arc very long, I believe that a relatively considerable amount of heat is taken up in the disintegration of the electrodes, which partially on this account may remain quite cold.

The ideal medium for a discharge gap should only *crack,* and the ideal electrode should be of some material which cannot be disintegrated. With small currents through the gap it is best to employ aluminum, but not when the currents are large. The disruptive break in the air, or more or less in any ordinary medium, is not of the nature of a crack, but it is rather comparable to the piercing of innumerable bullets through a mass offering great frictional resistances to the motion of the bullets, this involving considerable loss of energy. A medium which would merely crack when strained electrostatically — and this possibly might be the case with a perfect vacuum, that is, pure ether — would involve a very small loss in the gap, so small as to be entirely negligible, at least theoretically, because a crack may be produced by an infinitely small displacement. In exhausting an oblong bulb provided with two aluminum terminals, with the greatest care, I have succeeded in producing such a vacuum that the secondary discharge of a disruptive discharge coil would break disruptively through the bulb in the form of fine spark streams. The curious point was that the discharge would completely ignore the terminals and start far behind the two aluminum plates which served as electrodes. This extraordinary high vacuum could only be maintained for a very short while. To return to the ideal medium, think, for the sake of illustration, of a piece of glass or similar body clamped in a vice, and the latter tightened more and more. At a certain point a minute increase of the pressure will cause the glass to crack. The loss of energy involved in splitting the glass may be practically nothing, for though the force is great, the displacement need be but extremely small. Now imagine that the glass would possess the property of closing again perfectly the crack upon a minute diminution of the pressure. This is the way the dielectric in the discharge space should behave. But inasmuch as there would be always some loss in the gap, the medium, which should be continuous, should exchange through the gap at a rapid rate. In the preceding example, the glass being perfectly closed, it would mean that the dielectric in the discharge space possesses a great insulating power; the glass being cracked, it would signify that the medium in the space is a good conductor. The dielectric should vary enormously in resistance by minute variations of the E. M. F. across the discharge space. This condition is attained, but in an extremely imperfect manner, by warming the air space to a certain critical temperature, dependent on the E. M. F. across the gap, or by otherwise impairing the insulating power of the air. But as a matter of fact the air does never break down *disruptively,* if this term be rigorously interpreted, for before the sudden rush of the current occurs, there is always a weak current preceding it, which rises first gradually and then with comparative suddenness. That is the reason why the rate of change is very much greater when glass, for instance, is broken through, than when the break takes place through an air space of equivalent dielectric strength. As a medium for the discharge space, a solid, or even a liquid, would be preferable therefore. It is somewhat difficult to conceive of a solid body which would possess the property of closing instantly after it has been cracked. But a liquid, especially under great pressure, behaves practically like a solid, while it possesses the property of closing the crack. Hence it was thought that a liquid insulator might be more suitable as a dielectric than air. Following out this idea, a number of different forms of dischargers in which a variety of such insulators, sometimes under great pressure, were employed, have been experimented upon. It is thought sufficient to dwell in a few words upon one of the forms experimented upon. One of these dischargers is illustrated in Figs. 4a and 4b.

A hollow metal pulley P (Fig. 4a), was fastened upon an arbor a, which by suitable means was rotated at a considerable speed. On the inside of the pulley, but disconnected from the same, was supported a thin disc *h* (which is shown thick for the sake of clearness), of hard rubber in which there were embedded two metal segments s *s* with metallic extensions *e e* into which were screwed conducting terminals *t t* covered with thick tubes of hard rubber t t. The rubber disc *h* with its metallic segments *s* s, was finished in a lathe, and its entire surface highly polished so as to offer the smallest possible frictional resistance to the motion through a fluid. In the hollow of

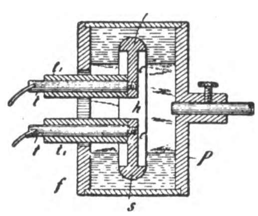


Fig. 4a.

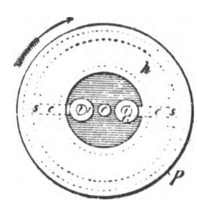


Fig. 4b.

the pulley an insulating liquid such as a thin oil was poured so as to reach very nearly to the opening left in the flange *f,* which was screwed tightly on the front side of the pulley. The terminals *t t,* were connected to the opposite coatings of a battery of condensers so that the discharge occurred through the liquid. When the pulley was rotated, the liquid was forced against the rim of the pulley and considerable fluid pressure resulted. In this simple way the discharge gap was filled with a medium which behaved practically like a solid, which possessed the quality of closing instantly upon the occurrence of the break, and which moreover was circulating through the gap at a rapid rate. Very powerful effects were produced by discharges of this kind with liquid interrupters, of which a number of different forms were made. It was found that, as expected, a longer spark for a given length of wire was obtainable in this way than by using air as an interrupting device. Generally the speed, and therefore also the fluid pressure, was limited by reason of the fluid friction, in the form of discharger described, but the practically obtainable speed was more than sufficient to produce a number of breaks suitable for the circuits ordinarily used. In such instances the metal pulley P was provided with a few projections inwardly, and a definite number of breaks was then produced which could be computed from the speed of rotation of the pulley. Experiments were also carried on with liquids of different insulating power with the view of reducing the loss in the arc. When an insulating liquid is moderately warmed, the loss in the arc is diminished.

A point of some importance was noted in experiments with various discharges of this kind. It was found, for instance, that whereas the conditions maintained in these forms were favorable for the production of a great spark length, the current so obtained was not best suited to the production of light effects. Experience undoubtedly has shown, that for such purposes a harmonic rise and fall of the potential is preferable. Be it that a solid is rendered incandescent, or phosphorescent, or be it that energy is transmitted by condenser coating through the glass, it is quite certain that a harmonically rising and falling potential produces less destructive action, and that the vacuum is more permanently maintained. This would be easily explained if it were ascertained that the process going on in an exhausted vessel is of an electrolytic nature.

In the diagrammatical sketch, Fig. 1, which has been already referred to, the cases which are most likely to be met with in practice are illustrated. One has at his disposal either direct or alternating currents from a supply station. It is convenient for an experimenter in an isolated laboratory to employ a machine G, such as illustrated, capable of giving both kinds of currents. In such case it is also preferable to use a machine with multiple circuits, as in many experiments it is useful and convenient to have at one's disposal currents of different phases. In the sketch, D represents the direct and A the alternating circuit. In each of these, three branch circuits are shown, all of which are provided with double line switches *s s s s s s*. Consider first the direct current conversion; *la* represents the simplest case. If the E. M. F. of the generator is sufficient to break through a small air space, at least when the latter is warmed or otherwise rendered poorly insulating, there is no difficulty in maintaining a vibration with fair economy by judicious adjustment of the capacity, self-induction and resistance of the circuit L containing the devices *l l m*. The magnet N, S, can be in this case advantageously combined with the air space. The discharger *d d* with the magnet may be placed either way, as indicated by the full or by the dotted lines. The circuit l*a* with the connections and devices is supposed to possess dimensions such as are suitable for the maintenance of a vibration. But usually the E. M. F. on the circuit or branch l*a* will be something like a 100 volts or so, and in this case it is not sufficient to break through the gap. Many different means may be used to remedy this by raising the E. M. F. across the gap. The simplest is probably to insert a large self-induction coil in series with the circuit L. When the arc is established, as by the discharger illustrated in Fig. 2, the magnet blows the arc out the instant it is formed. Now the extra current of the break, being of high E. M. F., breaks through the gap, and a path of low resistance for the dynamo current being again provided, there is a sudden rush of current from the dynamo upon the weakening or subsidence of the extra current. This process is repeated in rapid succession, and in this manner I have maintained oscillation with as low as 50 volts, or even less, across the gap. But conversion on this plan is not to be recommended on account of the too heavy currents through the gap and consequent heating of the electrodes; besides, the frequencies obtained in this way are low, owing to the high self-induction necessarily associated with the circuit. It is very desirable to have the E. M. F. as high as possible, first, in order to increase the economy of the conversion, and secondly, to obtain high frequencies. The difference of potential in this electric oscillation is, of course, the equivalent of the stretching force in the mechanical vibration of the spring. To obtain very rapid vibration in a circuit of some inertia, a great stretching force or difference of potential is necessary. Incidentally, when the E. M. F. is very great, the condenser which is usually employed in connection with the circuit need but have a small capacity, and many other advantages are gained. With a view of raising the E. M. F. to a many times greater value than obtainable from ordinary distribution circuits, a rotating transformer *g* is used, as indicated at I l*a,* Fig. 1, or else a separate high potential machine is driven by means of a motor operated from the generator G. The latter plan is in fact preferable, as changes are easier made. The connections from the high tension winding are quite similar to those in branch *la* with the exception that a condenser C, which should be adjustable, is connected to the high tension circuit. Usually, also, an adjustable self-induction coil in series with the circuit has been employed in these experiments. When the tension of the currents is very high, the magnet ordinarily used in connection with the discharger is of comparatively small value, as it is quite easy to adjust the dimensions of the circuit so that oscillation is maintained. The employment of a steady E. M. F. in the high frequency conversion affords some advantages over the employment of alternating E. M. F., as the adjustments are much simpler and the action can be easier controlled. But unfortunately one is limited by the obtainable potential difference. The winding also breaks down easily in consequence of the sparks which form between the sections of the armature or commutator when a vigorous oscillation takes place. Besides, these transformers are expensive to build. It has been found by experience that it is best to follow the plan illustrated at III*a.* In this arrangement a rotating transformer *g,* is employed to convert the low tension direct currents into low frequency alternating currents, preferably also of small tension. The tension of the currents is then raised in a stationary transformer T. The secondary s of this transformer is connected to an adjustable condenser C which discharges through the gap or discharger *d d,* placed in either of the ways indicated, through the primary P of a disruptive discharge coil, the high frequency current being obtained from the secondary s of this coil, as described on previous occasions. This will undoubtedly be found the cheapest and most convenient way of converting direct currents.

The three branches of the circuit A represent the usual cases met in practice when alternating currents are converted. In Fig. I*b* a condenser C, generally of large capacity, is connected to the circuit L containing the devices *l l, m m.* The devices *m m* are supposed to be of high self-induction so as to bring the frequency of the circuit more or less to that of the dynamo. In this instance the discharger *d d* should best have a number of makes and breaks per second equal to twice the frequency of the dynamo. If not so, then it should have at least a number equal to a multiple or even fraction of the dynamo frequency. It should be observed, referring to I *b,* that the conversion to a high potential is also effected when the discharger *d d,* which is shown in the sketch, is omitted. But the effects which are produced by currents which rise instantly to high values, as in a disruptive discharge, are entirely different from those produced by dynamo currents which rise and fall harmonically. So, for instance, there might be in a given case a number of makes and breaks at *d d* equal to just twice the frequency of the dynamo, or in other words, there may be the same number of fundamental oscillations as would be produced without the discharge gap, and there might even not be any quicker superimposed vibration; yet the differences of potential at the various points of the circuit, the impedance and other phenomena, dependent upon the rate of change, will bear no similarity in the two cases. Thus, when working with currents discharging disruptively, the element chiefly to be considered is not the frequency, as a student might be apt to believe, but the rate of change per unit of time. With low frequencies in a certain measure the same effects may be obtained as with high frequencies, provided the rate of change is sufficiently great. So if a low frequency current is raised to a potential of, say, 75,000 volts, and the high tension current passed through a series of high resistance lamp filaments, the importance of the rarefied gas surrounding the filament is clearly noted, as will be seen later; or, if a low frequency current of several thousand amperes is passed through a metal bar, striking phenomena of impedance are observed, just as with currents of high frequencies. But it is, of course, evident that with low frequency currents it is impossible to obtain such rates of change per unit of time as with high frequencies, hence the effects produced by the latter are much more prominent. It is deemed advisable to make the preceding remarks, inasmuch as many more recently described effects have been unwittingly identified with high frequencies. Frequency alone in reality does not mean anything, except when an undisturbed harmonic oscillation is considered.

In the branch III*b* a similar disposition to that in I*b* is illustrated, with the difference that the currents discharging through the gap *d d* are used to induce currents in the secondary s of a transformer T. In such case the secondary should be provided with an adjustable condenser for the purpose of tuning it to the primary.

II*b* illustrates a plan of alternate current high frequency coaversion which is most frequently used and which is found to be most convenient. This plan has been dwelt upon in detail on previous occasions and need not be described here.

Some of these results were obtained by the use of a high frequency alternator. A description of such machines will be found in my original paper before the American Institute of Electrical Engineers, and in periodicals of that period, notably in The Electrical Engineer of March 18, 1891.

I will now proceed with the experiments.

ON PHENOMENA PRODUCED BY ELECTROSTATIC FORCE

The first class of effects I intend to show you are effects produced by electrostatic force. It is the force which governs the motion of the atoms, which causes them to collide and develop the life-sustaining energy of heat and light, and which causes them to aggregate in an infinite variety of ways, according to Nature’s fanciful designs, and to form all these wondrous structures we perceive around us; it is, in fact, if our present views be true, the most important force for us to consider in Nature. As the term *electrostatic* might imply a steady electric condition, it should be remarked, that in these experiments the force is not constant, but varies at a rate which may be considered moderate, about one million times a second, or thereabouts. This enables me to produce many effects which are not producible with an unvarying force.

When two conducting bodies are insulated and electrified, we say that an electrostatic force is acting between them. This force manifests itself in attractions, repulsions and stresses in the bodies and space or medium without. So great may be the strain exerted in the air, or whatever separates the two conducting bodies, that it may break down, and we observe sparks or bundles of light or streamers, as they are called. These streamers form abundantly when the force through the air is rapidly varying. I will illustrate this action of electrostatic force in a novel experiment in which I will employ the induction coil before referred to. The coil is contained in a trough filled with oil, and placed under the table. The two ends of the secondary wire pass through the two thick columns of hard rubber which protrude to some height above the table. It is necessary to insulate the ends or terminals of the secondary heavily with hard rubber, because even dry wood is by far too poor an insulator for these currents of enormous potential differences. On one of the terminals of the coil, I have placed a large sphere of sheet brass, which is connected to a larger insulated brass plate, in order to enable me to perform the experiments under conditions, which, as you will see, are more suitable for this experiment. I now set the coil to work and approach the free terminal with a metallic object held in my hand, this simply to avoid burns. As I approach the metallic object to a distance of eight or ten inches, a torrent of furious sparks breaks forth from the end of the secondary wire, which passes through the rubber column. The sparks cease when the metal in my hand touches the wire. My arm is now traversed by a powerful electric current, vibrating at about the rate of one million times a second. All around me the electrostatic force makes itself felt, and the air molecules and particles of dust flying about are acted upon and are hammering violently against my body. So great is this agitation of the particles, that when the lights are turned out you may see streams of feeble light appear on some parts of my body. When such a streamer breaks out on any part of the body, it produces a sensation like the pricking of a needle. Were the potentials sufficiently high and the frequency of the vibration rather low, the skin would probably be ruptured under the tremendous strain, and the blood would rush out with great force in the form of fine spray or jet so thin as to be invisible, just as oil will when placed on the positive terminal of a Holtz machine. The breaking through of the skin though it may seem impossible at first, would perhaps occur, by reason of the tissues under the skin being incomparably better conducting. This, at least, appears plausible, judging from some observations.

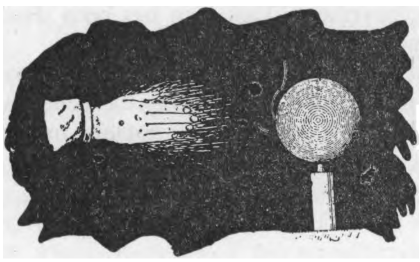


Fig. 5.

I can make these streams of light visible to all, by touching with the metallic object one of the terminals as before, and aproach-ing my free hand to the brass sphere, which is connected to the second terminal of the coil. As the hand is approached, the air between it and the sphere, or in the immediate neighborhood, is more violently agitated, and you see streams of light now break forth from my finger tips and from the whole hand (Fig. 5). Were I to approach the hand closer, powerful sparks would jump from the brass sphere to my hand, which might be injurious. The streamers offer no particular inconvenience, except that in the ends of the finger tips a burning sensation is felt. They should not be confounded with those produced by an influence machine, because in many respects they behave differently. I have attached the brass sphere and plate to one of the terminals in order to prevent the formation of visible streamers on that terminal, also in order to prevent sparks from jumping at a considerable distance. Besides, the attachment is favorable for the working of the coil.

The streams of light which you have observed issuing from my hand are due to a potential of about 200,000 volts, alternating in rather irregular intervals, sometimes like a million times a second. A vibration of the same amplitude, but four times as fast, to maintain which over 3,000,000 volts would be required, would be more than sufficient to envelop my body in a complete sheet of flame. But this flame would not burn me up; quite contrarily, the probability is that I would not be injured in the least. Yet a hundredth part of that energy, otherwise directed, would be amply sufficient to kill a person.

The amount of energy which may thus be passed into the body of a person depends on the frequency and potential of the currents, and by making both of these very great, a vast amount of energy may be passed into the body without causing any discomfort, except perhaps, in the arm, which is traversed by a true conduction current. The reason why no pain in the body is felt, and no injurious effect noted, is that everywhere, if a current be imagined to flow through the body, the direction of its flow would be at right angles to the surface; hence the body of the experimenter offers an enormous section to the current, and the density is very small, with the exception of the arm, perhaps, where the density may be considerable. But if only a small fraction of that energy would be applied in such a way that a current would traverse the body in the same manner as a low frequency current, a shock would be received which might be fatal. A direct or low frequency alternating current is fatal, I think, principally because its distribution through the body is not uniform, as it must divide itself in minute streamlets of great density, whereby some organs are vitally injured. That such a process occurs I have not the least doubt, though no evidence might apparently exist, or be found upon examination. The surest to injure and destroy life, is a continuous current, but the most painful is an alternating current of very low frequency. The expression of these views, which are the result of long continued experiment and observation, both with steady and varying currents, is elicited by the interest which is at present taken in this subject, and by the manifestly erroneous ideas which are daily propounded in journals on this subject.

I may illustrate an effect of the electrostatic force by another striking experiment, but before, I must call your attention to one or two facts. I have said before, that whet: the medium between two oppositely electrified bodies is strained beyond a certain limit it gives way and, stated in popular language, the opposite electric charges unite and neutralize each other. This breaking down of the medium occurs principally when the force acting between the bodies is steady, or varies at a moderate rate. Were the variation sufficiently rapid, such a destructive break would not occur, no matter how great the force, for all the energy would be spent in radiation, convection and mechanical and chemical action. Thus the *spark* length, or greatest distance which a *spark* will jump between the electrified bodies is the smaller, the greater the variation or time rate of change. But this rule may be taken to be true only in a general way, when comparing rates which are widely different.

I will show you by an experiment the difference in the effect produced by a rapidly varying and a steady or moderately varying force. I have here two large circular brass plates *p p* (Fig. 6a and Fig. 6b), supported on movable insulating stands on the table, connected to the ends of the secondary of a coil similar to the one used before. I place the plates ten or twelve inches apart and set the coil to work. You see the whole space between the plates, nearly two cubic feet, filled with uniform light, Fig. 6a. This light is due to the streamers you have seen in the first experiment, which are now much more intense. I have already pointed out the importance of these streamers in commercial apparatus and their still greater importance in some purely scientific investigations. Often they are to weak to be visible, but they always exist, consuming energy and modifying the action of the apparatus. When intense, as they are at present, they produce ozone in great quantity, and also, as Professor Crookes has pointed out, nitrous acid. So quick is the chemical action that if a coil, such as this one, is worked for a very long time it will make the atmosphere of a small room unbearable, for the eyes and throat are attacked. But when moderately produced, the streamers refresh the atmosphere wonderfully, like a thunder-storm, and exercises unquestionably a beneficial effect.

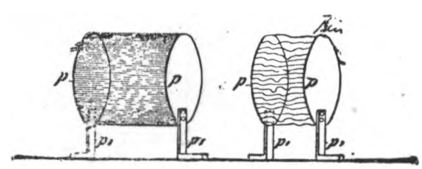


Fig. 6a. Fig. 6b.

In this experiment the force acting between the plates changes in intensity and direction at a very rapid rate. I will now make the rate of change per unit time much smaller. This I effect by rendering the discharges through the primary of the induction coil less frequent, and also by diminishing the rapidity of the vibration in the secondary. The former result is conveniently secured by lowering the E. M. F. over the air gap in the primary circuit, the latter by approaching the two brass plates to a distance of about three or four inches. When the coil is set to work, you see no streamers or light between the plates, yet the medium between them is under a tremendous strain. I still further augment the strain by raising the E. M. F. in the primary circuit, and soon you see the air give away and the hall is illuminated by a shower of brilliant and noisy sparks, Fig. 6b. These sparks could be produced also with unvarying force; they have been for many years a familiar phenomenon, though they were usually obtained from an entirely different apparatus. In describing these two phenomena so radically different in appearance, I have advisedly spoken of a "force" acting between the plates. It would be in accordance with the accepted views to say, that there was an "alternating E. M. F.", acting between the plates. This term is quite proper and applicable in all cases where there is evidence of at least a possibility of an essential inter-dependence of the electric state of the plates, or electric action in their neighborhood. But if the plates were removed to an infinite distance, or if at a finite distance, there is no probability or necessity whatever for such dependence. I prefer to use the term "electrostatic force", and to say that such a force is acting around each plate or electrified insulated body in general. There is an inconvenience in using this expression as the term incidentally means a steady electric condition; but a proper nomenclature will eventually settle this difficulty.

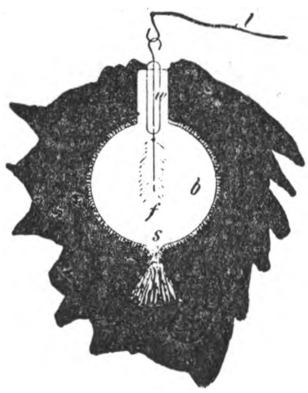


Fig. 7.

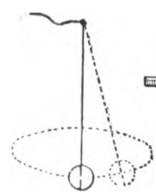


Fig. 8a.

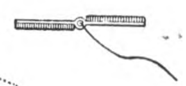


Fig. 8b.

I now return to the experiment to which I have already alluded, and with which I desire to illustrate a striking effect produced by a rapidly varying electrostatic force. I attach to the end of the wire, *l* (Fig. 7), which is in connection with one of the terminals of the secondary of the induction coil, an exhausted bulb *b.* This bulb contains a thin carbon filament *f,* which is fastened to a platinum wire *w,* sealed in the glass and leading outside of the bulb, where it connects to the wire *l.* The bulb may be exhausted to any degree attainable with ordinary apparatus. Just a moment before, you have witnessed the breaking down of the air between the charged brass plates. You know that a plate of glass, or any other insulating material, would break down in like manner. Had I therefore a metallic coating attached to the outside of the bulb, or placed near the same, and were this coating connected to the other terminal of the coil, you would be prepared to see the glass give way if the strain were sufficiently increased. Even were the coating not connected to the other terminal, but to an insulated plate, still, if you have followed recent developments, you would naturally expect a rupture of the glass.

But it will certainly surprise you to note that under the action of the varying electrostatic force, the glass gives way when all other bodies are removed from the bulb. In fact, all the surrounding bodies we perceive might be removed to an infinite distance without affecting the result in the slightest. When the coil is set to work, the glass is invariably broken through at the seal, or other narrow channel, and the vacuum is quickly impaired. Such a damaging break would not occur with a steady force, even if the same were many times greater. The break is due to the agitation of the molecules of the gas within the bulb, and outside of the same. This agitation, which is generally most violent in the narrow pointed channel near the seal, causes a heating and rupture of the glass. This rupture would, however, not occur, not even with a varying force, if the medium filling the inside of the bulb, and that surrounding it, were perfectly homogeneous. The break occurs much quicker if the top of the bulb is drawn out into a fine fibre. In bulbs used with these coils such narrow, pointed channels must therefore be avoided.

When a conducting body is immersed in air, or similar insulating medium, consisting of, or containing, small freely movable particles capable of being electrified, and when the electrification of the body is made to undergo a very rapid change — which is equivalent to saying that the electrostatic force acting around the body is varying in intensity, — the small particles are attracted and repelled, and their violent impacts against the body may cause a mechanical motion of the latter. Phenomena of this kind are noteworthy, inasmuch as they have not been observed before with apparatus such as has been commonly in use. If a very light conducting sphere be suspended on an exceedingly fine wire, and charged to a steady potential, however high, the sphere will remain at rest. Even if the potential would be rapidly varying, provided that the small particles of matter, molecules or atoms, are evenly distributed, no motion of the sphere should result. But if one side of the conducting sphere is covered with a thick insulating layer, the impacts of the particles will cause the sphere to move about, generally in irregular curves, Fig. 8a. In like manner, as I have shown on a previous occasion, a fan of sheet metal, Fig. 8b, covered partially with insulating material as indicated, and placed upon the terminal of the coil so as to turn freely on it, is spun around.

All these phenomena you have witnessed and others which will be shown later, are due to the presence of a medium like air, and would not occur in a continuous medium. The action of the air may be illustrated still better by the following experiment. I take a glass tube *t,* Fig. 9, of about an inch in diameter, which has a platinum wire *w* sealed in the lower end, and to which is attached a thin lamp filament *f.* I connect the wire with the terminal of the coil and set the coil to work. The platinum wire is now electrified positively and negatively in rapid succession and the wire and air inside of the tube is rapidly heated by the impacts of the particles, which may be so violent as to render the filament incandescent. But if I pour oil in the tube, just as soon as the wire is covered with the oil, all action apparently ceases and there is no marked evidence of heating. The reason of this is that the oil is a practically continuous medium. The displacements in such a continuous medium are, with these frequencies, to all appearance incomparably smaller than in air, hence the work performed in such a medium is insignificant. But oil would behave very differently with frequencies many times as great, for even though the displacements be small, if the frequency were much greater, considerable work might be performed in the oil.

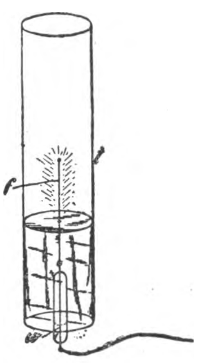


Fig. 9.

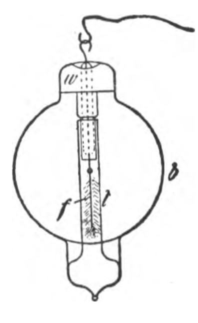


Fig. 10.

The electrostatic attractions and repulsions between bodies of measurable dimensions are, of all the manifestations of this force, the first so-called *electrical* phenomena noted.

But though they have been known to us for many centuries, the precise nature of the mechanism concerned in these actions is still unknown to us, and has not been even quite satisfactorily explained. What kind of mechanism must that be? We cannot help wondering when we observe two magnets attracting and repelling each other with a force of hundreds of pounds with apparently nothing between them. We have in our commercial dynamos magnets capable of sustaining in mid-air tons of weight. But what are even these forces acting between magnets when compared with the tremendous attractions and repulsions produced by electrostatic force, to which there is apparently no limit as to intensity. In lightning discharges bodies are often charged to so high a potential that they are thrown away with inconceivable force and torn asunder or shattered into fragments. Still even such effects cannot compare with the attractions and repulsions which exist between charged molecules or atoms, and which are sufficient to project them with speeds of many kilometres a second, so that under their violent impact bodies are rendered highly incandescent and are volatilized. It is of special interest for the thinker who inquires into the nature of these forces to note that whereas the actions between individual molecules or atoms occur seemingly under any conditions, the attractions and repulsions of bodies of measurable dimensions imply a medium possessing insulating properties. So, if air, either by being rarefied or heated, is rendered more or less conducting, these actions between two electrified bodies practically cease, while the actions between the individual atoms continue to manifest themselves.

An experiment may serve as an illustration and as a means of bringing out other features of interest. Some time ago I showed that a lamp filament or wire mounted in a bulb and connected to one of the terminals of a high tension secondary coil is set spinning, the top of the filament generally describing a circle. This vibration was very energetic when the air in the bulb was at ordinary pressure and became less energetic when the air in the bulb was strongly compressed. It ceased altogether when the air was exhausted so as to become comparatively good conducting. I found at that time that no vibration took place when the bulb was very highly exhausted. But I conjectured that the vibration which I ascribed to the electrostatic action between the walls of the bulb and the filament should take place also in a, highly exhausted bulb. To test this under conditions which were more favorable, a bulb like the one in Fig. 10, was constructed. It comprised a globe *b,* in the neck of which was sealed a platinum wire *w* carrying a thin lamp filament *f.* In the lower part of the globe a tube *t* was sealed so as to surround the filament. The exhaustion was carried as far as it was practicable with the apparatus employed.

This bulb verified my expectation, for the filament was set spinning when the current was turned on, and became incandescent. It also showed another interesting feature, bearing upon the preceding remarks, namely, when the filament had been kept incandescent some time, the narrow tube and the space inside were brought to an elevated temperature, and as the gas in the tube then became conducting, the electrostatic attraction between the glass and the filament became very weak or ceased, and the filament came to rest. When it came to rest it would glow far more intensely. This was probably due to its assuming the position in the centre of the tube where the molecular bombardment was most intense, and also partly to the fact that the individual impacts were more violent and that no part of the supplied energy was converted into mechanical movement. Since, in accordance with accepted views, in this experiment the incandescence must be attributed to the impacts of the particles, molecules or atoms in the heated space, these particles must therefore, in order to explain such action, be assumed to behave as independent carriers of electric charges immersed in an insulating medium; yet there is no attractive force between the glass tube and the filament because the space in the tube is, as a whole, conducting.

It is of some interest to observe in this connection that whereas the attraction between two electrified bodies may cease owing to the impairing of the insulating power of the medium in which they are immersed, the repulsion between the bodies may still be observed. This may be explained in a plausible way. When the bodies are placed at some distance in a poorly conducting medium, such as slightly warmed or rarefied air, and are suddenly electrified, opposite electric charges being imparted to them, these charges equalize more or less by leakage through the air. But if the bodies are similarly electrified, there is less opportunity afforded for such dissipation, hence the repulsion observed in such case is greater than the attraction. Repulsive actions in a gaseous medium are however, as Prof. Crookes has shown, enhanced by molecular bombardment.

ON CURRENT OR DYNAMIC ELECTRICITY PHENOMENA

So far, I have considered principally effects produced by a varying electrostatic force in an insulating medium, such as air. When such a force is acting upon a conducting body of measurable dimensions, it causes within the same, or on its surface, displacements of the electricity, and gives rise to electric currents, and these produce another kind of phenomena, some of which I shall presently endeavor to illustrate. In presenting this second class of electrical effects, I will avail myself principally of such as are producible without any return circuit, hoping to interest you the more by presenting these phenomena in a more or less novel aspect.

It has been a long time customary, owing to the limited experience with vibratory currents, to consider an electric current as something circulating in a closed conducting path. It was astonishing at first to realize that a current may flow through the conducting path even if the latter be interrupted, and it was still more surprising to learn, that sometimes it may be even easier to make a current flow under such conditions than through a closed path. But that old idea is gradually disappearing, even among practical men, and will soon be entirely forgotten.

If I connect an insulated metal plate P, Fig. 11, to one of the terminals T of the induction coil by means of a wire, though this plate be very well insulated, a current passes through the wire when the coil is set to work. First I wish to give you evidence that there *is* a current passing through the connecting wire. An obvious way of demonstrating this is to insert between the terminal of the coil and the insulated plate a very thin platinum or german silver wire *w* and bring the latter to incandescence or fusion by the current. This requires a rather large plate of else current impulses of very high potential and frequency. Another way is to take a coil C, Fig. 11, containing many turns of thin insulated wire and to insert the same in the path of the current to the plate. When I connect one of the ends of the coil to the wire leading to another insulated plate P_1, and its other end to the terminal T_1 of the induction coil, and set the latter to work, a current passes through the inserted coil C and the existence of the current may be made manifest in various ways. For instance, I insert an iron core *i* within the coil. The current being one of very high frequency, will, if it be of some strength, soon bring the iron core to a noticeably higher temperature, as the hysteresis and current losses are great with such high frequencies. One might take a core of some size, laminated or not, it would matter little; but ordinary iron wire $^{1}/_{16}$th or $^{1}/_{8}$th of an inch thick is suitable for the purpose. While the induction coil is working, a current

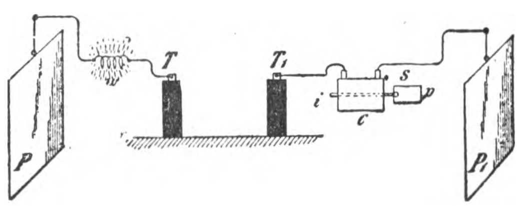


Fig. 11.

traverses the inserted coil and only a few moments are sufficient to bring the iron wire *i to* an elevated temperature sufficient to soften the sealing wax *s,* and cause a paper washer *p* fastened by it to the iron wire to fall off. But with the apparatus such as I have here, other, much more interesting, demonstrations of this kind can be made. I have a secondary s, Fig. 12, of coarse wire, wound upon a coil similar to the first. In the preceding experiment the current through the coil C, Fig. 11, was very small, but there, being many turns a strong heating effect was, nevertheless, produced in the iron wire.

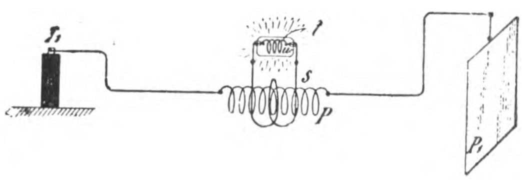


Fig. 12.

Had I passed that current through a conductor in order to show the heating of the latter, the current might have been too small to produce the effect desired. But with this coil provided with a secondary winding, I can now transform the feeble current of high tension which passes through the primary P into a strong secondary current of low tension, and this current will quite certainly do what I expect. In a small glass tube (*t*, Fig. 12), I have enclosed a coiled platinum wire, *w,* this merely in order to protect the wire. On each end of the glass tube is sealed a terminal of stout wire to which one of the ends of the platinum wire *w,* is connected. I join the terminals of the secondary coil to these terminals and insert the primary *p,* between the insulated plate P_t, and the terminal T_t, of the induction coil as before. The latter being set to work, instantly the platinum wire *w* is rendered incandescent and can be fused, even if it be very thick.

Instead of the platinum wire I now take an ordinary 50-volt 16 c. p. lamp. When I set the induction coil in operation the lamp filament is brought to high incandescence. It is, however, not necessary to use the insulated plate, for the lamp (*l*, Fig. 13) is rendered incandescent even if the plate P_1 be disconnected. The secondary may also be connected to the primary as indicated by the dotted line in Fig. 13, to do away more or less with the electrostatic induction or to modify the action otherwise.

I may here call attention to a number of interesting observations with the lamp. First, I disconnect one of the terminals of the lamp from the secondary s. When the induction coil plays, a glow is noted which fills the whole bulb. This glow is due to electrostatic induction. It increases when the bulb is grasped with the hand, and the capacity of the experimenter's body thus added to the secondary circuit. The secondary, in effect, is equivalent to a metallic coating, which would be placed near the primary. If the secondary, or its equivalent, the coating, were placed symmetrically to the primary, the electrostatic induction would be nil under ordinary conditions, that is, when a primary return circuit is used, as both halves would neutralize each other. The secondary *is* in fact placed symmetrically to the primary, but the action of both halves of the latter, when only one of its ends is connected to the induction coil, is not exactly equal; hence electrostatic induction takes place, and hence the glow in the bulb.

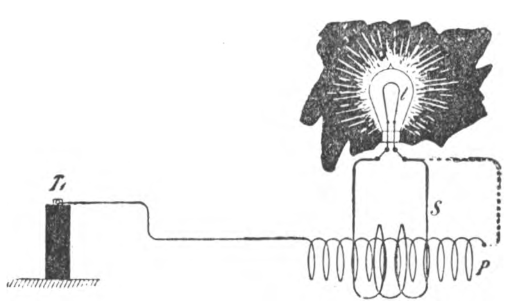


Fig. 13.

I can nearly equalize the action of both halves of the primary by connecting the other, free end of the same to the insulated plate, as in the preceding experiment. When the plate is connected, the glow disappears. With a smaller plate it would not entirely disappear and then it would contribute to the brightness of the filament when the secondary is closed, by warming the air in the bulb.

To demonstrate another interesting feature, I have adjusted the coils used in a certain way. I first connect both the terminals of the lamp to the secondary, one end of the primary being connected to the terminal T_1 of the induction coil and the other to the insulated plate P_1 as before. When the current is turned on, the lamp glows brightly, as shown in Fig. 14b, in which *C* is a fine wire coil and *s* a coarse wire secondary wound upon it. If the insulated plate P_1 is disconnected, leaving one of the ends *a* of the primary insulated, the filament becomes dark or generally it diminishes in brightness (Fig. 14a). Connecting again the plate P_1 and raising the frequency of the current, I make the filament quite dark or barely red (Fig. 15b). Once more I will disconnect the plate. One will of course infer that when the plate is disconnected, the current through the primary will be weakened, that therefore the E. M. F. will fall in the secondary *s,* and that the brightness of the lamp will diminish. This might be the case and the result can be secured by an easy adjustment or the coils; also by varying the frequency and potential of the currents. But it is perhaps of greater interest to note, that the lamp increases in brightness when the plate is disconnected (Fig. 15a). In this case all the energy the primary receives is now sunk into it, like the charge of a battery in an ocean cable, but most of that energy is recovered through the secondary and used to light the lamp. The current traversing the primary is strongest at the end *b* which is connected to the terminal T_1 of the induction coil, and diminishes in strength towards the remote end *a.* But the dynamic inductive effect exerted upon the secondary *s* is now greater than before, when the suspended plate was connected to the primary. These results might have been produced by a number of causes. For instance, the plate P_1 being connected, the reaction from the coil C may be such as to diminish the potential at the terminal T_1 of the induction coil, and therefore weaken the current through the primary of the coil C. Or the disconnecting of the plate may diminish the capacity effect with relation to the primary of the latter coil to such an extent that the current through it is diminished, though the potential at the terminal T_1 of the induction coil may be the same or even higher. Or the result might have been produced by the change of phase of the primary and secondary currents and consequent reaction. But the chief determining factor is the relation of the self-induction and capacity of coil C and plate P_1 and the frequency of the currents. The greater brightness of the filament in Fig. 15a, is, however, in part due to the heating of the rarefied gas in the lamp by electrostatic induction, which, as before remarked, is greater when the suspended plate is disconnected.

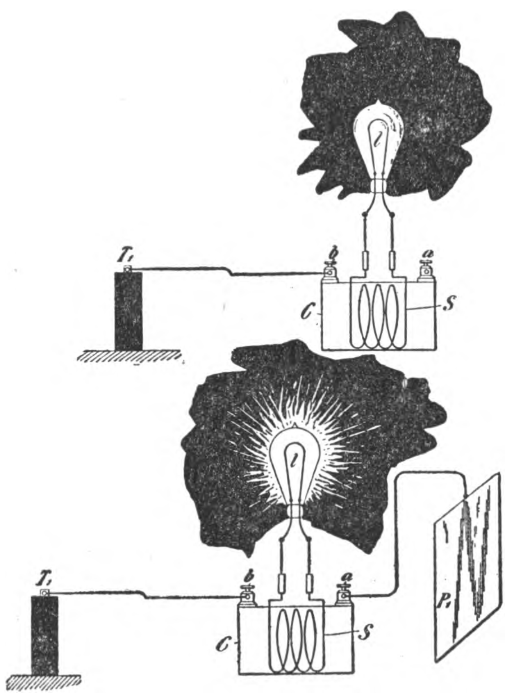


Fig. 14a.
Fig. 14b.

Still another feature of some interest I may here bring to your attention. When the insulated plate is disconnected and the secondary of the coil opened, by approaching a small object to the secondary, but very small sparks can be drawn from it, showing that the electrostatic induction is small in this case. But upon the secondary being closed upon itself or through the lamp, the filament glowing brightly, strong sparks are obtained from the secondary. The electrostatic induction is now much greater, because the closed secondary determines a greater flow of current through the primary and principally through that half of it which is connected to the induction coil. If now the bulb be grasped with the hand, the capacity of the secondary with reference to the primary is augmented by the experimenter's body and the luminosity of the filament is increased, the incandescence now being due partly to the flow of current through the filament and partly to the molecular bombardment of the rarefied gas in the bulb.

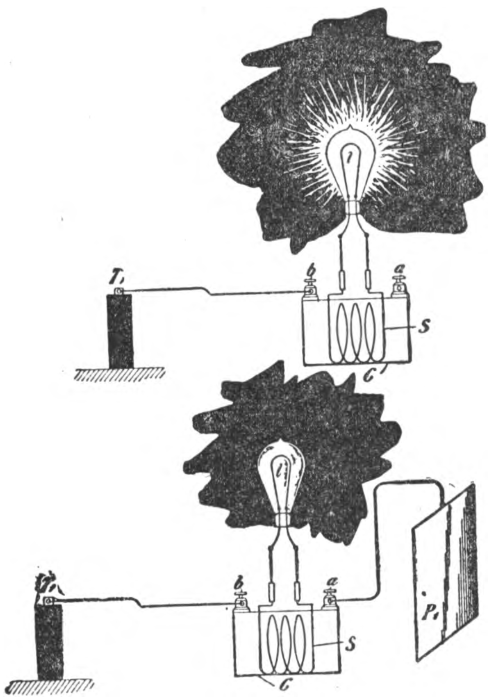
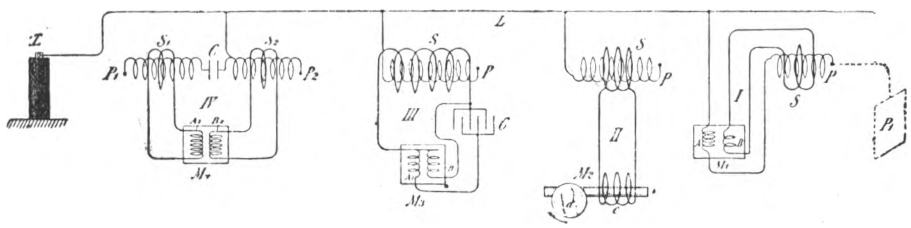


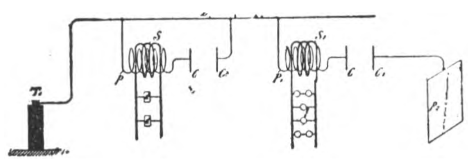
Fig. 15a.
Fig. 15b.

The preceding experiments will have prepared one for the next following results of interest, obtained in the course of these investigations. Since I can pass a current through an insulated wire merely by connecting one of its ends to the source of electrical energy, since I can induce by it another current, magnetize an iron core, and, in short, perform all operations as though a return circuit were used, clearly I can also drive a motor by the aid of only one wire. On a former occasion I have described a simple form of motor comprising a single exciting coil, an iron core and disc. Fig. 16 illustrates a modified way of operating such an alternate current motor by currents induced in a transformer connected to one lead, and several other arrangements of circuits for operating a certain class of alternating motors founded on the action of currents of differing phase. In view of the present state of the art it is thought sufficient to describe these arrangements in a few words only. The diagram, Fig. 16 II., shows a primary coil P, connected with one of its ends to the line L leading from a high tension transformer terminal T_1. In inductive relation to this primary P is a secondary s of coarse wire in the circuit of which is a coil *C.* The currents induced in the secondary energize the iron core *i,* which is preferably, but not necessarily, subdivided, and set the metal disc *d* in rotation. Such a motor M_2 as diagrammatically shown in Fig. 16 II., has been called a "magnetic lag motor", but this expression maybe objected to by those who attribute the rotation of the disc to eddy currents circulating in minute paths when the core *i* is finally subdivided. In order to operate such a motor effectively on the plan indicated, the frequencies should not be too high, not more than four or five thousand, though the rotation is produced even with ten thousand per second, or more.

In Fig. 16 I., a motor M_1 having two energizing circuits, A and B, is diagrammatically indicated. The circuit A is connected to the line L and in series with it is a primary P, which may have its free end connected to an insulated plate P_1, such connection being indicated by the dotted lines. The other motor circuit B is connected to the secondary *s* which is in inductive relation to the primary P. When the transformer terminal T_1 is alternately electrified, currents traverse the open line L and also circuit A and primary P. The currents through the latter induce secondary currents in the circuit S, which pass through the energizing coil B of the motor. The currents through the secondary S and those through the primary P differ in phase 90 degrees, or nearly so, and are capable of rotating an armature placed in inductive relation to the circuits A and B.

In Fig. 16 III., a similar motor M_3 with two energizing circuits A_1 and B_1 is illustrated. A primary P, connected with one of its ends to the line L has a secondary S, which is preferably wound for a tolerably high E. M. F., and to which the two energizing circuits of the motor are connected, one directly to the ends of the secondary and the other through a condenser C, by the action of which the currents traversing the circuit A_1 and B_1 are made to differ in phase.





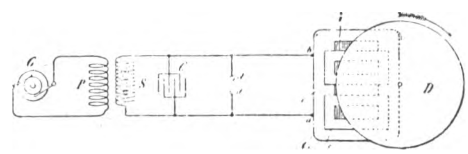


Fig. *16.*

Fig. 17.

Fig. 18.

In Fig. 16 IV., still another arrangement is shown. In this case two primaries P_1 and P_2 are connected to the line L, one through a condenser C of small capacity, and the other directly. The primaries are provided with secondaries S_1 and S_2 which are in series with the energizing circuits, A_2 and B_2 and a motor M_3, the condenser C again serving to produce the requisite difference in the phase of the currents traversing the motor circuits. As such phase motors with two or more circuits are now well known in the art, they have been here illustrated diagrammatically. No difficulty whatever is found in operating a motor in the manner indicated, or in similar ways; and although such experiments up to this day present only scientific interest, they may at a period not far distant, be carried out with practical objects in view.

It is thought useful to devote here a few remarks to the subject of operating devices of all kinds by means of only one leading wire. It is quite obvious, that when high-frequency currents are made use of, ground connections are — at least when the E. M. F. of the currents is great — better than a return wire. Such ground connections are objectionable with steady or low frequency currents on account of destructive chemical actions of the former and disturbing influences exerted by both on the neighboring circuits; but with high frequencies these actions practically do not exist. Still, even ground connections become superfluous when the E. M. F. is very high, for soon a condition is reached, when the current may be passed more economically through open, than through closed, conductors. Remote as might seem an industrial application of such single wire transmission of energy to one not experienced in such lines of experiment, it will not seem so to anyone who for some time has carried on investigations of such nature. Indeed I cannot see why such a plan should not be practicable. Nor should it be thought that for carrying out such a plan currents of very high frequency are expressly required, for just as soon as potentials of say 30,000 volts are used, the single wire transmission may be effected with low frequencies, and experiments have been made by me from which these inferences are made.

When the frequencies are very high it has been found in laboratory practice quite easy to regulate the effects in the manner shown in diagram Fig. 17. Here two primaries P and P_1 are shown, each connected with one of its ends to the line L and with the other end to the condenser plates C and C, respectively. Near these are placed other condenser plates C_1 and C_1 the former being connected to the line L and the latter to an insulated larger plate P_2. On the primaries are wound secondaries S and S_1, of coarse wire, connected to the devices *d* and *l* respectively. By varying the distances of the condenser plates C and C_1, and C and C, the currents through the secondaries S and S_1 are varied in intensity. The curious feature is the great sensitiveness, the slightest change in the distance of the plates producing considerable variations in the intensity or strength of the currents. The sensitiveness may be rendered extreme by making the frequency such, that the primary itself, without any plate attached to its free end, satisfies, in conjunction with the closed secondary, the condition of resonance. In such condition an extremely small change in the capacity of the free terminal produces great variations. For instance, I have been able to adjust the conditions so that the mere approach of a person to the coil produces a considerable change in the brightness of the lamps attached to the secondary. Such observations and experiments possess, of course, at present, chiefly scientific interest, but they may soon become of practical importance.

Very high frequencies are of course not practicable with motors on account of the necessity of employing iron cores. But one may use sudden discharges of low frequency and thus obtain certain advantages of high-frequency currents without rendering the iron core entirely incapable of following the changes and without entailing a very great expenditure of energy in the core. I have found it quite practicable to operate with such low frequency disruptive discharges of condensers, alternating-current motors. A certain class of such motors which I advanced a few years ago, which contain closed secondary circuits, will rotate quite vigorously when the discharges are directed through the exciting coils. One reason that such a motor operates so well with these discharges is that the difference of phase between the primary and secondary currents is 90 degrees, which is generally not the case with harmonically rising and falling currents of low frequency. It might not be without interest to show an experiment with a simple motor of this kind, inasmuch as it is commonly thought that disruptive discharges are unsuitable for such purposes. The motor is illustrated in Fig. 18. It comprises a rather large iron core *i* with slots on the top into which are embedded thick copper washers *C C*. In proximity to the core is a freely-movable metal disc D. The core is provided with a primary exciting coil C, the ends *a* and *b* of which are connected to the terminals of the secondary S of an ordinary transformer, the primary P of the latter being connected to an alternating distribution circuit or generator G of low or moderate frequency. The terminals of the secondary S are attached to a condenser C which discharges through an air gap *d d* which may be placed in series or shunt to the coil C_1. When the conditions are properly chosen the disc D rotates with considerable effort and the iron core *i* does not get very perceptibly hot. With currents from a high-frequency alternator, on the contrary, the core gets rapidly hot and the disc rotates with a much smaller effort. To perform the experiment properly it should be first ascertained that the disc D is not set in rotation when the discharge is not occurring at *d d.* It is preferable to use a large iron core and a condenser of large capacity so as to bring the superimposed quicker oscillation to a very low pitch or to do away with it entirely. By observing certain elementary rules I have also found it practicable to operate ordinary series or shunt direct-current motors with such disruptive discharges, and this can be done with or without a return wire.

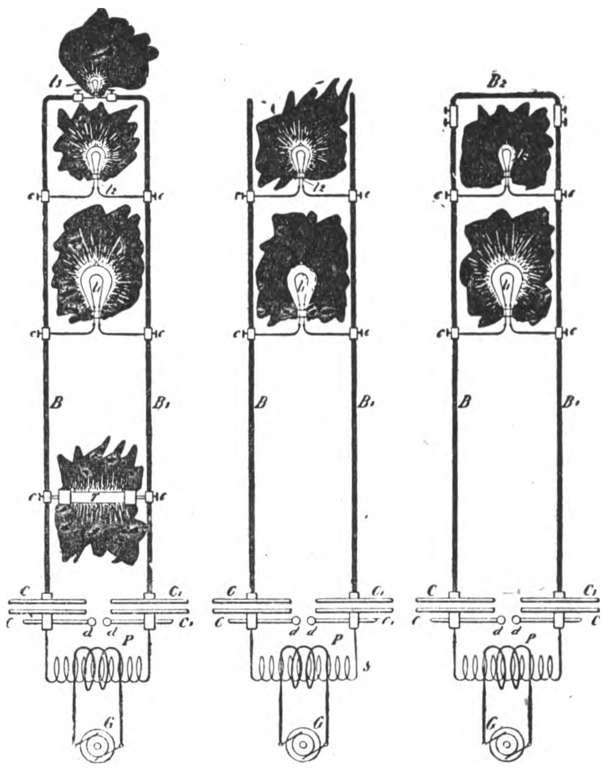
IMPEDANCE PHENOMENA

Among the various current phenomena observed, perhaps the most interesting are those of impedance presented by conductors to currents varying at a rapid rate. In my first paper before the American Institute of Electrical Engineers, I have described a few striking observations of this kind. Thus I showed that when such currents or sudden discharges are passed through a thick metal bar there may be points on the bar only a few inches apart, which have a sufficient potential difference between them to maintain at bright incandescence an ordinary filament lamp. I have also described the curious behavior of rarefied gas surrounding a conductor, due to such sudden rushes of current. These phenomena have since been more carefully studied and one or two novel experiments of this kind are deemed of sufficient interest to be described here.

Referring to Fig. 19a, B and B_1 are very stout copper bars connected at their lower ends to plates C and C_1, respectively, of a condenser, the opposite plates of the latter being connected to the terminals of the secondary S of a high-tension transformer, the primary P of which is supplied with alternating currents from an ordinary low-frequency dynamo G or distribution circuit. The condenser discharges through an adjustable gap *d d* as usual. By establishing a rapid vibration it was found quite easy to perform the following curious experiment. The bars B and B_1 were joined at the top by a low-voltage lamp l_3: a little lower was placed by means of clamps *C C,* a 50-volt lamp l_2; and still lower another 100-volt lamp l_1; and finally, at a certain distance below the latter lamp, an exhausted tube T. By carefully determining the positions of these devices it was found practicable to maintain them all at their proper illuminating power. Yet they were all connected in multiple arc to the two stout copper bars and required widely different pressures. This experiment requires of course some time for adjustment but is quite easily performed.

In Figs. 19b and 19c, two other experiments are illustrated which, unlike the previous experiment, do not require very careful adjustments. In Fig. 19b, two lamps, and l_2, the former a 100-volt and the latter a 50-volt are placed in certain positions as indicated, the 100-volt lamp being below the 50-volt lamp. When the arc is playing at *d d* and the sudden discharges are passed through the bars B B_1, the 50-volt lamp will, as a rule, burn brightly, or at least this result is easily secured, while the 100-volt lamp will burn very low or remain quite dark, Fig. 19b. Now the bars B B_1 may be joined at the top by a thick cross bar B_2 and it is quite easy to maintain the 100-volt lamp at full candle-power while the 50-volt lamp remains dark, Fig. 19c. These results, as I have pointed out previously, should not be considered to be due exactly to frequency but rather to the time rate of change which may be great, even with low frequencies. A great many other results of the same kind, equally interesting, especially to those who are only used to manipulate steady currents, may be obtained and they afford precious clues in investigating the nature of electric currents.

In the preceding experiments I have already had occasion to show some light phenomena and it would now be proper to study these in particular; but to make this investigation more complete I think it necessary to make first a few remarks on the subject of electrical resonance which has to be always observed in carrying out these experiments.



Figs. 19a, 19b and 19c.

ON ELECTRICAL RESONANCE

The effects of resonance are being more and more noted by engineers and are becoming of great importance in the practical operation of apparatus of all kinds with alternating currents. A few general remarks may therefore be made concerning these effects. It is clear, that if we succeed in employing the effects of resonance practically in the operation of electric devices the return wire will, as a matter of course, become unnecessary, for the electric vibration may be conveyed with one wire just as well as, and sometimes even better than, with two. The question first to answer is, then, whether pure resonance effects are producible. Theory and experiment both show that such is impossible in Nature, for as the oscillation becomes more and more vigorous, the losses in the vibrating bodies and environing media rapidly increase and necessarily check the vibration which otherwise would go on increasing forever. It is a fortunate circumstance that pure resonance is not producible, for if it were there is no telling what dangers might not lie in wait for the innocent experimenter. But to a certain degree resonance is producible, the magnitude of the effects being limited by the imperfect conductivity and imperfect elasticity of the media or, generally stated, by frictional losses. The smaller these losses, the more striking are the effects. The same is the case in mechanical vibration. A stout steel bar may be set in vibration by drops of water falling upon it at proper intervals; and with glass, which is more perfectly elastic, the resonance effect is still more remarkable, for a goblet may be burst by singing into it a note of the proper pitch. The electrical resonance is the more perfectly attained, the smaller the resistance or the impedance of the conducting path and the more perfect the dielectric. In a Leyden jar discharging through a short stranded cable of thin wires these requirements are probably best fulfilled, and the resonance effects are therefore very prominent. Such is not the case with dynamo machines, transformers and their circuits, or with commercial apparatus in general in which the presence of iron cores complicates the action or renders it impossible. In regard to Leyden jars with which resonance effects are frequently demonstrated, I would say that the effects observed are often *attributed* but are seldom *due* to true resonance, for an error is quite easily made in this respect. This may be undoubtedly demonstrated by the following experiment. Take, for instance, two large insulated metallic plates or spheres which I shall designate A and B; place them at a certain small distance apart and charge them from a frictional or influence machine to a potential so high that just a slight increase of the difference of potential between them will cause the small air or insulating space to break down. This is easily reached by making a few preliminary trials. If now another plate — fastened on an insulating handle and connected by a wire to one of the terminals of a high tension secondary of an induction coil, which is maintained in action by an alternator (preferably high frequency) — is approached to one of the charged bodies A or B, so as to be nearer to either one of them, the discharge will invariably occur between them; at least it will, if the potential of the coil in connection with the plate is sufficiently high. But the explanation of this will soon be found in the fact that the approached plate acts inductively upon the bodies A and B and causes a spark to pass between them. When this spark occurs, the charges which were previously imparted to these bodies from the influence machine, must needs be lost, since the bodies are brought in electrical connection through the arc formed. Now this arc is formed whether there be resonance or not. But even if the spark would not be produced, still there is an alternating E. M. F. set up between the bodies when the plate is brought near one of them; therefore the approach of the plate, if it *does* not always actually, will, at any rate, *tend* to break down the air space by inductive action. Instead of the spheres or plates A and B we may take the coatings of a Leyden jar with the same result, and in place of the machine, — which is a high frequency alternator preferably, because it is more suitable for the experiment and also for the argument, — we may take another Leyden jar or battery of jars. When such jars are discharging through a circuit of low resistance the same is traversed by currents of very high frequency. The plate may now be connected to one of the coatings of the second jar, and when it is brought near to the first jar just previously charged to a high potential from an influence machine, the result is the same as before, and the first jar will discharge through a small air space upon the second being caused to discharge. But both jars and their circuits need not be tuned any closer than a basso profundo is to the note produced by a mosquito, as small sparks will be produced through the air space, or at least the latter will be considerably more strained owing to the setting up of an alternating E. M. F. by induction, which takes place when one of the jars begins to discharge. Again another error of a similar nature is quite easily made. If the circuits of the two jars are run parallel and close together, and the experiment has been performed of discharging one by the other, and now a coil of wire be added to one of the circuits whereupon the experiment does not succeed, the conclusion that this is due to the fact that the circuits are now not tuned, would be far from being safe. For the two circuits act as condenser coatings and the addition of the coil to one of them is equivalent to bridging them, at the point where the coil is placed, by a small condenser, and the effect of the latter might be to prevent the spark from jumping through the discharge space by diminishing the alternating E. M. F. acting across the same. All these remarks, and many more which might be added but for fear of wandering too far from the subject, are made with the pardonable intention of cautioning the unsuspecting student, who might gain an entirely unwarranted opinion of his skill at seeing every experiment succeed; but they are in no way thrust upon the experienced as novel observations.

In order to make reliable observations of electric resonance effects it is very desirable, if not necessary, to employ an alternator giving currents which rise and fall harmonically, as in working with make and break currents the observations are not always trustworthy, since many phenomena, which depend on the rate of change, may be produced with widely different frequencies. Even when making such observations with an alternator one is apt to be mistaken. When a circuit is connected to an alternator there are an indefinite number of values for capacity and self-induction which, in conjunction, will satisfy the condition of resonance. So there are in mechanics an infinite number of tuning forks which will respond to a note of a certain pitch, or loaded springs which have a definite period of vibration. But the resonance will be most perfectly attained in that case in which the motion is effected with the greatest freedom. Now in mechanics, considering the vibration in the common medium — that is, air — it is of comparatively little importance whether one tuning fork be somewhat larger than another, because the losses in the air are not very considerable. One may, of course, enclose a tuning fork in an exhausted vessel and by thus reducing the air resistance to a minimum obtain better resonant action. Still the difference would not be very great. But it would make a great difference if the tuning fork were immersed in mercury. In the electrical vibration it is of enormous importance to arrange the conditions so that the vibration is effected with the greatest freedom. The magnitude of the resonance effect depends, under otherwise equal conditions, on the quantity of electricity set in motion or on the strength of the current driven through the circuit. But the circuit opposes the passage of the currents by reason of its impedance and therefore, to secure the best action it is necessary to reduce the impedance to a minimum. It is impossible to overcome it entirely, but merely in part, for the ohmic resistance cannot be overcome. But when the frequency of the impulses is very great, the flow of the current is practically determined by self-induction. Now self-induction can be overcome by combining it with capacity. If the relation between these is such, that at the frequency used they annul each other, that is, have such values as to satisfy the condition of resonance, and the greatest quantity of electricity is made to flow through the external circuit, then the best result is obtained. It is simpler and safer to join the condenser in series with the self-induction. It is clear that in such combinations there will be, for a given frequency, and considering only the fundamental vibration, values which will give the best result, with the condenser in shunt to the self-induction coil; of course more such values than with the condenser in series. But practical conditions determine the selection. In the latter case in performing the experiments one may take a small self-induction and a large capacity or a small capacity and a large self-induction, but the latter is preferable, because it is inconvenient to adjust a large capacity by small steps. By taking a coil with a very large self-induction the critical capacity is reduced to a very small value, and the capacity of the coil itself may be sufficient. It is easy, especially by observing certain artifices, to wind a coil through which the impedance will be reduced to the value of the ohmic resistance only; and for any coil there is, of course, a frequency at which the maximum current will be made to pass through the coil. The observation of the relation between self-induction, capacity and frequency is becoming important in the operation of alternate current apparatus, such as transformers or motors, because by a judicious determination of the elements the employment of an expensive condenser becomes unnecessary. Thus it is possible to pass through the coils of an alternating current motor under the normal working conditions the required current with a low E. M. F. and do away entirely with the false current, and the larger the motor, the easier such a plan becomes practicable; but it is necessary for this to employ currents of very high potential or high frequency.

In Fig. 20 I. is shown a plan which has been followed in the study of the resonance effects by means of a high frequency alternator. C_1 is a coil of many turns, which is divided into small separate sections for the purpose of adjustment. The final adjustment was made sometimes with a few thin iron wires (though this is not always advisable) or with a closed secondary. The coil C_1 is connected with one of its ends to the line L from the alternator G and with the other end to one of the plates *C* of a condenser *C* C_1, the plate (C_1) of the latter being connected to a much larger plate P_1, In this manner both capacity and self-induction were adjusted to suit the dynamo frequency.

As regards the rise of potential through resonant action, of course, theoretically, it may amount to anything since it depends on self-induction and resistance and since these may have any value. But in practice one is limited in the selection of these values and besides these, there are other limiting causes. One may start with, say, 1,000 volts and raise the E. M. F. to 50 times that value, but one cannot start with 100,000 and raise it to ten times that value because of the losses in the media which are great, especially if the frequency is high. It should be possible to start with, for instance, two

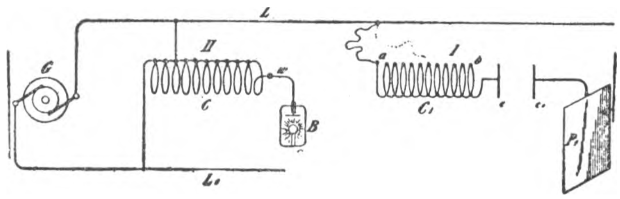


Fig. 20.

volts from a high or low frequency circuit of a dynamo and raise the E. M. F. to many hundred times that value. Thus coils of the proper dimensions might be connected each with only one of its ends to the mains from a machine of low E. M. F., and though the circuit of the machine would not be closed in the ordinary acceptance of the term, yet the machine might be burned out if a proper resonance effect would be obtained. I have not been able to produce, nor have I observed with currents from a dynamo machine, such great rises of potential. It is possible, if not probable, that with currents obtained from apparatus containing iron the disturbing influence of the latter is the cause that these theoretical possibilities cannot be realized. But if such is the case I attribute it solely to the hysteresis and Foucault current losses in the core. Generally it was necessary to transform upward, when the E. M. F. was very low, and usually an ordinary form of induction coil was employed, but sometimes the arrangement illustrated in Fig. 20 II., has been found to be convenient. In this case a coil C is made in a great many sections, a few of these being used as a primary. In this manner both primary and secondary are adjustable. One end of the coil is connected to the line L_1 from the alternator, and the other line L is connected to the intermediate point of the coil. Such a coil with adjustable primary and secondary will be found also convenient in experiments with the disruptive discharge. When true resonance is obtained the top of the wave must of course be on the free end of the coil as, for instance, at the terminal of the phosphorescence bulb B. This is easily recognized by observing the potential of a point on the wire *w* near to the coil.

In connection with resonance effects and the problem of transmission of energy-over a single conductor which was previously considered, I would say a few words on a subject which constantly fills my thoughts and which concerns the welfare of all. I mean the transmission of intelligible signals or perhaps even power to any distance without the use of wires. I am becoming daily more convinced of the practicability of the scheme; and though I know full well that the great majority of scientific men will not believe that such results can be practically and immediately realized, yet I think that all consider the developments in recent years by a number of workers to have been such as to encourage thought and experiment in this direction. My conviction has grown so strong, that I no longer look upon this plan of energy or intelligence transmission as a mere theoretical possibility, but as a serious problem in electrical engineering, which must be carried out some day. The idea of transmitting intelligence without wires is the natural outcome of the most recent results of electrical investigations. Some enthusiasts have expressed their belief that telephony to any distance by induction through the air is possible. I cannot stretch my imagination so far, but I do firmly believe that it is practicable to disturb by means of powerful machines the electrostatic condition of the earth and thus transmit intelligible signals and perhaps power. In fact, what is there against the carrying out of such a scheme? We now know that electric vibration may be transmitted through a single conductor. Why then not try to avail ourselves of the earth for this purpose? We need not be frightened by the idea of distance. To the weary wanderer counting the mile-posts the earth may appear very large, but to that happiest of all men, the astronomer, who gazes at the heavens and by their standard judges the magnitude of our globe, it appears very small. And so I think it must seem to the electrician, for when he considers the speed with which an electric disturbance is propagated through the earth all his ideas of distance must completely vanish.

A point of great importance would be first to know what is the capacity of the earth? and what charge does it contain if electrified? Though we have no positive evidence of a charged body existing in space without other oppositely electrified bodies being near, there is a fair probability that the earth is such a body, for by whatever process it was separated from other bodies — and this is the accepted view of its origin — it must have retained a charge, as occurs in all processes of mechanical separation. If it be a charged body insulated in space its capacity should be extremely small, less than one-thousandth of a farad. But the upper strata of the air are conducting, and so, perhaps, is the medium in free space beyond the atmosphere, and these may contain an opposite charge. Then the capacity might be incomparably greater. In any case it is of the greatest importance to get an idea of what quantity of electricity the earth contains. It is difficult to say whether we shall ever acquire this necessary knowledge, but there is hope that we may, and that is, by means of electrical resonance. If ever we can ascertain at what period the earth's charge, when disturbed, oscillates with respect to an oppositely electrified system or known circuit, we shall know a fact possibly of the greatest importance to the welfare of the human race. I propose to seek for the period by means of an electrical oscillator, or a source of alternating electric currents. One of the terminals of the source would be connected to earth as, for instance, to the city water mains, the other to an insulated body of large surface. It is possible that the outer conducting air strata, or free space, contain an opposite charge and that, together with the earth, they form a condenser of very large capacity. In such case the period of vibration may be very low and an alternating dynamo machine might serve for the purpose of the experiment. I would then transform the current to a potential as high as it would be found possible and connect the ends of the high tension secondary to the ground and to the insulated body. By varying the frequency of the currents and carefully observing the potential of the insulated body and watching for the disturbance at various neighboring points of the earth's surface resonance might be detected. Should, as the majority of scientific men in all probability believe, the period be extremely small, then a dynamo machine would not do and a proper electrical oscillator would have to be produced and perhaps it might not be possible to obtain such rapid vibrations. But whether this be possible or not, and whether the earth contains a charge or not, and whatever may be its period of vibration, it certainly is possible — for of this we have daily evidence — to produce some electrical disturbance sufficiently powerful to be perceptible by suitable instruments at any point of the earth's surface.

Assume that a source of alternating currents be connected, as in Fig. 21, with one of its terminals to earth (conveniently to the water mains) and with the other to a body of large surface P. When the electric oscillation is set up there will be a movement of electricity in and out of P, and alternating currents will pass through the earth, converging to, or diverging from, the point C where the ground connection is made. In this manner neighboring points on the earth's surface within a certain radius will be disturbed. But the disturbance will diminish with the distance, and the distance at which the effect will still be perceptible will depend on the quantity of electricity set in motion. Since the body P is insulated, in order to displace a considerable quantity, the potential of the source must be excessive, since there would be limitations as to the surface of P. The conditions might be adjusted so that the generator or source S will set up the same electrical movement as though its circuit were closed. Thus it is certainly practicable to impress an electric vibration at least of a certain low period upon the earth by means of proper machinery. At what distance such a vibration might be made perceptible can only be conjectured. I have on another occasion considered the question how the earth might behave to electric disturbances. There is no doubt that, since in such an experiment the electrical density at the surface could be but extremely small considering the size of the earth, the air would not act as a very disturbing factor, and there would be not much energy lost through the action of the air, which would be the case if the density were great. Theoretically, then, it could not require a great amount of energy to produce a disturbance perceptible at great distance, or even all over the surface of the globe. Now, it is quite certain that at any point within a certain radius of the source S a properly adjusted self-induction and capacity device can be set in action by resonance. But not only can this be done, but another source S_1, Fig. 21, similar to S, or any number of such sources, can be set to work in synchronism with the latter, and the vibration thus intensified and spread over a large area, or a flow of electricity produced to or from the source S_1 if the same be of opposite phase to the source S. I think that beyond doubt it is possible to operate electrical devices in a city through the ground or pipe system by resonance from an electrical oscillator located at a central point. But the practical solution of this problem would be of incomparably smaller benefit to man than the realization of the scheme of transmitting intelligence, or perhaps power, to any distance through the earth or environing medium. If this is at all possible, distance does not mean anything. Proper apparatus must first be produced by means of which the problem can be attacked and I have devoted much thought to this subject. I am firmly convinced that it can be done and hope that we shall live to see it done.

Fig. 21.

ON THE LIGHT PHENOMENA PRODUCED BY HIGH-FREQUENCY CURRENTS OF HIGH POTENTIAL AND GENERAL REMARKS RELATING TO THE SUBJECT

Returning now to the light effects which it has been the chief object to investigate, it is thought proper to divide these effects into four classes: 1. Incandescence of a solid. 2. Phosphorescence. 3. Incandescence or phosphorescence of a rarefied gas; and 4. Luminosity produced in a gas at ordinary pressure. The first question is: How are these luminous effects produced? In order to answer this question as satisfactorily as I am able to do in the light of accepted views and with the experience acquired, and to add some interest to this demonstration, I shall dwell here upon a feature which I consider of great importance, inasmuch as it promises, besides, to throw a better light upon the nature of most of the phenomena produced by high-frequency electric currents, I have on other occasions pointed out the great importance of the presence of the rarefied gas, or atomic medium in general, around the conductor through which alternate currents of high frequency are passed, as regards the heating of the conductor by the currents. My experiments, described some time ago, have shown that, the higher the frequency and potential difference of the currents, the more important becomes the rarefied gas in which the conductor is immersed, as a factor of the heating. The potential difference, however, is, as I then pointed out, a more important element than the frequency. When both of these are sufficiently high, the heating may be almost entirely due to the presence of the rarefied gas. The experiments to follow will show the importance of the rarefied gas, or, generally, of gas at ordinary or other pressure as regards the incandescence or other luminous effects produced by currents of this kind.

I take two ordinary 50-volt 16 C. P. lamps which are in every respect alike, with the exception, that one has been opened at the top and the air has filled the bulb, while the other is at the ordinary degree of exhaustion of commercial lamps. When I attach the lamp which is exhausted to the terminal of the secondary of the coil, which I have already used, as in experiments illustrated in Fig. 15a for instance, and turn on the current, the filament, as you have before seen, comes to high incandescence. When I attach the second lamp, which is filled with air, instead of the former, the filament still glows, but much less brightly. This experiment illustrates only in part the truth of the statements before made. The importance of the filament's being immersed in rarefied gas is plainly noticeable but not to such a degree as might be desirable. The reason is that the secondary of this coil is wound for low tension, having only 150 turns, and the potential difference at the terminals of the lamp is therefore small. Were I to take another coil with many more turns in the secondary, the effect would be increased, since it depends partially on the potential difference, as before remarked. But since the effect likewise depends on the frequency, it may be properly stated that it depends on the time rate of the variation of the potential difference. The greater this variation, the more important becomes the gas as an element of heating. I can produce a much greater rate of variation in another way, which, besides, has the advantage of doing away with the objections, which might be made in the experiment just shown, even if both the lamps were connected in series or multiple arc to the coil, namely, that in consequence of the reactions existing between the primary and secondary coil the conclusions are rendered uncertain. This result I secure by charging, from an ordinary transformer which is fed from the alternating current supply station, a battery of condensers, and discharging the latter directly through a circuit of small self-induction, as before illustrated in Figs. 19a, 19b and 19c.

In Figs. 22a, 22b and 22c, the heavy copper bars BB_1, are connected to the opposite coatings of a battery of condensers, or generally in such way, that the high frequency or sudden discharges are made to traverse them. I connect first an ordinary 50-volt incandescent lamp to the bars by means of the clamps *C C*. The discharges being passed through the lamp, the filament is rendered incandescent, though the current through it is very small, and would not be nearly sufficient to produce a visible effect under the conditions of ordinary use of the lamp. Instead of this I now attach to the bars another lamp exactly like the first, but with the seal broken off, the bulb being therefore filled with air at ordinary pressure. When the discharges are directed through the filament, as before, it does not become incandescent. But the result might still be attributed to one of the many possible reactions. I therefore connect both the lamps in multiple arc as illustrated in Fig. 22a. Passing the discharges through both the lamps, again the filament in the exhausted lamp *l* glows very brightly while that in the non-exhausted lamp l_1 remains dark, as previously. But it should not be thought that the latter lamp is taking only a small fraction of the energy supplied to both the lamps; on the contrary, it may consume a considerable portion of the energy and it may become even hotter than the one which burns brightly. In this experiment the potential difference at the terminals of the lamps varies in sign theoretically three to four million times a second. The ends of the filaments are correspondingly electrified, and the gas in the bulbs is violently agitated and a large portion of the supplied energy is thus converted into heat. In the non-exhausted bulb, there being a few million times more gas molecules than in the exhausted one, the bombardment, which is most violent at the ends of the

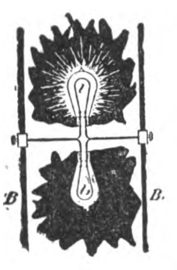


Fig. 22a.

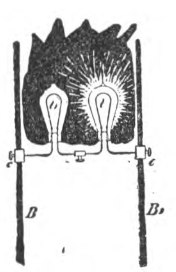


Fig. 22b.

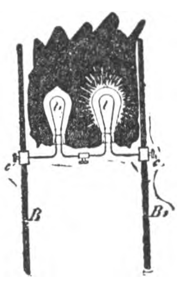


Fig. 22c.

filament, in the neck of the bulb, consumes a large portion of the energy without producing any visible effect. The reason is that, there being many molecules, the bombardment is quantitatively considerable, but the individual impacts are not very violent, as the speeds of the molecules are comparatively small owing to the small free path. In the exhausted bulb, on the contrary, the speeds are very great, and the individual impacts are violent and therefore better adapted to produce a visible effect. Besides, the convection of heat is greater in the former bulb. In both the bulbs the current traversing the filaments is very small, incomparably smaller than that which they require on an ordinary low-frequency circuit. The potential difference, however, at the ends of the filaments is very great and might be possibly 20,000 volts or more, if the filaments were straight and their ends far apart. In the ordinary lamp a spark generally occurs between the ends of the filament or between the platinum wires outside, before such a difference of potential can be reached.

It might be objected that in the experiment before shown the lamps, being in multiple arc, the exhausted lamp might take a much larger current and that the effect observed might not be exactly attributable to the action of the gas in the bulbs. Such objections will lose much weight if I connect the lamps in series, with the same result. When this is done and the discharges are directed through the filaments, it is again noted that the filament in the non-exhausted bulb l_1 remains dark, while that in the exhausted one (*l*) glows even more intensely than under its normal conditions of working, Fig. 22b. According to general ideas the current through the filaments should now be the same, were it not modified by the presence of the gas around the filaments.

At this juncture I may point out another interesting feature, which illustrates the effect of the rate of change of potential of the currents. I will leave the two lamps connected in series to the bars BB_1, as in the previous experiment, Fig. 22b, but will presently reduce considerably the frequency of the currents, which was excessive in the experiment just before shown. This I may do by inserting a self-induction coil in the path of the discharges, or by augmenting the capacity of the condensers. When I now pass these low-frequency discharges through the lamps, the exhausted lamp l again is as bright as before, but it is noted also that the non-exhausted lamp l_1 glows, though not quite as intensely as the other. Reducing the current through the lamps, I may bring the filament in the latter lamp to redness, and, though the filament in the exhausted lamp l is bright, Fig. 22c, the degree of its incandescence is much smaller than in Fig. 22b, when the currents were of a much higher frequency.

In these experiments the gas acts in two opposite ways in determining the degree of the incandescence of the filaments, that is, by convection and bombardment. The higher the frequency and potential of the currents, the more important becomes the bombardment. The convection on the contrary should be the smaller, the higher the frequency. When the currents are steady there is practically no bombardment, and convection may therefore with such currents also considerably modify the degree of incandescence and produce results similar to those just before shown. Thus, if two lamps exactly alike, one exhausted and one not exhausted, are connected in multiple arc or series to a direct-current machine, the filament in the non-exhausted lamp will require a considerably greater current to be rendered incandescent. This result is entirely due to convection, and the effect is the more prominent the thinner the filament. Professor Ayrton and Mr. Kilgour some time ago published quantitative results concerning the thermal emissivity by radiation and convection in which the effect with thin wires was clearly shown. This effect may be strikingly illustrated by preparing a number of small, short, glass tubes, each containing through its axis the thinnest obtainable platinum wire. If these tubes be highly exhausted, a number of them may be connected in multiple arc to a direct-current machine and all of the wires may be kept at incandescence with a smaller current than that required to render incandescent a single one of the wires if the tube be not exhausted. Could the tubes be so highly exhausted that convection would be nil, then the relative amounts of heat given off by convection and radiation could be determined without the difficulties attending thermal quantitative measurements. If a source of electric impulses of high frequency and very high potential is employed, a still greater number of the tubes may be taken and the wires rendered incandescent by a current not capable of warming perceptibly a wire of the same size immersed in air at ordinary pressure, and conveying the energy to all of them.

I may here describe a result which is still more interesting, and to which I have been led by the observation of these phenomena. I noted that small differences in the density of the air produced a considerable difference in the degree of incandescence of the wires, and I thought that, since in a tube, through which a luminous discharge is passed, the gas is generally not of uniform density, a very thin wire contained in the tube might be rendered incandescent at certain places of smaller density of the gas, while it would remain dark at the places of greater density, where the convection would be greater and the bombardment less intense. Accordingly a tube t was prepared, as illustrated in Fig. 23, which contained through the middle a very fine platinum wire w. The tube was exhausted to a moderate degree and it was found that when it was attached to the terminal of a high-frequency coil the platinum wire w would indeed, become incandescent in patches, as illustrated in Fig. 23. Later a number of these tubes with one or more wires were prepared, each showing this result. The effect was best noted when the striated discharge occurred in the tube, but was also produced when the striae were not visible, showing that, even then, the gas in the tube was not or uniform density. The position of the striae was generally such, that the rarefactions corresponded to the places of incandescence or greater brightness on the wire *w*. But in a few instances it was noted, that the bright spots on the wire were covered by the dense parts of the striated discharge as indicated by *l* in Fig. 23, though the effect was barely perceptible. This was explained in a plausible way by assuming that the convection was not widely different in the dense and rarefied places, and that the bombardment was greater on the dense places of the striated discharge. It is, in fact,

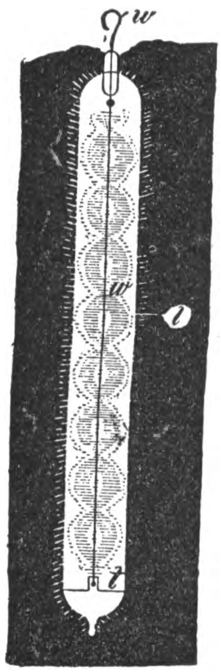


Fig. 23

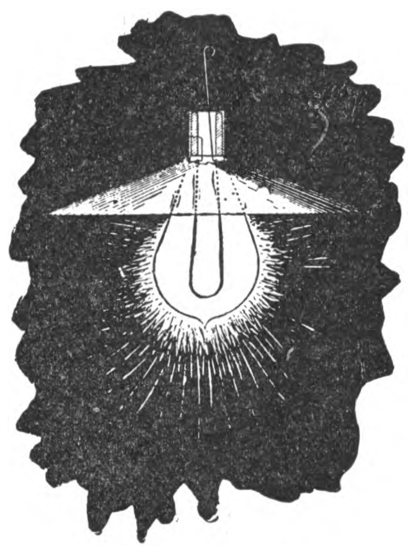


Fig. 24.

often observed in bulbs, that under certain conditions a thin wire is brought to higher incandescence when the air is not too highly rarefied. This is the case when the potential of the coil is not high enough for the vacuum, but the result may be attributed to many different causes. In all cases this curious phenomenon of incandescence disappears when the tube, or rather the wire, acquires throughout a uniform temperature.

Disregarding now the modifying effect of convection there are then two distinct causes which determine the incandescence of a wire or filament with varying currents, that is, conduction current and bombardment. With steady currents we have to deal only with the former of these two causes, and the heating effect is a minimum, since the resistance is least to steady flow. When the current is a varying one the resistance is greater, and hence the heating effect is increased. Thus if the rate of change of the current is very great, the resistance may increase to such an extent that the filament is brought to incandescence with inappreciable currents, and we are able to take a short and thick block of carbon or other material and bring it to bright incandescence with a current incomparably smaller than that required to bring to the same degree of incandescence an ordinary thin lamp filament with a steady or low frequency current. This result is important, and illustrates how rapidly our views on these subjects are changing, and how quickly our field of knowledge is extending. In the art of incandescent lighting, to view this result in one aspect only, it has been commonly considered as an essential requirement for practical success, that the lamp filament should be thin and of high resistance. But now we know that the resistance of the filament to the steady flow does not mean anything; the filament might as well be short and thick; for if it be immersed in rarefied gas it will become incandescent by the passage of a small current. It all depends on the frequency and potential of the currents. We may conclude from this, that it would be of advantage, so far as the lamp is considered, to employ high frequencies for lighting, as they allow the use of short and thick filaments and smaller currents.

If a wire or filament be immersed in a homogeneous medium, all the heating is due to true conduction current, but if it be enclosed in an exhausted vessel the conditions are entirely different. Here the gas begins to act and the heating effect of the conduction current, as is shown in many experiments, may be very small compared with that of the bombardment. This is especially the case if the circuit is not closed and the potentials are of course very high. Suppose that a fine filament enclosed in an exhausted vessel be connected with one of its ends to the terminal of a high tension coil and with its other end to a large insulated plate. Though the circuit is not closed, the filament, as I have before shown, is brought to incandescence. If the frequency and potential be comparatively low, the filament is heated by the current passing *through it.* If the frequency and potential, and principally the latter, be increased, the insulated plate need be but very small, or may be done away with entirely; still the filament will become incandescent, practically all the heating being then due to the bombardment. A practical way of combining both the effects of conduction currents and bombardment is illustrated in Fig. 24, in which an ordinary lamp is shown provided with a very thin filament which has one of the ends of the latter connected to a shade serving the purpose of the insulated plate, and the other end to the terminal of a high tension source. It should not be thought that only rarefied gas is an important factor in the heating of a conductor by varying currents, but gas at ordinary pressure may become important, if the potential difference and frequency of the currents is excessive. On this subject I have already stated, that when a conductor is fused by a stroke of lightning, the current through it may be exceedingly small, not even sufficient to heat the conductor perceptibly, were the latter immersed in a homogeneous medium.

From the preceding it is clear that when a conductor of high resistance is connected to the terminals of a source of high frequency currents of high potential, there may occur considerable dissipation of energy, principally at the ends of the conductor, in consequence of the action of the gas surrounding the conductor. Owing to this, the current through a section of the conductor at a point midway between its ends may be much smaller than through a section near the ends. Furthermore, the current passes principally through the outer portions of the conductor, but this effect is to be distinguished from the skin effect as ordinarily interpreted, for the latter would, or should, occur also in a continuous incompressible medium. If a great many incandescent lamps are connected in series to a source of such currents, the lamps at the ends may burn brightly, whereas those in the middle may remain entirely dark. This is due principally to bombardment, as before stated. But even if the currents be steady, provided the difference of potential is very great, the lamps at the end will burn more brightly than those in the middle. In such case there is no rhythmical bombardment, and the result is produced entirely by leakage. This leakage or dissipation into space when the tension is high, is considerable when incandescent lamps are used, and still more considerable with arcs, for the latter act like flames. Generally, of course, the dissipation is much smaller with steady, than with varying, currents.

I have contrived an experiment which illustrates in an interesting manner the effect of lateral diffusion. If a very long tube is attached to the terminal of a high frequency coil, the luminosity is greatest near the terminal and falls off gradually towards the remote end. This is more marked if the tube is narrow.

A small tube about one-half inch in diameter and twelve inches long (Fig. 25), has one of its ends drawn out into a fine fibre *f* nearly three feet long. The tube is placed in a brass socket T which can be screwed on the terminal T_1 of the induction coil. The discharge passing through the tube first illuminates the bottom of the same,

Fig. 25

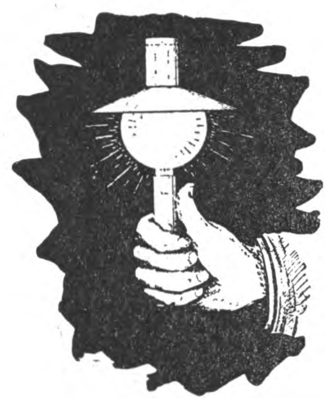


Fig. 26

which is of comparatively large section; but through the long glass fibre the discharge cannot pass. But gradually the rarefied gas inside becomes warmed and more conducting and the discharge spreads into the glass fibre. This spreading is so slow, that it may take half a minute or more until the discharge has worked through up to the top of the glass fibre, then presenting the appearance of a strongly luminous thin thread. By adjusting the potential at the terminal the light may be made to travel upwards at any speed. Once, however, the glass fibre is heated, the discharge breaks through its entire length instantly. The interesting point to be noted is that, the higher the frequency of the currents, or in other words, the greater relatively the lateral dissipation, at a slower rate may the light be made to propagate through the fibre. This experiment is best performed with a highly exhausted and freshly made tube. When the tube has been used for some time the experiment often fails. It is possible that the gradual and slow impairment of the vacuum is the cause. This slow propagation of the discharge through a very narrow glass tube corresponds exactly to the propagation of heat through a bar warmed at one end. The quicker the heat is carried away laterally the longer time it will take for the heat to warm the remote end. When the current of a low frequency coil is passed through the fibre from end to end, then the lateral dissipation is small and the discharge instantly breaks through almost without exception.

After these experiments and observations which have shown the importance of the discontinuity or atomic structure of the medium and which will serve to explain, in a measure at least, the nature of the four kinds of light effects producible with these currents, I may now give you an illustration of these effects. For the sake of interest I may do this in a manner which to many of you might be novel. You have seen before that we may now convey the electric vibration to a body by means of a single wire or conductor of any kind. Since the human frame is conducting I may convey the vibration through my body.

First, as in some previous experiments, I connect my body with one of the terminals of a high-tension transformer and take in my hand an exhausted bulb which contains a small carbon button mounted upon a platinum wire leading to the outside of the bulb, and the button is rendered incandescent as soon as the transformer is set to work (Fig. 26). I may place a conducting shade on the bulb which serves to intensify the action, but it is not necessary. Nor is it required that the button should be in conducting connection

Fig. 27.

Fig. 28.

with the hand through a wire leading through the glass, for sufficient energy may be transmitted through the glass itself by inductive action to render the button incandescent.

Next I take a highly exhausted bulb containing a strongly phosphorescent body, above which is mounted a small plate of aluminum on a platinum wire leading to the outside, and the currents flowing through my body excite intense phosphorescence in the bulb (Fig. 27). Next again I take in my hand a simple exhausted tube, and in the same manner the gas inside the tube is rendered highly incandescent or phosphorescent (Fig. 28). Finally, I may take in my hand a wire, bare or covered with thick insulation, it is quite immaterial; the electrical vibration is so intense as to cover the wire with a luminous film (Fig. 29).

A few words must now be devoted to each of these phenomena. In the first place, I will consider the incandescence of a button or of a solid in general, and dwell upon some facts which apply equally to all these phenomena. It was pointed out before that when a thin conductor, such as a lamp filament, for instance, is connected with one of its ends to the terminal of a transformer of high tension the filament is brought to incandescence partly by a conduction current and partly by bombardment. The shorter and thicker the filament the more important becomes the latter, and finally, reducing the filament to a mere button, all the heating must practically be attributed to the bombardment. So in the experiment before shown, the button is rendered incandescent by the rhythmical impact of freely movable small bodies in the bulb. These bodies may be the molecules of the residual gas, particles of dust or lumps torn from the electrode; whatever they are, it is certain that the heating of the button is essentially connected with the pressure of such freely movable particles, or of atomic matter in general in the bulb. The heating is the more intense the greater the number of impacts per second and the greater the energy of each impact. Yet the button would be heated also if it were connected to a source of a steady potential. In such a case electricity would be carried away from the button by the freely movable carriers or particles flying about, and the quantity of electricity thus carried away might be sufficient to bring the button to incandescence by its passage through the latter. But the bombardment could not be of great importance in such case. For this reason it would require a comparatively very great supply of energy to the button to maintain it at incandescence with a steady potential. The higher the frequency of the electric impulses the more

Fig. 29.

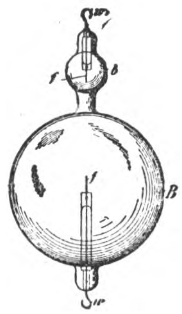


Fig. 30.

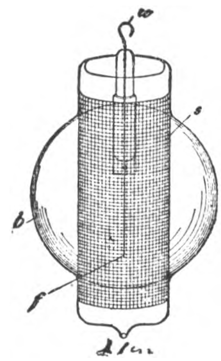


Fig. 31.

economically can the button be maintained at incandescence. One of the chief reasons why this is so, is, I believe, that with impulses of very high frequency there is less exchange of the freely movable carriers around the electrode and this means, that in the bulb the heated matter is better confined to the neighborhood of the button. If a double bulb, as illustrated in Fig. 30 be made, comprising a large globe B and a small one *b,* each containing as usual a filament *l* mounted on a platinum wire *w* and w_1, it is found, that if the filaments *f f be* exactly alike, it requires less energy to keep the filament in the globe *b* at a certain degree of incandescence, than that in the globe B. This is due to the confinement of the movable particles around the button. In this case it is also ascertained, that the filament in the small globe *b* is less deteriorated when maintained a certain length of time at incandescence. This is a necessary consequence of the fact that the gas in the small bulb becomes strongly heated and therefore a very good conductor, and less work is then performed on the button, since the bombardment becomes less intense as the conductivity of the gas increases. In this construction, of course, the small bulb becomes very hot and when it reaches an elevated temperature the convection and radiation on the outside increase. On another occasion I have shown bulbs in which this drawback was largely avoided. In these instances a very small bulb, containing a refractory button, was mounted in a large globe and the space between the walls of both was highly exhausted. The outer large globe remained comparatively cool in such constructions. When the large globe was on the pump and the vacuum between the walls maintained permanent by the continuous action of the pump, the outer globe would remain quite cold, while the button in the small bulb was kept at incandescence. But when the seal was made, and the button in the small bulb maintained incandescent some length of time, the large globe too would become warmed. From this I conjecture that if vacuous space (as Prof. Dewar finds) cannot convey heat, it is so merely in virtue of our rapid motion through space or, generally speaking, by the motion of the medium relatively to us, for a permanent condition could not be maintained without the medium being constantly renewed. A vacuum cannot, according to all evidence, be permanently maintained around a hot body.

In these constructions, before mentioned, the small bulb inside would, at least in the first stages, prevent all bombardment against the outer large globe. It occurred to me then to ascertain how a metal sieve would behave in this respect, and several bulbs, as illustrated in Fig. 31, were prepared for this purpose. In a globe *b,* was mounted a thin filament *l* (or button) upon a platinum wire *w* passing through a glass stem and leading to the outside of the globe. The filament *f* was surrounded by a metal sieve *s.* It was found in experiments with such bulbs that a sieve with wide meshes apparently did not in the slightest affect the bombardment against the globe *b.* When the vacuum was high, the shadow of the sieve was clearly projected against the globe and the latter would get hot in a short while. In some bulbs the sieve *s* was connected to a platinum wire sealed in the glass. When this wire was connected to the other terminal of the induction coil (the E. M. F. being kept low in this case), or to an insulated plate, the bombardment against the outer globe *b* was diminished. By taking a sieve with fine meshes the bombardment against the globe *b* was always diminished, but even then if the exhaustion was carried very far, and when the potential of the transformer was very high, the globe *b* would be bombarded and heated quickly, though no shadow of the sieve was visible, owing to the smallness of the meshes. But a glass tube or other continuous body mounted so as to surround the filament, did entirely cut off the bombardment and for a while the outer globe *b* would remain perfectly cold. Of course when the glass tube was sufficiently heated the bombardment against the outer globe could be noted at once. The experiments with these bulbs seemed to show that the speeds of the projected molecules or particles must be considerable (though quite insignificant when compared with that of light), otherwise it would be difficult to understand how they could traverse a fine metal sieve without being affected, unless it were found that such small particles or atoms cannot be acted upon directly at measurable distances. In regard to the speed of the projected atoms, Lord Kelvin has recently estimated it at about one kilometre a second or thereabouts in an ordinary Crookes bulb. As the potentials obtainable with a disruptive discharge coil are much higher than with ordinary coils, the speeds must, of course, be much greater when the bulbs are lighted from such a coil. Assuming the speed to be as high as five kilometres and uniform through the whole trajectory, as it should be in a very highly exhausted vessel, then if the alternate electrifications of the electrode would be of a frequency of five million, the greatest distance a particle could get away from the electrode would be one millimetre, and if it could be acted upon directly at that distance, the exchange of electrode matter or of the atoms would be very slow and there would be practically no bombardment against the bulb. This at least should be so, if the action of an electrode upon the atoms of the residual gas would be such as upon electrified bodies which we can perceive. A hot body enclosed in an exhausted bulb produces always atomic bombardment, but a hot body has no definite rhythm, for its molecules perform vibrations of all kinds.

If a bulb containing a button or filament be exhausted as high as is possible with the greatest care and by the use of the best artifices, it is often observed that the discharge cannot, at first, break through, but after some time, probably in consequence of some changes within the bulb, the discharge finally passes through and the button is rendered incandescent. In fact, it appears that the higher the degree of exhaustion the easier is the incandescence produced. There seem to be no other causes to which the incandescence might be attributed in such case except to the bombardment or similar action of the residual gas, or of particles of matter in general. But if the bulb be exhausted with the greatest care can these play an important part? Assume the vacuum in the bulb to be tolerably perfect, the great interest then centres in the question: Is the medium which pervades all space continuous or atomic? If atomic, then the heating of a conducting button or filament in an exhausted vessel might be due largely to ether bombardment, and then the heating of a conductor in general through which currents of high frequency or high potential are passed must be modified by the behavior of such medium; then also the skin effect, the apparent increase of the ohmic resistance, etc., admit, partially at least, of a different explanation.

It is certainly more in accordance with many phenomena observed with high-frequency currents to hold that all space is pervaded with free atoms, rather than to assume that it is devoid of these, and dark and cold, for so it must be, if filled with a continuous medium, since in such there can be neither heat nor light. Is then energy transmitted by independent carriers or by the vibration of a continuous medium? This important question is by no means as yet positively answered. But most of the effects which are here considered, especially the light effects, incandescence, or phosphorescence, involve the presence of free atoms and would be impossible without these.

In regard to the incandescence of a refractory button (or filament) in an exhausted receiver, which has been one of the subjects of this investigation, the chief experiences, which may serve as a guide in constructing such bulbs, may be summed up as follows: 1. The button should be as small as possible, spherical, of a smooth or polished surface, and of refractory material which withstands evaporation best. 2. The support of the button should be very thin and screened by an aluminum and mica sheet, as I have described on another occasion. 3. The exhaustion of the bulb should be as high as possible. 4. The frequency of the currents should be as high as practicable. 5. The currents should be of a harmonic rise and fall, without sudden interruptions. 6. The heat should be confined to the button by inclosing the same in a small bulb or otherwise. 7. The space between the walls of the small bulb and the outer globe should be highly exhausted.

Most of the considerations which apply to the incandescence of a solid just considered may likewise be applied to phosphorescence. Indeed, in an exhausted vessel the phosphorescence is, as a rule, primarily excited by the powerful beating of the electrode stream of atoms against the phosphorescent body. Even in many cases, where there is no evidence of such a bombardment, I think that phosphorescence is excited by violent impacts of atoms, which are not necessarily thrown off from the electrode but are acted upon from the same inductively through the medium or through chains of other atoms. That mechanical shocks play an important part in exciting phosphorescence in a bulb may be seen from the following experiment. If a bulb, constructed as that illustrated in Fig. 10, be taken and exhausted with the greatest care so that the discharge cannot pass, the filament *f* acts by electrostatic induction upon the tube *t* and the latter is set in vibration. If the tube *o* be rather wide, about an inch or so, the filament may be so powerfully vibrated that whenever it hits the glass tube it excites phosphorescence. But the phosphorescence ceases when the filament comes to rest. The vibration can be arrested and again started by varying the frequency of the currents. Now the filament has its own period of vibration, and if the frequency of the currents is such that there is resonance, it is easily set vibrating, though the potential of the currents be small. I have often observed that the filament in the bulb is destroyed by such mechanical resonance. The filament vibrates as a rule so rapidly that it cannot be seen and the experimenter may at first be mystified. When such an experiment as the one described is carefully performed, the potential of the currents need be extremely small, and for this reason I infer that the phosphorescence is then due to the mechanical shock of the filament against the glass, just as it is produced by striking a loaf of sugar with a knife. The mechanical shock produced by the projected atoms is easily noted when a bulb containing a button is grasped in the hand and the current turned on suddenly. I believe that a bulb could be shattered by observing the conditions of resonance.

In the experiment before cited it is, of course, open to say, that the glass tube, upon coming in contact with the filament, retains a charge of a certain sign upon the point of contact. If now the filament again touches the glass at the same point while it is oppositely charged, the charges equalize under evolution of light. But nothing of importance would be gained by such an explanation. It is unquestionable that the initial charges given to the atoms or to the glass play some part in exciting phosphorescence. So, for instance, if a phosphorescent bulb be first excited by a high frequency coil by connecting it to one of the terminals of the latter and the degree of luminosity be noted, and then the bulb be highly charged from a Holtz machine by attaching it preferably to the positive terminal of the machine, it is found that when the bulb is again connected to the terminal of the high frequency coil, the phosphorescence is far more intense. On another occasion I have considered the possibility of some phosphorescent phenomena in bulbs being produced by the incandescence of an infinitesimal layer on the surface of the phosphorescent body. Certainly the impact of the atoms is powerful enough to produce intense incandescence by the collisions, since they bring quickly to a high temperature a body of considerable bulk. If any such effect exists, then the best appliance for producing phosphorescence in a bulb, which we know so far, is a disruptive discharge coil giving an enormous potential with but few fundamental discharges, say 25—30 per second, just enough to produce a continuous impression upon the eye. It is a fact that such a coil excites phosphorescence under almost any condition and at all degrees of exhaustion, and I have observed effects which appear to be due to phosphorescence even at ordinary pressures of the atmosphere, when the potentials are extremely high. But if phosphorescent light is produced by the equalization of charges of electrified atoms (whatever this may mean ultimately), then the higher the frequency of the impulses or alternate electrifications, the more economical will be the light production. It is a long known and noteworthy fact that all the phosphorescent bodies are poor conductors of electricity and heat, and that all bodies cease to emit phosphorescent light when they are brought to a certain temperature. Conductors on the contrary do not possess this quality. There are but few exceptions to the rule. Carbon is one of them. Becquerel noted that carbon phosphoresces at a certain elevated temperature preceding the dark red. This phenomenon may be easily observed in bulbs provided with a rather large carbon electrode (say, a sphere of six millimetres diameter). If the current is turned on after a few seconds, a snow white film covers the electrode, just before it gets dark red. Similar effects are noted with other conducting bodies, but many scientific men will probably not attribute them to true phosphorescence. Whether true incandescence has anything to do with phosphorescence excited by atomic impact or mechanical shocks still remains to be decided, but it is a fact that all conditions, which tend to localize and increase the heating effect at the point of impact, are almost invariably the most favorable for the production of phosphorescence. So, if the electrode be very small, which is equivalent to saying in general, that the electric density is great; if the potential be high, and if the gas be highly rarefied, all of which things imply high speed of the projected atoms, or matter, and consequently violent impacts — the phosphorescence is very intense. If a bulb provided with a large and small electrode be attached to the terminal of an induction coil, the small electrode excites phosporescence while the large one may not do so, because of the smaller electric density and hence smaller speed of the atoms. A bulb provided with a large electrode may be grasped with the hand while the electrode is connected to the terminal of the coil and it may not phosphoresce; but if instead of grasping the bulb with the hand, the same be touched with a pointed wire, the phosphorescence at once spreads through the bulb, because of the great density at the point of contact. With low frequencies it seems that gases of great atomic weight excite more intense phosphorescence than those of smaller weight, as for instance, hydrogen. With high frequencies the observations are not sufficiently reliable to draw a conclusion. Oxygen, as is well-known, produces exceptionally strong effects, which may be in part due to chemical action. A bulb with hydrogen residue seems to be most easily excited. Electrodes which are most easily deteriorated produce more intense phosphorescence in bulbs, but the condition is not permanent because of the impairment of the vacuum and the deposition of the electrode matter upon the phosphorescent surfaces. Some liquids, as oils, for instance, produce magnificent effects of phosphorescence (or fluorescence?), but they last only a few seconds. So if a bulb has a trace of oil on the walls and the current is turned on, the phosphorescence only persists for a few moments until the oil is carried away. Of all bodies so far tried, sulphide of zinc seems to be the most susceptible to phosphorescence. Some samples, obtained through the kindness of Prof. Henry in Paris, were employed in many of these bulbs. One of the defects of this sulphide is, that it loses its quality of emitting light when brought to a temperature which is by no means high. It can therefore, be used only for feeble intensities. An observation which might deserve notice is, that when violently bombarded from an aluminum electrode it assumes a black color, but singularly enough, it returns to the original condition when it cools down.

The most important fact arrived at in pursuing investigations in this direction is, that in all cases it is necessary, in order to excite phosphorescence with a minimum amount of energy, to observe certain conditions. Namely, there is always, no matter what the frequency of the currents, degree of exhaustion and character of the bodies in the bulb, a certain potential (assuming the bulb excited from one terminal) or potential difference (assuming the bulb to be excited with both terminals) which produces the most economical result. If the potential be increased, considerable energy may be wasted without producing any more light, and if it be diminished, then again the light production is not as economical. The exact condition under which the best result is obtained seems to depend on many things of a different nature, and it is to be yet investigated by other experimenters, but it will certainly have to be observed when such phosphorescent bulbs are operated, if the best results are to be obtained.

Coming now to the most interesting of these phenomena, the incandescence or phosphorescence of gases, at low pressures or at the ordinary pressure of the atmosphere, we must seek the explanation of these phenomena in the same primary causes, that is, in shocks or impacts of the atoms. Just as molecules or atoms beating upon a solid body excite phosphorescence in the same or render it incandescent, so when colliding among themselves they produce similar phenomena. But this is a very insufficient explanation and concerns only the crude mechanism. Light is produced by vibrations which go on at a rate almost inconceivable. If we compute, from the energy contained in the form of known radiations in a definite space the force which is necessary to set up such rapid vibrations, we find, that though the density of the ether be incomparably smaller than that of any body we know, even hydrogen, the force is something surpassing comprehension. What is this force, which in mechanical measure may amount to thousands of tons per square inch? It is electrostatic force in the light of modern views. It is impossible to conceive how a body of measurable dimensions could be charged to so high a potential that the force would be sufficient to produce these vibrations. Long before any such charge could be imparted to the body it would be shattered into atoms. The sun emits light and heat, and so does an ordinary flame or incandescent filament, but in neither of these can the force be accounted for if it be assumed that it is associated with the body as a whole. Only in one way may we account for it, namely, by identifying it with the atom. An atom is so small, that if it be charged by coming in contact with an electrified body and the charge be assumed to follow the same law as in the case of bodies of measurable dimensions, it must retain a quantity of electricity which is fully capable of accounting for these forces and tremendous rates of vibration. But the atom behaves singularly in this respect — it always takes the same "charge".

It is very likely that resonant vibration plays a most important part in all manifestations of energy in nature. Throughout space all matter is vibrating, and all rates of vibration are represented, from the lowest musical note to the highest pitch of the chemical rays, hence an atom, or complex of atoms, no matter what its period, must find a vibration with which it is in resonance. When we consider the enormous rapidity of the light vibrations, we realize the impossibility of producing such vibrations directly with any apparatus of measurable dimensions, and we are driven to the only possible means of attaining the object of setting up waves of light by electrical means and economically, that is, to affect the molecules or atoms of a gas, to cause them to collide and vibrate. We then must ask ourselves — How can free molecules or atoms be affected?

It is a fact that they can be affected by electrostatic force, as is apparent in many of these experiments. By varying the electrostatic force we can agitate the atoms, and cause them to collide accompanied by evolution of heat and light. It is not demonstrated beyond doubt that we can affect them otherwise. If a luminous discharge is produced in a closed exhausted tube, do the atoms arrange themselves in obedience to any other but to electrostatic force acting in straight lines from atom to atom? Only recently I investigated the mutual action between two circuits with extreme rates of vibration. When a battery of a few jars (*c c c c,* Fig. 32), is discharged through a primary P of low resistance (the connections being as illustrated in Figs. 19a, 19b and 19c), and the frequency of vibration is many millions there are great differences of potential between points on the primary not more than a few inches apart. These differences may be 10,000 volts per inch, if not more, taking the maximum value of the E. M. F. The secondary *S* is therefore acted upon by electrostatic induction, which is in such extreme cases of much greater importance than the electro-dynamic. To such sudden impulses the primary as well as the secondary are poor conductors, and therefore great differences of potential may be produced by electrostatic induction between adjacent points on the secondary. Then sparks may jump between the wires and streamers become visible in the dark if the light of the discharge through the spark gap *d d* be carefully excluded. If now we substitute a closed vacuum tube for the metallic secondary *S,* the differences of potential produced in the tube by electrostatic induction from the primary are fully sufficient to excite portions of it; but as the points of certain differences of potential on the primary are not fixed, but are generally constantly changing in position, a luminous band is produced in the tube, apparently not touching the glass, as it should, if the points of maximum and minimum differences of potential were fixed on the primary. I do not exclude the possibility of such a tube being excited only by electro-dynamic induction, for very able physicists hold this view; but in my opinions, there is as yet no positive proof given that atoms of a gas in a closed tube may arrange themselves in chains under the action of an electromotive impulse produced by electro-dynamic induction in the tube. I have been unable so far to produce striae in a tube, however long, and at whatever degree of exhaustion, that is, striae at right angles to the supposed direction of the discharge or the axis of the tube; but I have distinctly observed in a large bulb, in which a wide luminous band was produced by passing a discharge of a battery through a wire surrounding the bulb, a circle of feeble luminosity between two luminous bands, one of which was more intense than the other. Furthermore, with my present experience I do not think that such a gas discharge in a closed tube can vibrate, that is, vibrate as a whole. I am convinced that no discharge through a gas can vibrate. The atoms of a gas behave very curiously in respect to sudden electric impulses. The gas does not seem to possess any appreciable inertia to such impulses, for it is a fact, that the higher the frequency of the impulses, with the greater freedom does the discharge pass through the gas. If the gas possesses no inertia then it cannot vibrate, for some inertia is necessary for the free vibration. I conclude from this that if a lightning discharge occurs between two clouds, there can be no oscillation, such as would be expected, considering the capacity of the clouds. But if the lightning discharge strike the earth, there is always vibration — in the earth, but not in the cloud. In a gas discharge each atom vibrates at its own rate, but there is no vibration of the conducting gaseous mass as a whole. This is an important consideration in the great problem of producing light economically, for it teaches us that to reach this result we must use impulses of very high frequency and necessarily also of high potential. It is a fact that oxygen produces a more intense light in a tube. Is it because oxygen atoms possess some inertia and the vibration does not die out instantly? But then nitrogen

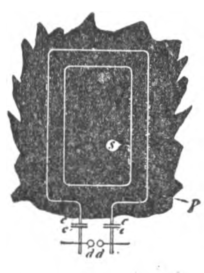


Fig. 32.

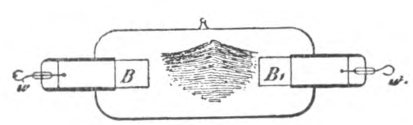


Fig. 33.

should be as good, and chlorine and vapors of many other bodies much better than oxygen, unless the magnetic properties of the latter enter prominently into play. Or, is the process in the tube of an electrolytic nature? Many observations certainly speak for it, the most important being that matter is always carried away from the electrodes and the vacuum in a bulb cannot be permanently maintained. If such process takes place in reality, then again must we take refuge in high frequencies, for, with such, electrolytic action should be reduced to a minimum, if not rendered entirely impossible. It is an undeniable fact that with very high frequencies, provided the impulses be of harmonic nature, like those obtained from an alternator, there is less deterioration and the vacua are more permanent. With disruptive discharge coils there are sudden rises of potential and the vacua are more quickly impaired, for the electrodes are deteriorated in a very short time. It was observed in some large tubes, which were provided with heavy carbon blocks B B_1, connected to platinum wires w w_1 (as illustrated in Fig. 33), and which were employed in experiments with the disruptive discharge instead of the ordinary air gap, that the carbon particles under the action of the powerful magnetic field in which the tube was placed, were deposited in regular fine lines in the middle of the tube, as illustrated. These lines were attributed to the deflection or distortion of the discharge by the magnetic field, but why the deposit occurred principally where the field was most intense did not appear quite clear. A fact of interest, likewise noted, was that the presence of a strong magnetic field increases the deterioration of the electrodes, probably by reason of the rapid interruptions it produces, whereby there is actually a higher

E. M. F. maintained between the electrodes.

Much would remain to be said about the luminous effects produced in gases at low or ordinary pressures. With the present experiences before us we cannot say that the essential nature of these charming phenomena is sufficiently known. But investigations in this direction are being pushed with exceptional ardor. Every line of scientific pursuit has its fascinations, but electrical investigation appears to possess a peculiar attraction, for there is no experiment or observation of any kind in the domain of this wonderful science which would not forcibly appeal to us. Yet to me it seems, that of all the many marvelous things we observe, a vacuum tube, excited by an electric impulse from a distant source, bursting forth out of the darkness and illuminating the room with its beautiful light, is as lovely a phenomenon as can greet our eyes. More interesting still it appears when, reducing the fundamental discharges across the gap to a very small number and

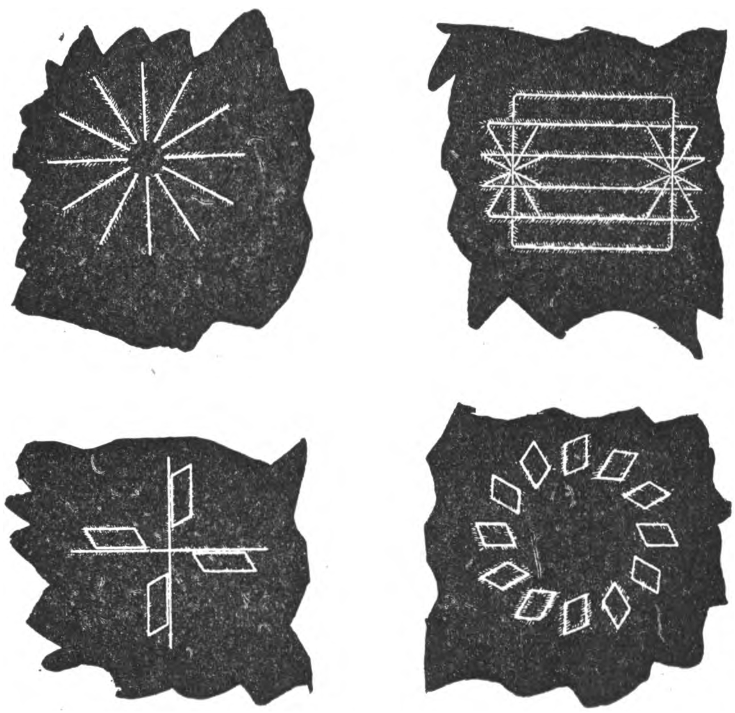


Fig. 34

waving the tube about we produce all kinds of designs in luminous lines. So by way of amusement I take a straight long tube, or a square one, or a square attached to a straight tube, and by whirling them about in the hand, I imitate the spokes of a wheel, a Gramme winding, a drum winding, an alternate current motor winding, etc (Fig. 34). Viewed from a distance the effect is weak and much of its beauty is lost, but being near or holding the tube in the hand, one cannot resist its charm.

In presenting these insignificant results I have not attempted to arrange and co-ordinate them, as would be proper in a strictly scientific investigation, in which every succeeding result should be a logical sequence of the preceding, so that it might be guessed in advance by the careful reader or attentive listener. I have preferred to concentrate my energies chiefly upon advancing novel facts or ideas which might serve as suggestions to others, and this may serve as an excuse for the lack of harmony. The explanations of the phenomena have been given in good faith and in the spirit of a student prepared to find that they admit of a better interpretation. There can be no great harm in a student taking an erroneous view, but when great minds err, the world must dearly pay for their mistakes.

5

HIGH FREQUENCY OSCILLATORS FOR ELECTRO-THERAPEUTIC AND OTHER PURPOSES*

Some theoretical possibilities offered by currents of very high frequency and observations which I casually made while pursuing experiments with alternating currents, as well as the stimulating influence of the work of Hertz and of views boldly put forth by Oliver Lodge, determined me some time during 1889 to enter a systematic investigation of high frequency phenomena, and the results soon reached were such as to justify further efforts towards providing the laboratory with efficient means for carrying on the research in this particular field, which has proved itself so fruitful since. As a consequence alternators of special design were constructed and various arrangements for converting ordinary into high frequency currents perfected, both of which were duly described and are now — I assume — familiar.

One of the early observed and remarkable features of the high frequency currents, and one which was chiefly of interest to the physician, was their apparent harmlessness which made it possible to pass relatively great amounts of electrical energy through the body of a person without causing pain or serious discomfort. This peculiarity which, together with other mostly unlooked-for properties of these currents I had the honor to bring to the attention of scientific men first in an article in a technical journal in February, 1891, and in subsequent contributions to scientific societies, made it at once evident, that these currents would lend themselves particularly to electro-therapeutic uses.

With regard to the electrical actions in general, and by analogy it was reasonable to infer that the physiological effects, however complex, might be resolved in three classes. First the statical, that is, such as are chiefly dependent on the magnitude of electrical potential; second, the dynamical, that is, those principally dependent on the quality of electrical movement or current's strength through the body, and third, effects of a distinct nature due to electrical waves or oscillations, that is, impulses in which the electrical energy is alternately passing in more or less rapid succession through the static and dynamic forms.

Most generally in practice these different actions are coexistent, but by a suitable selection of apparatus and observance of conditions the experimenter may make one or other of these effects predominate. Thus he may pass through the body, or any part of the same, currents of comparatively large volume under a small electrical pressure, or he may subject the body to a high electrical pressure while the current is negligibly small, or he may put the patient under the influence of electrical waves transmitted, if desired, at considerable distance through space.

While it remained for the physician to investigate the specific actions on the organism and indicate proper methods of treatment, the various ways of applying these currents to the body of a patient suggested themselves readily to the electrician.

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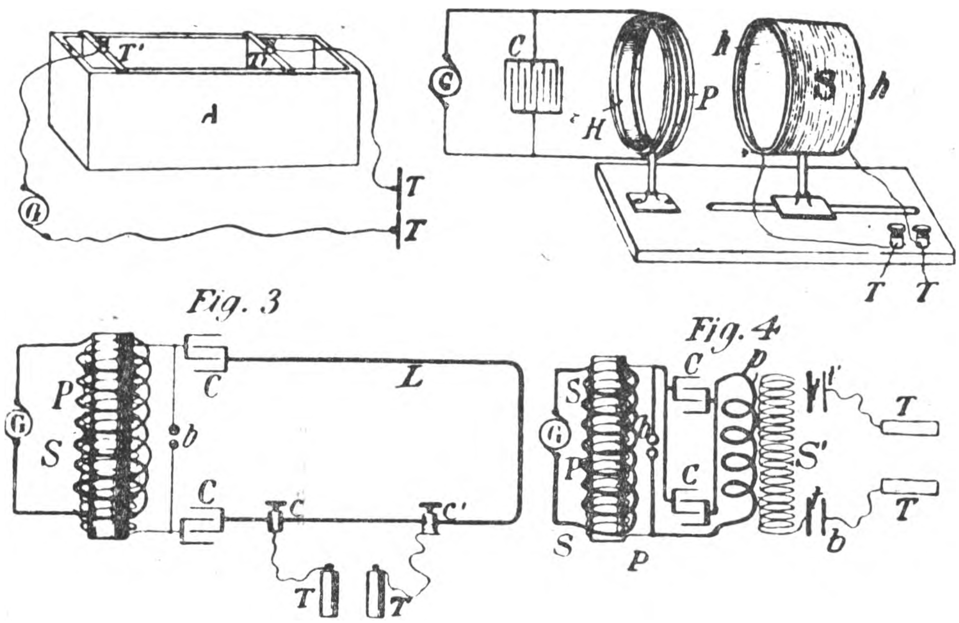
* Read at the eighth annual meeting of The American Electro-Therapeutic Association, Buffalo, N. Y., Sept. 13 to 15, 1898

As one cannot be too clear in describing a subject, a diagrammatic illustration of the several modes of connecting the circuits which I will enumerate, though obvious for the majority, is deemed of advantage.

The first and simplest method of applying the currents was to connect the body of the patient to two points of the generator, be it a dynamo or induction coil. Fig. 1 is intended to illustrate this case. The alternator G may be one giving from five to ten thousand complete vibrations per second, this number being still within the limit of practicability. The electromotive force — as measured by a hot wire instrument — may be from fifty to one hundred volts. To enable strong currents to be passed through the tissues, the terminals T T, which serve to establish contact with the patient's body should, of course, be of large area, and covered with cloth saturated with a solution of electrolyte harmless to the skin, or else the contacts are made by immersion. The regulation of the currents is best effected by means of an insulating trough A provided with two metal



Figs. 1, 2, 3, 4.

terminals T T of considerable surface, one of which, at least, should be movable. The trough is filled with water, and an electrolytic solution is added to the same, until a degree of conductivity is obtained suitable for the experiments.

When it is desired to use small currents of high tension, a secondary coil is resorted to, as illustrated in Fig. 2. I have found it from the outset convenient to make a departure from the ordinary ways of winding the coils with a considerable number of small turns. For many reasons the physician will find it better to provide a large hoop H of not less than, say, three feet in diameter and preferably more, and to wind upon it a few turns of stout cable P. The secondary coil S is easily prepared by taking two wooden hoops h h and joining them with stiff cardboard. One single layer of ordinary magnet wire, and not too thin at that, will be generally sufficient, the number of turns necessary for the particular use for which the coil is intended being easily ascertained by a few trials. Two plates of large surface, forming an adjustable condenser, may be used for the purpose of synchronizing the secondary with the primary circuit, but this is generally not necessary. In this manner a cheap coil is obtained, and one which cannot be easily injured. Additional advantages, however, will be found in the perfect regulation which is effected merely by altering the distance between the primary and secondary, for which adjustment provision should be made, and, furthermore, in the occurrence of harmonics which are more pronounced in such large coils of thick wire, situated at some distance from the primary.

The preceding arrangements may also be used with alternating or interrupted currents of low frequency, but certain peculiar properties of high frequency currents make it possible to apply the latter in ways entirely impracticable with the former.

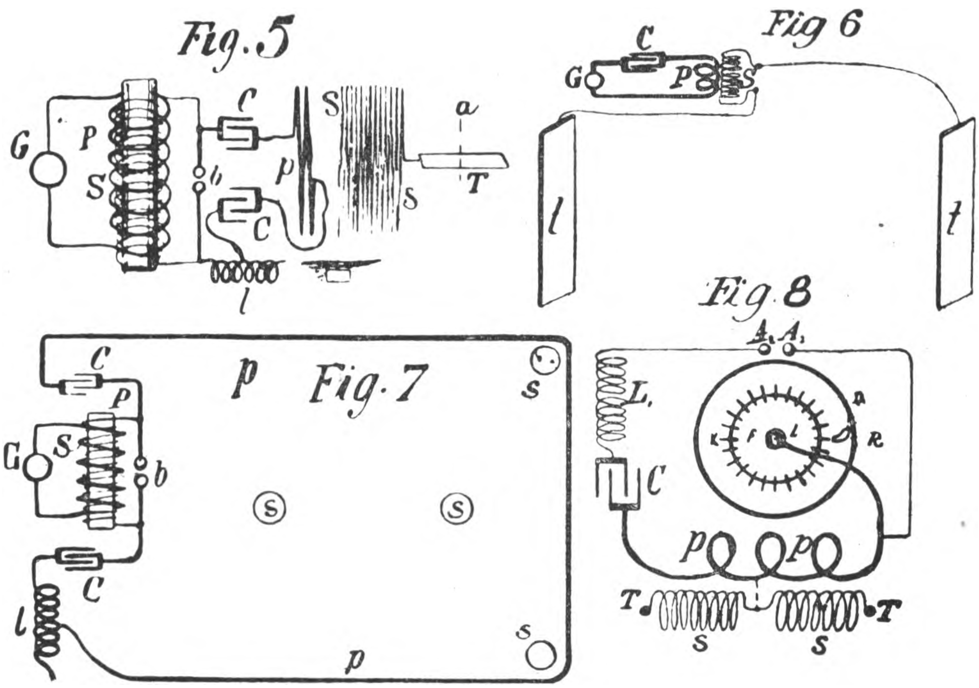
One of the prominent characteristics of high frequency or, to be more general, of rapidly varying currents, is that they pass with difficulty through stout conductors of high self-induction. So great is the obstruction which self-induction offers to their passage that it was found practicable, as shown in the early experiments to which reference has been made, to maintain differences of potential of many thousands of volts between two points — not more than a few inches apart — of a thick copper bar of inappreciable resistance. This observation naturally suggested the disposition illustrated in Fig. 3. The source of high frequency impulses is in this instance a familiar type of transformer which may be supplied from a generator G of ordinary direct or alternating currents. The transformer comprises a primary P, a secondary S, two condensers C C which are joined in series, a loop or coil of very thick wire L and a circuit interrupting device or break b. The currents are derived from the loop L by two contacts *c c,* one or both of which are capable of displacement along the wire L. By varying the distance between these contacts, any difference of potential, from a few volts to many thousands, is readily obtained on the terminals or handles T T. This mode of using the currents is entirely safe and particularly convenient, but it requires a very uniform working of the break b employed for charging and discharging the condenser.

Another equally remarkable feature of high frequency impulses was found in the facility with which they are transmitted through condensers, moderate electromotive forces and very small capacities being required to enable currents of considerable volume to pass. This observation made it practicable to resort to a plan such as indicated in Fig. 4. Here the connections are similar to those shown in the preceding case, except that the condensers C C are joined in parallel. This lowers the frequency of the currents, but has the advantage of allowing the working with a much smaller difference of potential on the terminals of the secondary S. Since the latter is the chief item of expense of such apparatus and since its price rapidly increases with the number of turns required, the experimenter will find it generally cheaper to make a sacrifice in the frequency, which, however, will be high enough for most purposes. However, he only needs to reduce proportionately the number of turns or the length of primary p to obtain the same frequency as before, but the economy of transformation will be somewhat reduced in so doing and the break b will require more attention. The secondary S’ of the high frequency coil has two metal plates t t of considerable surface connected to its terminals, and the current for use is derived from two similar plates t’ t’ in proximity to the former. Both the tension and volume of the currents taken from terminals T T may be easily regulated and in a continuous manner by simply varying the distance between the two pairs of plates t t and t’ t’ respectively.

A facility is also afforded in this disposition for raising or lowering the potential of one of the terminals T, irrespective of the changes produced on the other terminal, this making it possible to cause a stronger action on one or other part of the patient’s body.

The physician may find it for some or other reason convenient to modify the arrangements in Figs. 2, 3 and 4 by connecting one terminal of the high frequency source to the ground. The effects will be in most respects the same, but certain peculiarities will be noted in each case. When a ground connection is made it may be of some consequence which of the terminals of the secondary is connected to the ground, as in high frequency discharges the impulses of one direction are generally preponderating.

Among the various noteworthy features of these currents there is one which lends itself especially to many valuable uses. It is the facility which they afford for conveying large amounts of electrical energy to a body entirely insulated in space. The practicability of this method of energy transmission, which is already receiving useful applications and promises to become of great importance in the near future, has helped to dispel the old notion assuming the necessity of a return circuit for the conveyance of electrical



Figs. 5, 6, 7, 8.

energy in any considerable amount. With novel appliances we are enabled to pass through a wire, entirely insulated on one end, currents strong enough to fuse it, or to convey through the wire any amount of energy to an insulated body. This mode of applying high frequency currents in medical treatment appears to me to offer the greatest possibilities at the hands of the physician. The effects produced in this manner possess features entirely distinct from those observed when the currents are applied in any of the before mentioned or similar ways.

The circuit connections as usually made are illustrated schematically in Fig. 5, which, with reference to the diagrams before shown, is self-explanatory. The condensers C C, connected in series, are preferably charged by a step-up transformer, but a high frequency alternator, static machine, or a direct current generator, if it be of sufficiently high tension to enable the use of small condensers, may be used with more or less success. The primary p, through which the high frequency discharges of the condensers are passed, consists of very few turns of cable of as low resistance as possible, and the secondary s, preferably at some distance from the primary to facilitate free oscillation, has one of its ends — that is the one which is nearer to the primary — connected to the ground, while the other end leads to on insulated terminal T, with which the body of the patient is connected. It is of importance in this case to establish synchronism between the oscillations in the primary and secondary circuits p and s respectively. This will be as a rule best effected by varying the self-induction of the circuit including the primary loop or coil p, for which purpose an adjustable self-induction e is provided; but in cases when the electromotive force of the generator is exceptionally high, as when a static machine is used and a condenser consisting of merely two plates offers sufficient capacity, it will be simpler to attain the same object by varying the distance of the plates.

The primary and secondary oscillations being in close synchronism, the points of highest potential will be on a part of terminal T, and the consumption of energy will occur chiefly there. The attachment of the patient's body to the terminal will in most cases very materially affect the period of oscillation in the secondary, making it longer, and a readjustment of the primary circuit will have to be made in each case to suit the capacity of the body connected with terminal T. Synchronism should always be preserved, and the intensity of the action varied by moving the secondary coil to or from the primary, as may be desired. I know of no method which would make it possible to subject the human body to such excessive electrical pressures as are practicable with this, or of one which would enable the conveying to and giving off from the body without serious injury amounts of electrical energy approximating even in a remote degree those which are entirely practicable when this manner of applying the energy is resorted to. This is evidently due to the fact that action is chiefly superficial, the largest possible section being offered to the transfer of the current, or, to say more correctly, of the energy. With a very rapidly and smoothly working break I would not think it impossible to convey to the body of a person and to give off into the space energy at the rate of several horse power with impunity, while a small part of this amount applied in other ways could not fail to produce injury.

When a person is subjected to the action of such a coil, the proper adjustments being carefully observed, luminous streams are seen in the dark issuing from all parts of the body. These streams are short and of delicate texture when the number of breaks is very great and the action of the device b (Fig. 5) free of any irregularities, but when the number of breaks is small or the action of the device imperfect, long and noisy streams appear which cause some discomfort. The physiological effects produced with apparatus of this kind may be graduated from a hardly perceptible action when the secondary is at a great distance from the primary, to a most violent one when both coils are placed at a small distance. In the latter case only a few seconds are sufficient to cause a feeling of warmth all over the body, and soon after the person perspires freely. I have repeatedly, in demonstrations to friends, exposed myself longer to the action of the oscillations, and each time, after the lapse of an hour or so, an immense fatigue, of which it is difficult to give an idea, would take hold of me. It was greater than I experienced on some occasions after the most straining and prolonged bodily exertion. I could scarcely make a step and could keep the eyes open only with the greatest difficulty. I slept soundly afterward, and the after-effect was certainly beneficial, but the medicine was manifestly too strong to be used frequently.

One should be cautious in performing such experiments for more than one reason. At or near the surface of the skin, where the most intense action takes place, various chemical products are formed, the chief being ozone and nitrogen compounds. The former is itself very destructive, this feature being illustrated by the fact that the rubber insulation of a wire is destroyed so quickly as to make the use of such insulation entirely impracticable. The compounds of nitrogen, when moisture is present, consist largely of nitric acid which might, by excessive application, prove hurtful to the skin. So far, I have not noted injuries which could be traced directly to this cause, though on several occasions burns were produced in all respects similar to those which were later observed and attributed to the Röntgen rays. This view is seemingly being abandoned, having not been substantiated by experimental facts, and so also is the notion that these rays are transverse vibrations. But while investigation is being turned in what appears to be the right direction, scientific men are still at sea. This state of things impedes the progress of the physicist in these new regions and makes the already hard task of the physician still more difficult and uncertain.

One or two observations made while pursuing experiments with the apparatus described might be found as deserving mention here. As before stated, when the oscillations in the primary and secondary circuits are in synchronism, the points of highest potential are on some portion of the terminal T. The synchronism being perfect and the length of the secondary coil just equal to one-quarter of the wave length, these points will be exactly on the free end of terminal T, that is, the one situated farthest from the end of the wire attached to the terminal. If this be so and if now the period of the oscillations in the primary be shortened, the points of highest potential will recede towards the secondary coil, since the wave-length is reduced and since the attachment of one end of the secondary coil to the ground determines the position of the nodal points, that is, the points of least potential. Thus, by varying the period of vibration of the primary circuit in any manner, the points of highest potential may be shifted accordingly along the terminal T, which has been shown, designedly, long to illustrate this feature. The same phenomenon is, of course, produced if the body of a patient constitutes the terminal, and an assistant may by the motion of a handle cause the points of highest potential to shift along the body with any speed he may desire. When the action of the coil is vigorous, the region of highest potential is easily and unpleasantly located by the discomfort or pain experienced, and it is most curious to feel how the pain wanders up and down, or eventually across the body, from hand to hand, if the connection to the coil is accordingly made — in obedience to the movement of the handle controlling the oscillations. Though I have not observed any specific action in experiments of this kind, I have, always felt that this effect might be capable of valuable use in electro-therapy.

Another observation which promises to lead to much more useful results is the following: As before remarked, by adopting the method described, the body of a person may be subjected without danger to electrical pressures vastly in excess of any producible by ordinary apparatus, for they may amount to several million volts, as has been shown in actual practice. Now, when a conducting body is electrified to so high a degree, small particles, which may be adhering firmly to its surface, are torn off with violence and thrown to distances which can be only conjectured. I find that not only firmly adhering matter, as paint, for instance, is thrown off, but even the particles of the toughest metals are torn off. Such actions have been thought to be restricted to a vacuous inclosure, but with a powerful coil they occur also in the ordinary atmosphere. The facts mentioned would make it reasonable to expect that this extraordinary effect which, in other ways, I have already usefully applied, will likewise prove to be of value in electro-therapy. The continuous improvement of the instruments and the study of the phenomenon may shortly lead to the establishment of a novel mode of hygienic treatment which would permit an instantaneous cleaning of the skin of a person, simply by connecting the same to, or possibly, by merely placing the person in the vicinity of a source of intense electrical oscillations, this having the effect of throwing off, in a twinkle of the eye, dust or particles of any extraneous matter adhering to the body. Such a result brought about in a practicable manner would, without doubt, be of incalculable value in hygiene and would be an efficient and time-saving substitute for a water bath, and particularly appreciated by those whose contentment consists in undertaking more than they can accomplish.

High frequency impulses produce powerful inductive actions and in virtue of this feature they lend themselves in other ways to the uses of the electro-therapeutist. These inductive effects are either electrostatic or electrodynamic. The former diminish much more rapidly with the distance — with the square of the same — the latter are reduced simply in proportion to the distance. On the other hand, the former grow with the square of intensity of the source, while the latter increase in a simple proportion with the intensity. Both of these effects may be utilized for establishing a field of strong action extending through considerable space, as through a large hall, and such an arrangement might be suitable for use in hospitals or institutions of this kind, where it is desirable to treat a number of patients at the same time.

Fig. 6 illustrates the manner, as I have shown it originally, in which such a field of electrostatic action is established. In this diagram G is a generator of currents of very high frequency, C a condenser for counteracting the self-induction of the circuit which includes the primary P of an induction coil, the secondary S of which has two plates *t t* of large surface connected to its terminals. Well known adjustments being observed, a very strong action occurs chiefly in the space between the plates, and the body of a person

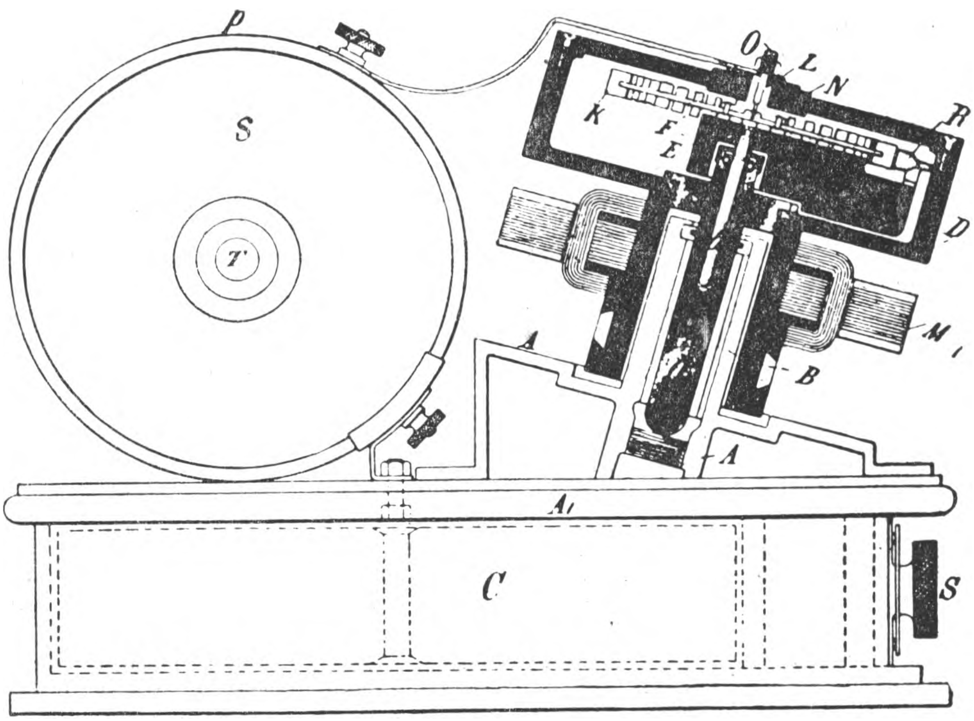


Fig. 9.

is subjected to rapid variations of potential and surgings of current, which produce, even at a great distance, marked physiological effects. In my first experiments I used two metal plates as shown, but later I found it preferable to replace them by two large hollow spheres of brass covered with wax of a thickness of about two inches. The cables leading to the terminals of the secondary coil were similarly covered, so that any of them could be approached without danger of the insulation breaking down. In this manner the unpleasant shocks, to which the experimenter was exposed when using the plates, were prevented.

In Fig. 7 a plan for similarly utilizing the dynamic inductive effects of high frequency currents is illustrated. As the frequencies obtainable from an alternator are not as high as is desired, conversion by means of condensers is resorted to. The diagram will be understood at a glance from the foregoing description. It only need be stated that the primary p, through which the condensers are made to discharge, is formed by a thick stranded cable of low self-induction and resistance, and passes all around the hall. Any number of secondary coils s s s, each consisting generally of a single layer of rather thick wire, may be provided. I have found it practicable to use as many as one hundred, each being adjusted for a definite period and responding to a particular vibration passed through the primary. Such a plant I have had in use in my laboratory since 1892, and many times it has contributed to the pleasure of my visitors and also proved itself of practical utility. On a latter occasion I had the pleasure of entertaining some of the members with experiments of this kind, and this opportunity I cannot let pass without expressing my thanks for the interest which was awakened in me by their visit, as well as for the generous acknowledgment of the courtesy by the Association. Since that time my apparatus has been very materially improved, and now I am able to create a field of such intense induction in the laboratory that a coil three feet in diameter, by careful adjustment, will deliver energy at the rate of one-quarter of a horse power, no matter where it is placed within the area inclosed by the primary loops. Long sparks, streamers and all other phenomena obtainable with induction coils are easily producible anywhere within the space, and such coils, though not connected to anything, may be utilized exactly as ordinary coils, and what is still more remarkable, they are more effective. For the past few years I have often been urged to show experiments in public, but, though I was desirous to comply with such requests, pressing work has so far made it impossible. These advances have been the result of slow but steady improvement in the details of the apparatus which I hope to be able to describe connectedly in the near future.

However remarkable the electrodynamic inductive effects, which I have mentioned, may appear, they may be still considerably intensified by concentrating the action upon a very small space. It is evident that since, as before stated, electromotive forces of many thousand volts are maintained between two points of a conducting bar or loon only a few inches long, electromotive forces of approximately the same magnitude will be set up in conductors situated near by. Indeed, I found that it was practicable in this manner to pass a discharge through a highly exhausted bulb, although the electromotive force required amounted to as much as ten or twenty thousand volts, and for a long time I followed no experiments in this direction with the object of producing light in a novel and more economical way. But the tests left no doubt that there was great energy consumption attendant to this mode of illumination, at least with the apparatus I had then at command, and, finding another method which promised a higher economy of transformation, my efforts turned in this new direction. Shortly afterward (some time in June, 1891), Prof. J. J. Thomson described experiments which were evidently the outcome of long investigation, and in which he supplied much novel and interesting information, and this made me return with renewed zeal to my own experiments. Soon my efforts were centered upon producing in a small space the most intense inductive action, and by gradual improvement in the apparatus I obtained results of a surprising character. For instance, when the end of a heavy bar of iron was thrust within a loon powerfully energized, a few moments were sufficient to raise the bar to a high temperature. Even heavy lumps of other metals were heated as rapidly as though they were placed in a furnace. When a continuous band formed of a sheet of tin was thrust into the loop, the metal was fused instantly, the action being comparable to an explosion, and no wonder, for the frictional losses accumulated in it at the rate of possibly ten horse power. Masses of poorly conducting material behaved similarly, and when a highly exhausted bulb was pushed into the loop, the glass was heated in a few seconds nearly to the point of melting.

When I first observed these astonishing actions, I was interested to study their effects upon living tissues, As may be assumed, I proceeded with all the necessary caution, and well I might, for I had the evidence that in a turn of only a few inches in diameter an electromotive force of more than ten thousand volts was produced, and such high pressure would be more than sufficient to generate destructive currents in the tissue. This appeared all the more certain as bodies of comparatively poor conductivity were rapidly heated and even partially destroyed. One may imagine my astonishment when I found that I could thrust my hand or any other part of the body within the loop and hold it there with impunity. More than on one occasion, impelled by a desire to make some novel and useful observation, I have willingly or unconsciously performed an experiment connected with some risk, this being scarcely avoidable in laboratory experience, but have always believed, and do so now, that I have never undertaken anything in which, according to my own estimation, the chances of being injured were so great as when I placed my head within the space in which such terribly destructive forces were at work. Yet I have done so, and repeatedly, and have felt nothing. But I am firmly convinced that there is great danger attending such experiment, and some one going just a step farther than I have gone may be instantly destroyed. For, conditions may exist similar to those observable with a vacuum bulb. It may be placed in the field of the loop, however intensely energized, and so long as no path for the current is formed, it will remain cool and consume practically no energy. But the moment the first feeble current passes, most of the energy of the oscillations rushes to the place of consumption. If by any action whatever, a conducting path were formed within the living tissue or bones of the head, it would result in the instant destruction of these and death of the foolhardy experimenter. Such a method of killing, if it were rendered practicable, would be absolutely painless. Now, why is it that in a space in which such violent turmoil is going on living tissue remains uninjured? One might say the currents cannot pass because of the great self-induction offered by the large conducting mass. But this it cannot be, because a mass of metal offers a still higher self-induction and is heated just the same. One might argue the tissues offer too great a resistance. But this again cannot be the reason, for all evidence shows that the tissues conduct well enough, and besides, bodies of approximately the same resistance are raised to a high temperature. One might attribute the apparent harmlessness of the oscillations to the high specific heat of the tissue, but even a rough quantitative estimate from experiments with other bodies shows that this view is untenable. The only plausible explanation I have so far found is that the tissues are condensers. This only can account for the absence of injurious action. But it is remarkable that, as soon as a heterogeneous circuit is constituted, as by taking in the hands a bar of metal and forming a closed loop in this manner, the passage of the currents through the arms is felt, and other physiological effects are distinctly noted. The strongest action is, of course, secured when the exciting loop makes only one turn, unless the connections take up a considerable portion of the total length of the circuit, in which case the experimenter should settle upon the least number of turns by carefully estimating what he loses by increasing the number of turns, and what he gains by utilizing thus a greater proportion of the total length of the circuit. It should be borne in mind that, when the exciting coil has a considerable number of turns and is of some length, the effects of electrostatic induction may preponderate, as there may exist a very great difference of potential — a hundred thousand volts or more — between the first and last turn. However, these latter effects are always present even when a single turn is employed.

When a person is placed within such a loop, any pieces of metal, though of small bulk, are perceptibly warmed. Without doubt they would be also heated — particularly if they were of iron — when embedded in Jiving tissue, and this suggests the possibility of surgical treatment by this method. It might be possible to sterilize wounds, or to locate, or even to extract metallic objects, or to perform other operations of this kind within the sphere of the surgeon's duties in this novel manner.

Most of the results enumerated, and many others still more remarkable, are made possible only by utilizing the discharges of a condenser. It is probable that but a very few — even among those who are working in these identical fields — fully appreciate what a wonderful instrument such a condenser is in reality. Let me convey an idea to this effect. One may take a condenser, small enough to go in one's vest pocket, and by skilfully using it he may create an electrical pressure vastly in excess — a hundred times greater if necessary — than any producible by the largest static machine ever constructed. Or, he may take the same condenser and, using it in a. different way, he may obtain from it currents against which those of the most powerful welding machine are utterly insignificant. Those who are imbued with popular notions as to the pressure of static machines and currents obtainable with a commercial transformer, will be astonished at this statement — yet the truth of it is easy to see. Such results are obtainable, and easily, because the condenser can discharge the stored energy in an inconceivably short time. Nothing like this property is known in physical science. A compressed spring, or a storage battery, or any other form of device capable of storing energy, cannot do this; if they could, things undreamt of at present might be accomplished by their means. The nearest approach to a charged condenser is a high explosive, as dynamite. But even the most violent explosion of such a compound bears no comparison with the discharge or explosion of a condenser. For, while the pressures which are produced in the detonation of a chemical compound are measured in tens of tons per square inch, those which may be caused by condenser discharges may amount to thousands of tons per square inch, and if a chemical could be made which would explode as quickly as a condenser can be discharged under conditions which are realizable — an ounce of it would quite certainly be sufficient to render useless the largest battleship.

That important realizations would follow from the use of an instrument possessing such ideal properties I have been convinced since long ago, but I also recognized early that great difficulties would have to be overcome before it could replace less perfect implements now used in the arts for the manifold transformations of electrical energy. These difficulties were many. The condensers themselves, as usually manufactured, were inefficient, the conductors wasteful, the best insulation inadequate, and the conditions for the most efficient conversion were hard to adjust and to maintain. One difficulty, however, which was more serious than the others, and to which I called attention when I first described this system of energy transformation, was found in the devices necessarily used for controlling the charges and discharges of the condenser. They were wanting in efficiency and reliability and threatened to prove a decided drawback, greatly restricting the use of the system and depriving it of many valuable features. For a number of years I have tried to master this difficulty. During this time a great number of such devices were experimented upon. Many of them promised well at first, only to prove inadequate in the end. Reluctantly, I came back upon an idea on which I had worked long before. It was to replace the ordinary brushes and commutator segments by fluid contacts. I had encountered difficulties then, but the intervening years in the laboratory were not spent in vain, and I made headway. First it was necessary to provide for a circulation of the fluid, but forcing it through by a pump proved itself impractical. Then the happy idea presented itself to make the pumping device an integral part of the circuit interrupter, inclosing both in a receptacle to prevent oxidation. Next some simple ways of maintaining the circulation, as by rotating a body of mercury, presented themselves. Then I learned how to reduce the wear and losses which still existed. I fear that these statements, indicating how much effort was spent in these seemingly insignificant details will not convey a high idea of my ability, but I confess that my patience was taxed to the utmost. Finally, though, I had the satisfaction of producing devices which are simple and reliable in their operation, which require practically no attention and which are capable of effecting a transformation of considerable amounts of energy with fair economy. It is not the best that can be done, by any means, but it is satisfactory, and I feel that the hardest task is done.

The physician will now be able to obtain an instrument suitable to fulfil many requirements. He will be able to use it in electro-therapeutic treatment in most of the ways enumerated. He will have the facility of providing himself with coils such as he may desire to have for any particular purpose, which will give him any current or any pressure he may wish to obtain. Such coils will consist of but a few turns of wire, and the expense of preparing them will be quite insignificant. The instrument will also enable him to generate Röntgen rays of much greater power than obtainable with ordinary apparatus. A tube must still be furnished by the manufacturers which will not deteriorate and which will allow to concentrate larger amounts of energy upon the electrodes. When this is done, nothing will stand in the way of an extensive and efficient application of this beautiful discovery which must ultimately prove itself of the highest value, not only at the hands of the surgeon, but also of the electro-therapist and, what is most important, of the bacteriologist.

To give a general idea of an instrument in which many of the latter improvements are embodied, I would refer to Fig. 9. which illustrates the chief parts of the same in side elevation and partially in vertical cross-section. The arrangement of the parts is the same as in the form of instrument exhibited on former occasions, only the exciting coil with the vibrating interrupter is replaced by one of the improved circuit breakers to which reference has been made.

This device comprises a casting A with a protruding sleeve B, which in a bushing supports a freely rotatable shaft a. The latter carries an armature within a stationary field magnet M and on the top, a hollow iron pulley D, which contains the break proper. Within the shaft a, and concentrically with the same, is placed a smaller shaft b, likewise freely movable on ball-bearings and supporting a weight E. This weight being on one side and the shafts a and b inclined to the vertical, the weight remains stationary as the pulley is rotated. Fastened to the weight E is a device R in the form of a scoop with very thin walls, narrow on the end nearer to the pulley and wider on the other end. A small quantity of mercury being placed in the pulley and the latter rotated against the narrow end of the scoop, a portion of the fluid is taken up and thrown in a thin and wide stream towards the centre of the pulley. The top of the latter is hermetically closed by an iron washer, as shown, this washer supporting on a steel rod L a disk F of the same metal provided with a number of thin contact blades K. The rod L is insulated by washers N from the pulley, and for the convenience of filling in the mercury a small screw *o* is provided. The bolt L forming one terminal of the circuit breaker is connected by a copper strip to the primary p. The other end of the primary coil leads to one of the terminals of the condenser C, contained in a compartment of a box A, another compartment of the same being, reserved for switch S and terminals of the instrument. The other terminal of the condenser is connected to the casting A and through it to pulley D. When the pulley is rotated, the contact blades K are brought rapidly in and out of contact with the stream of mercury, thus closing and opening the circuit in quick succession. With such a device it is easy to obtain ten thousand makes and breaks per second and even more. The secondary a is made of two separate coils and so arranged that it can be slipped out, and a metal strip in its middle connects it to the primary coil. This is done to prevent the secondary from breaking down when one of the terminals is overloaded, as it often happens in working Röntgen bulbs. This form of coil will withstand a very much greater difference of potential than coils as ordinarily constructed.

The motor has both field and armature built of plates, so that it can be used on alternating as well as direct current supply circuits, and the shafts are as nearly as possible vertical, so as to require the least care in oiling. Thus, the only thing which really requires some attention is the commutator of the motor, but where alternating currents are always available, this source of possible trouble is easily done away with.

The circuit connections of the instrument have been already shown and the mode of operation explained in periodicals. The usual manner of connecting is illustrated in Fig. 8, in which A_2 A_2 are the terminals of the supply circuit, L, a self-induction coil for raising the pressure, which is connected in series with condenser C and primary P P. The remaining letters designate the parts correspondingly marked in Fig. 9 and will be understood with reference to the latter.

PATENTS

I
MOTORS AND GENERATORS

UNITED STATES PATENT OFFICE.

NIKOLA TESLA, OF SMILJAN LIKA, AUSTRIA-HUNGARY, ASSIGNOR TO THE TESLA ELECTRIC LIGHT AND MANUFACTURING COMPANY, OF RAHWAY, NEW JERSEY

COMMUTATOR FOR DYNAMO-ELECTRIC MACHINES.

SPECIFICATION forming part of Letters Patent No. 334.823. dated January 26. 1886.

Application filed May 6. 1885. Serial No. 164.534. (No model.)

To all whom it may concern:

Be it known that I, NIKOLA TESLA, of Smiljan Lika, border country of Austria Hungary, have invented an Improvement in Dynamo Electric Machines, of which the following is a specification.

My invention relates to the commutators on dynamo electric machines, especially in machines of great electromotive force, adapted to arc lights; and it consists in a device by means of which the sparking on the commutator is prevented.

It is known that in machines of great electromotive force—such, for instance, as those used for arc lights—whenever one commutator bar or plate comes out of contact with the collecting brush a spark appears on the commutator. This spark may be due to the break of the complete circuit, or of a shunt of low resistance formed by the brush between two or more commutator bars. In the first case the spark is more apparent, as there is at the moment when the circuit is broken a discharge of the magnets through the field-helices, producing a great spark or flash which causes an unsteady current, rapid wear of the commutator bars and brushes, and waste of power. The sparking may be reduced by various devices, such as providing a path for the current at the moment when the commutator segment or bar leaves the brush, by short-circuiting the field-helices, by increasing the number of the commutator-bars, or by other similar means; but all these devices are expensive or not fully available, and seldom attain the object desired.

My invention enables me to prevent the sparking in a simple manner. For this purpose I employ with the commutator-bars and intervening insulating material mica, asbestos paper or other insulating and preferably incombustible material, which I arrange to bear on the surface of the commutator, near to and behind the brush.

My invention will be easily understood by reference to the accompanying drawings.

In the drawings, Figure 1 is a section of a commutator with an asbestos insulating device; and Fig. 2 is, a similar view, representing two plates of mica upon the back of the brush.

In Fig. 1, C represents the commutator and intervening insulating material; B B, the brushes, *d d* are sheets of asbestos paper or other suitable non-conducting material. *f f* are springs, the pressure of which may be adjusted by means of the screws *g g*.

In Fig. 2 a simple arrangement, is shown with two plates of mica or other material. It will be seen that whenever one commutator-segment passes out of contact with the brush the formation of the are will be prevented by the intervening insulating material coming in contact with the insulating material on the brush.

My invention may be carried out in many ways; and I do not limit myself to any particular device, as my invention consists, broadly, in providing a solid non-conducting body to bear upon the surface of the commutator, by the intervention of which body the sparking is partly or completely prevented.

I prefer to use asbestos paper or cloth impregnated with zinc-oxide, magnesia, zirconia, or other suitable material, as the paper and cloth are soft, and serve at the same time to wipe and polish the commutator; but mica or any other suitable material may be employed, said material being an insulator or a bad conductor of electricity.

My invention may be applied to any electric apparatus in which sliding contacts are employed.

I claim as my invention—

1. The combination, with the commutator-bars and intervening insulating material and brushes in a dynamo electric machine, of a solid insulator or bad conductor of electricity arranged to bear upon the surface of the commutator adjacent to the end of the brush, for the purpose set forth.

2. In an electric apparatus in which sliding contacts with intervening insulating material are employed, the combination, with the contact springs or brushes, of a solid insulator or bad conductor of electricity, as and for the purposes set forth.

Signed by me this 2d day of May, A. D. 1885.

NIKOLA TESLA.

Witnesses:

GEO. T. PINCKNEY

WILLIAM G. MOTT.

P-6

(No Model)

N. TESLA

COMMUTATOR FOR DYNAMO ELECTRIC MACHINES.

No. 334,823. Patented Jan 26, 1886.

Fig 1

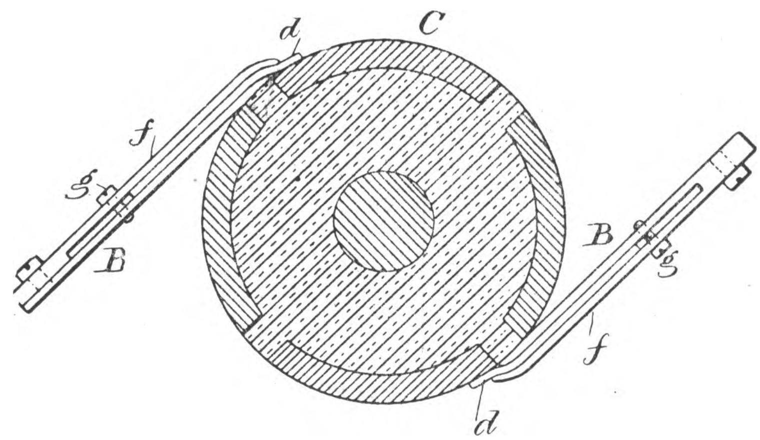
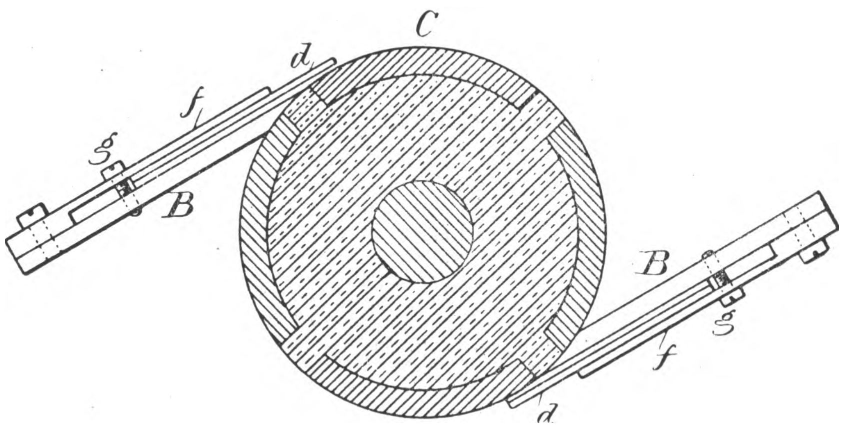


Fig 2



Witnesses
Chas H. Smith
J. Staib

Inventor
Nikola Tesla
per Lemuel W. Serrell
atty

UNITED STATES PATENT OFFICE.

NIKOLA TESLA, OF SMILJAN LIKA, AUSTRIA HUNGARY, ASSIGNOR TO THE TESLA ELECTRIC LIGHT AND MANUFACTURING COMPANY OF RAHWAY, NEW JERSEY.

REGULATOR FOR DYNAMO-ELECTRIC MACHINES.

SPECIFICATION forming part of Letters Patent No. 336,961, dated March 2, 1886.

Application filed May 18, 1865. Serial No. 165,793. (No model.)

To all whom it may concern:

Be it known that I, NIKOLA TESLA, of Smiljan Lika, border country of Austria-Hungary, have invented an Improvement in Dynamo-Electric Machines, of which the following is a specification.

The object of my invention is to provide an improved method for regulating the current on dynamo-electric machines.

In my improvement I make use of two main brushes, to which the ends of the helices of the field-magnets are connected, and an auxiliary brush and a branch or shunt connection from an intermediate point of the field-wire to the auxiliary brush.

The relative positions of the respective brushes are varied, either automatically or by hand, so that the shunt becomes inoperative when the auxiliary brush has a certain position upon the commutator; but when said auxiliary brush is moved in its relation to the main brushes, or the latter are moved in their relation to the auxiliary brush, the electric condition is disturbed and more or less of the current through the field-helices is diverted through the shunt or a current passed over said shunt to the field-helices.

By varying the relative position upon the commutator of the respective brushes automatically in proportion to the varying electrical conditions of the working-circuit the current developed can be regulated in proportion to the demands in the working-circuit.

Devices for automatically moving the brushes in dynamo-electric machines are well known, and those made use of in my machine may be of any desired or known character.

In the drawings, Figure 1 is a diagram illustrating my invention, showing one core of the field-magnets with one helix wound in the same direction throughout. Figs. 2 and 3 are diagrams showing one core of the field-magnets with a portion of the helices wound in opposite directions. Figs. 4 and 5 are diagrams illustrating the electric devices that may be employed for automatically adjusting the brushes, and Fig. 6 is a diagram illustrating the positions of the brushes when the machine is being energized on the start.

a and *b* are the positive and negative brushes of the main or working circuit, and c the auxiliary brush. The working-circuit D extends from the brushes a and *b,* as usual, and contains electric lamps or other devices, D', either in series or in multiple arc.

M M' represent the field-helices, the ends of which are connected to the main brushes a and *b*. The branch or shunt wire *c'* extends from the auxiliary brush c to the circuit of the field-helices, and is connected to the same at an intermediate point, X.

H represents the commutator, with the plates of ordinary construction. It is now to be understood that when the auxiliary brush *c* occupies such a position upon the commutator that the electro-motive force between the brushes *a* and c is to the electro motive force between the brushes c and *b* as the resistance of the circuit *a* M' *c' c* A to the resistance of the circuit *b* M' *c' c* B, the potentials of the points X and Y will be equal, and no current will flow over the auxiliary brush; but when the brush c occupies a different position the potentials of the points X and Y will be different, and a current will flow over the auxiliary brush to or from the commutator, according to the relative, position of the brushes. If, for instance, the commutator-space between the brushes a and *c,* when the latter is at the neutral point, is diminished, a current will flow from the point Y over the shunt C to the brush b, thus strengthening the current in the part M', and partly neutralizing the current in the part M; but if the space between the brushes a and c is increased, the current will flow over the auxiliary brush in an opposite direction, and the current in M will be strengthened, and in M' partly neutralized.

By combining with the brushes *a, b,* and c any known automatic regulating mechanism the current, developed can be regulated in proportion to the demands in the working-circuit. The parts M and M' of the field-wire may be wound in the same direction. (In this case they are arranged as shown in Fig. l; or, the part M may be wound in the opposite direction, as shown in Figs. 2 and 3.)

It will be apparent that the respective cores of the field-magnets are subjected to the neutralizing or intensifying effects of the current in the shunt through c', and the magnetism of the cores will be partially neutralized or the point of greatest magnetism shifted, so that it will be more or less remote from or approaching to the armature, and hence the aggregate energizing actions of the field magnets on the armature will be correspondingly varied.

In the form indicated in Fig. 1 the regulation is effected by shifting the point of great est magnetism, and in Figs. 2 and 3 the same effect is produced by the action of the current in the shunt passing through the neutralizing helix.

The relative positions of the respective brushes may be varied by moving the auxiliary brush or the brush *c* may remain quiescent and the core *p* be connected to the main-brush holder A', so as to adjust the brushes *a b* in their relation to the brush *c*. If, however, an adjustment is applied to all the brushes, as seen in Fig. 5, the solenoid should be connected to both A and C, so as to move them toward or away from each other.

There are several known devices for giving motion in proportion to an electric current. I have shown the moving cores in Figs. 4 and 5 as convenient devices for obtaining the required extent of motion with very slight changes in the current passing through the helices. It is understood that the adjustment of the main brushes causes variations in the Strength of the current independently of the relative position of said brushes to the auxiliary brush. In all cases the adjustment may be such that no current flows over the auxiliary brush when the dynamo is running with its normal load.

In Figs. 4 and 5, A A indicate the main-brush bolder, carrying the main brushes, and C the auxiliary brush holder, carrying the auxiliary brush. These brush-holders are movable in arcs concentric with the center of the commutator shaft. An iron piston, P, of the solenoid S. Fig. 4, is attached to the auxiliary-brush holder C. The adjustment is effected by means of a spring and screw or tightener.

In Fig. 5, instead of a solenoid, an iron tube inclosing a coil is shown. The piston of the coil is attached to both brush holders A A and C. When the brushes are moved directly by electrical devices, as shown in Figs. 4 and 5, these are so constructed that the force exerted for adjusting is practically uniform through the whole length of motion.

I am aware that auxiliary brushes have been used in connection with the helices of the field-wire; but in these instances the helices received the entire current through the auxiliary brush or brushes, and said brushes could not be taken off without breaking the circuit through the field. These brushes caused, however, a great sparking upon the commutator. In my improvement the auxiliary brush causes very little or no sparking, and can be taken off without breaking the circuit through the field helices.

My improvement has, besides, the advantage to facilitate the self exciting of the machine in all cases where the resistance of the field-wire is very great comparatively to the resistance of the main circuit at the start—for instance, on arc light machines. In this case I place the auxiliary brush *c* near to or in preference in contact with the brush *b*, as shown in Fig. 6. In this manner the part M' is completely cut out, and as the part M has a considerably smaller resistance than the whole length of the field-wire the machine excites itself, whereupon the auxiliary brush is shifted automatically to its normal position.

I claim as my invention—

The combination, with the commutator having two or more main brushes and an auxiliary brush, of the field-helices having their ends connected to the main brushes, and a branch or shunt connection from an intermediate point of the field-helices to the auxiliary brush, and means for varying the relative position upon the commutator of the respective brushes, substantially as set forth.

Signed by me this 13th day of May, A. D. 1885.

NIKOLA TESLA.

Witnesses:
GEO. T. PINCKNEY,
WALLACE L. SERRELL.

(No Model.) 2 Sheets — Sheet 1.

N. TESLA

REGULATOR FOR DYNAMO ELECTRIC MACHINES.

No. 336,961 Patented Mar. 2, 1886,

Fig. 1

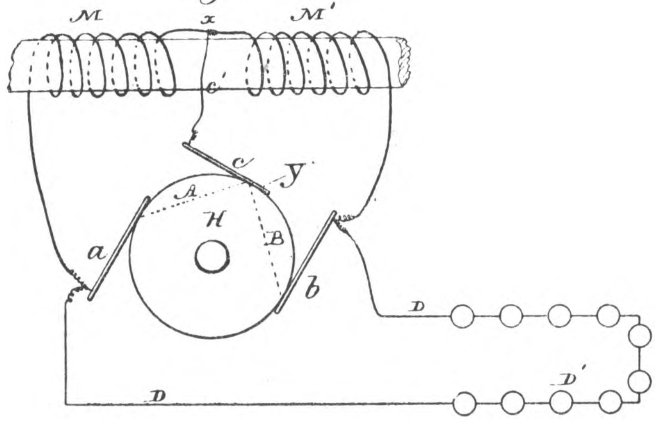


Fig 2

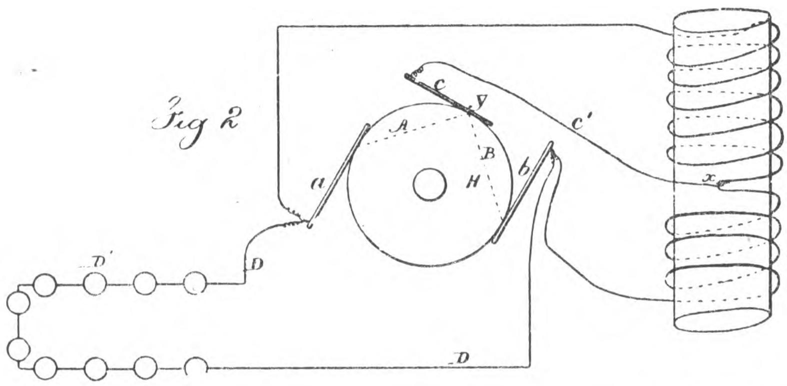
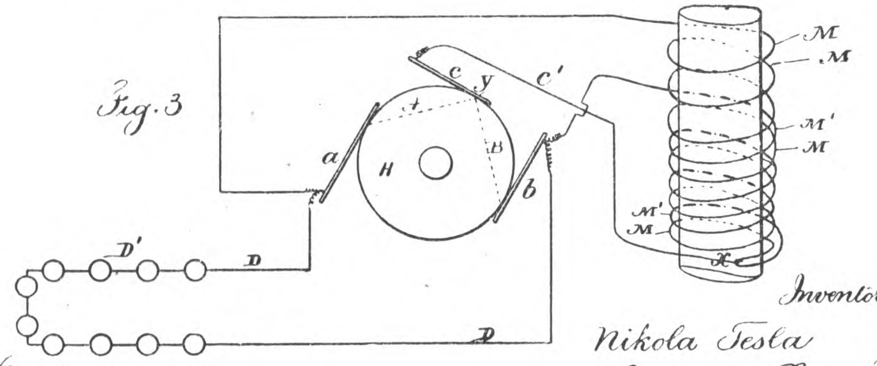


Fig. 3



Witnesses Chas H. Smith
Geo T Pinckney

Inventor
Nikola Tesla
per Lemuel W. Serrell Atty

P-10

(No Model.)

2 Sheets — Sheet 2.

N TESLA.

REGULATOR FOR DYNAMO ELECTRIC MACHINES.

No. 336,961.

Patented Mar. 2, 1886

Fig. 4

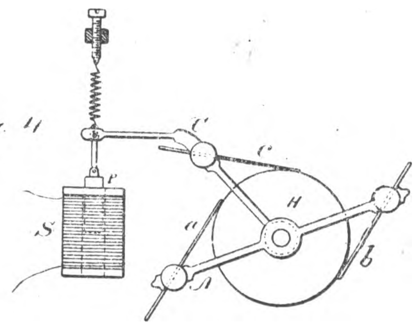


Fig. 5.

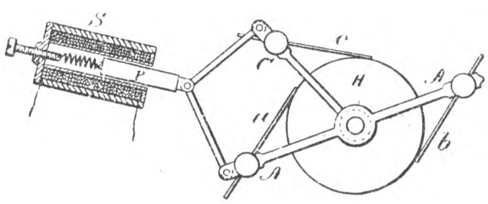
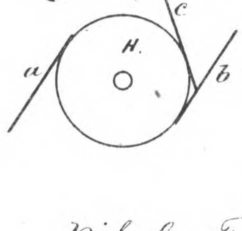


Fig. 6



Witnesses

Chas H Smith

J Staib

Inventor

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per Lemuel W Serrell

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UNITED STATES PATENT OFFICE.

NIKOLA TESLA, OF SMILJAN LIKA, AUSTRIA HUNGARY, ASSIGNOR TO THE TESLA ELECTRIC LIGHT AND MANUFACTURING COMPANY, OF RAHWAY, NEW JERSEY.

REGULATOR FOR DYNAMO - ELECTRIC MACHINES.

SPECIFICATION forming part of Letters Patent No. 336,962, dated March 2, 1886

Application filed June 1. 1883. Serial No. 107,110. (No model.)

To all whom it may concern:

Be it known that I, NIKOLA TESLA, of Smiljan Lika, border country of Austria-Hungary, have invented an Improvement in Dynamo-Electric Machines, of which the following is a specification.

My invention is designed to provide an improved method for regulating the current in dynamo-electric machines.

In another application, No. 165,793, filed by me May 18, 1885, I have shown a method for regulating the current in a dynamo having the field-helices in a shunt. My present application relates to a dynamo having its field-helices connected in the main circuit.

In my improvement I employ one or more auxiliary brushes, by means of which I shunt a portion or the whole of the field helices. According to the relative position upon the commutator of the respective brushes more or less current is caused to pass through the helices of the field, and the current developed by the machine can be varied at will by varying the relative positions of the brushes.

In the drawings the present invention is illustrated by diagrams, which are hereinafter separately referred to.

In Figure 1, *a* and *b* are the positive and negative brushes of the main circuit, and *c* an auxiliary brush. The main circuit D extends from the brushes *a* and *b,* as usual, and contains the helices M of the field-wire and the electric lamps or other working devices. The auxiliary brush *c* is connected to the point *x* of the main circuit by means of the wire *c'*.

H is a commutator of ordinary construction.

From that which has been said in the application above referred to it will be seen that when the electro motive force between the brushes *a* and *c* is to the electro-motive force between the brushes *c* and *b* as the resistance of the circuit *a* M *c' c* A to the resistance of the circuit *b* C B *c c'* D, the potentials of the points *x* and *y* will be equal, and no current will pass over the auxiliary brush *c;* but if said brush occupies a different position relatively to the main brushes the electric condition is disturbed, and current will flow either from *y* to *x* or from *x* to *y,* according to the relative position of the brushes. in the first case the current through the field-helices will be partly neutralized and the magnetism *of* the field-magnets diminished. In the second case the current will be increased and the magnets will gain strength. By combining with the brushes *a b c* any automatic regulating mechanism the current developed can be regulated automatically in proportion to the demands in the working-circuit.

In Figs. 6 and 7 I have represented some of the automatic means that may be used for moving the brushes. The core P, Fig. 6, of the solenoid helix S, is connected with the brush *c* to move the same, and in Fig. 7 the core P is shown as within the helix 8, and connected with both brushes *a* and *c,* so as to move the same toward or from each other, according to the strength of the current in the helix, the helix being within an iron tube, S', that becomes magnetized and increases the action of the solenoid.

In practice it is sufficient to move only the auxiliary brush, as shown in Fig. 6, as the regulation is very sensitive to the slightest changes; but the relative position of the auxiliary brush to the main brushes maybe varied by moving the main brushes, or both main and auxiliary brushes may be moved, as illustrated in Fig. 7. In the latter two eases, it will be understood, the motion of the main brushes relatively to the neutral hue of the machine causes variations in the strength of the current independently of their relative position to the auxiliary brush. In all cases the adjustment may be such that when the machine is running with the ordinary load no current flows over the auxiliary brush.

The field-helices may be connected as shown in Fig. 1, or a part of the field-helices may be in the outgoing and the other part in the return circuit, and two auxiliary brushes may be employed as shown in Figs. 3 and 4. Instead of shunting the whole of the field helices, a portion only of such helices may be shunted, as shown in Figs. 2 and 4.

The arrangement shown in Fig. 4 is advantageous, as it diminishes the sparking upon the commutator, the main circuit being closed through the auxiliary brushes at the moment of the break of the circuit at the main brushes.

The field-helices may be wound in the same direction, or a part may be wound in opposite directions.

The connection between the helices and the auxiliary brush or brushes may be made by a wire of small resistance, or a resistance may be interposed (R, Fig. 5) between the point *x* and the auxiliary brush or brushes to divide the sensitiveness when the brushes are adjusted.

I am aware that it is not new to use auxiliary brushes on the commutator, and that auxiliary brushes have been connected to the field helices; but I am not aware that the helices of a series dynamo have been shunted by means of auxiliary brushes, and that the relative position of the respective brushes has been varied for the purpose of regulating the current developed by the machine.

In instances where auxiliary brushes have been used in connection with the field helices said auxiliary brushes received the current continuously and caused great sparking, whereas in my invention the auxiliary brush receives current only when the normal electrical conditions of the circuit are disturbed.

I claim as my invention—

The combination, with the commutator and main brushes and one or more auxiliary brushes, of the field-helices in the main circuits and one or more shunt-connections from the field-helices to the auxiliary brushes, the relative positions upon the commutator of the respective brushes being adjustable, for the purpose set forth.

Signed by me this 16th day of May, A. D. 1885.

NIKOLA TESLA.

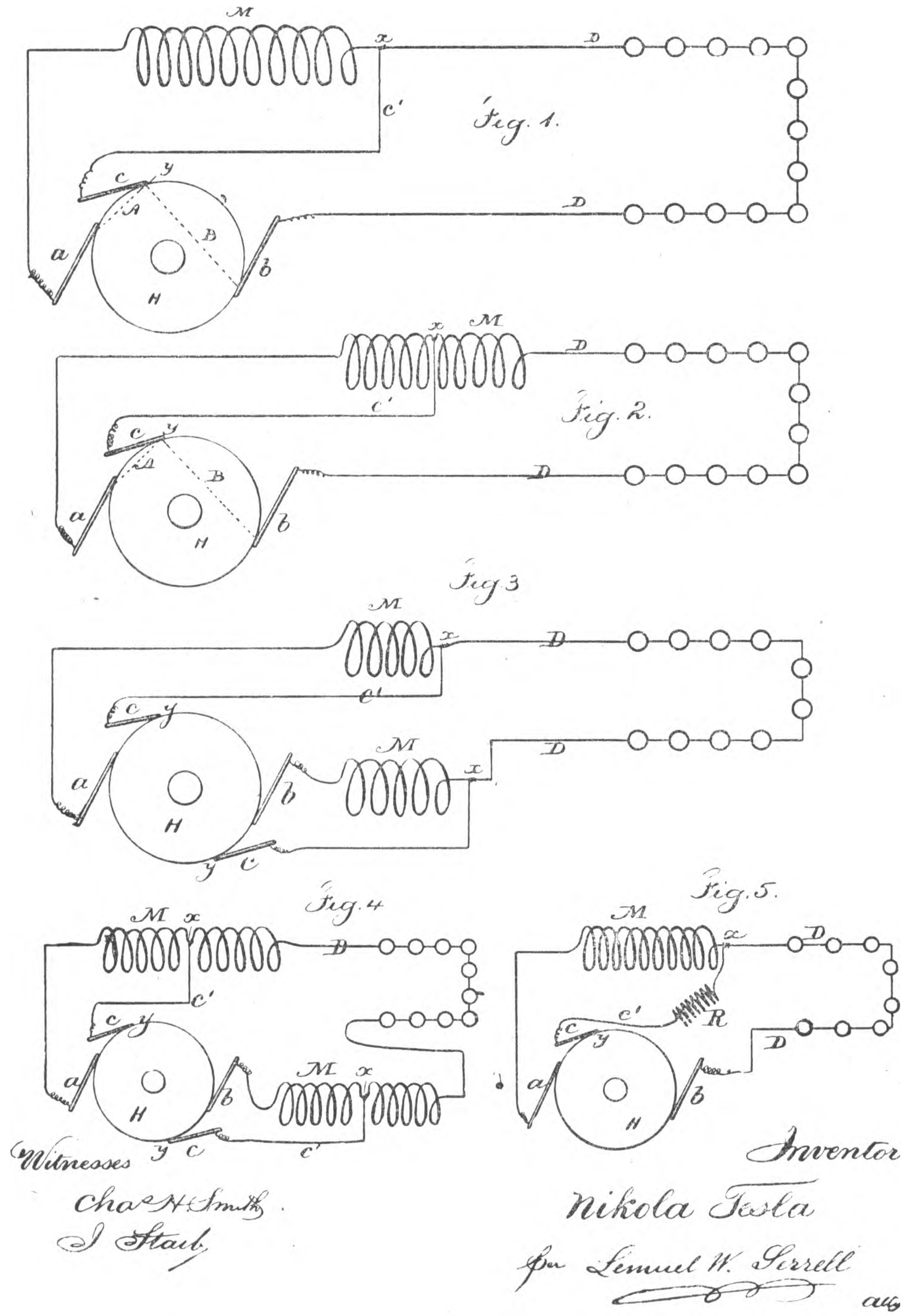
Witnesses:
GEO. T. PINCKNEY,
WALLACE L. SERRELL

(No Model.) 2 Sheets—Sheet 1.

N. TESLA.

REGULATOR FOR DYNAMO ELECTRIC MACHINES.

No. 336,962. Patented Mar. 2, 1886.



(No Model.) 2 Sheets — Sheet 2

N. TESLA

REGULATOR FOR DYNAMO ELECTRIC MACHINES.

No. 336,962. Patented Mar. 2, 1886.

Fig 6

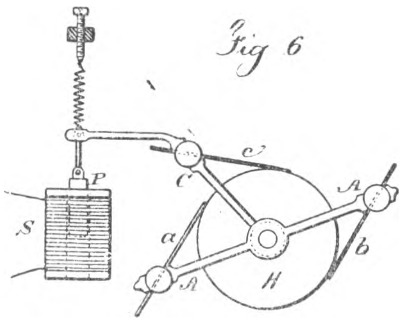
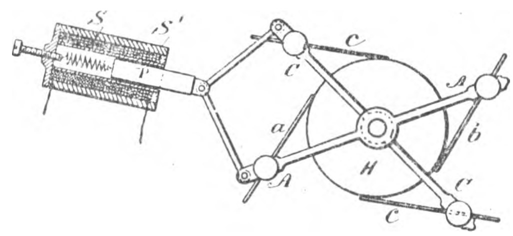


Fig. 7



Witnesses
Chas H. Smith
J. Staib

Inventor
Nikola Tesla
Lemuel W. Serrell

UNITED STATES PATENT OFFICE.

NIKOLA TESLA. OF SMILJAN LIKA, AUSTRIA. HUNGARY, ASSIGNOR TO THE TESLA ELECTRIC LIGHT AND MANUFACTURING COMPANY, OF RAHWAY, NEW JERSEY.

REGULATOR FOR DYNAMO-ELECTRIC MACHINES.

SPECIFICATION forming part of Letters Patent No. 350,954, dated October 19, 1886.

Application filed January 14, 1886. Serial No. 183,539. (No model.)

To all whom it may concern;

Be it known that I, NIKOLA TESLA, from Smiljan Lika, border country of Austria Hungary, have invented certain Improvements in Dynamo-Electric Machines, of which the following is a specification.

In other applications I have shown the commutator of a dynamo-machine with the main brushes connected in an electric circuit, and one or more auxiliary brushes serving to shunt a part or the whole of the field-coils, the regulation of the current being effected by shifting the respective brushes automatically upon the commutator in proportion to the varying resistances of the circuit.

My present invention relates to the mechanical devices which I employ to effect the shifting of the brushes.

My invention is clearly shown in the accompanying drawings, in which Figure 1 is an elevation of the regulator with the frame partly in section; and Fig. 2 is a section at the line *xx*, Fig. 1.

C is the commutator; B and B', the brush-holders, B carrying the main brushes *a a'* and B' the auxiliary or shunt brushes *b b*. The axis of the brush-holder B is supported by two pivot-screws, *p p*. The other brush-holder, B', has a sleeve, *d,* and is movable around the axis of the brush holder B. In this way both brush holders can turn very freely, the friction of the parts being reduced to a minimum. Over the brush holders is mounted the solenoid S, which rests upon a forked colump, c. This column also affords a support for the pivots *p p,* and is fastened upon a solid bracket of projection, P, which extends from the base of the machine, and is preferably cast in one piece with the same. The brush holders B B' are connected by means of the links *c c* and the cross-piece F to the iron core I, which slides freely in the tube T of the solenoid. The iron core I has a screw, *s,* by means of which it can be raised and adjusted in its position relatively to the solenoid, so that the pull exerted upon it by the solenoid is practically uniform through the whole length of motion which is required to effect the regulation. In order to effect the adjustment with a greater precision the core I is provided with a small iron screw, *s'*. The core being first brought very nearly in the required position relatively to the solenoid by means of the. screw *s,* the small screw *s'* is then adjusted until the magnetic attraction upon the core is the same when the core is in any position. A convenient stop, *t*, serves to limit the upward movement, of the iron core.

To check somewhat the. movement of the core I, a dash-pot, K, is used. The piston L of the dash-pot is provided with a valve, V. which opens by a downward pressure and allows an easy downward movement of the iron core I, but closes and checks the movement of the core when the same is pulled up under the action of the solenoid.

To balance the opposing forces, the weight of the moving parts, and the pull exerted by the solenoid upon the iron core, the weights W W may be used. The adjustment is such that when the solenoid is traversed by the normal current it is just strong enough to balance the downward pull of the parts.

The electrical circuit-connections are substantially the same, as indicated in my former applications, the solenoid being in series with the circuit when the translating devices are in series and in a shunt when the devices are in multiple arc.

The operation of the device is as follows: When upon a decrease of the resistance of the circuit or some other reason the current is increased, the solenoid S gains in strength and pulls up the iron core I, thus shifting the main brushes in the direction of rotation and the auxiliary brushes in the opposite way. This diminishes the strength of the current until the opposing forces are balanced and the solenoid is traversed by the normal current; but if from any cause the current in the circuit is diminished, then the weight of the moving parts overcomes the pull of the solenoid, the iron core I descends, thus shifting the brushes the opposite way and increasing the current to the normal strength. The dash pot connected to the iron core I may be of ordinary construction; but I prefer, especially in machines for arc lights, to provide the piston of the dash-pot with a valve, as indicated in the drawings. This valve permits a comparatively easy downward movement of the iron core, but checks its movement when it is drawn up by the solenoid. Such an arrangement has the advantage that a great number of lights may be put on without diminishing the light-power of the lamps in the circuit, as the brushes assume at once the proper position. When lights are cut out, the dash-pot acts to retard the movement; but if the current is considerably increased the solenoid gets abnormally strong and the brushes are shifted instantly.

The regulator being properly adjusted, lights or other devices may be put on or out with scarcely any perceptible difference.

It is obvious t hat instead of the dash pot any other retarding device may be used.

I claim as my invention—

1. The combination with the main and auxiliary brushes, of two brush holders, an axis fastened to one of the brush-holders, supporting screws for the same, a support for the other brush-holder surrounding the axis, a solenoid, a core for the same, and links connecting the core to the respective brush-holders, substantially as set forth.

2. The combination, with the brushes, brush-holders, and the axis upon which the brush-holders swing, of a solenoid and core, connections from the same to the brush-holders, and an adjusting screw to limit the movements of the core, substantially as set forth.

3. The combination, with the brush holders and their axes, of a solenoid and core, and a connection from the core to the brush holders, and an iron screw at the inner end of the core to adjust the action of the magnetism on the core, substantially as set forth.

4. The combination, with the brushes, the brush holders and their axes, of a solenoid and core, and connections to move the brush-holders, and a dash-pot provided with a valve, substantially as described, to diminish the speed of movement, of the core in one direction more than the other, substantially as set forth.

5. The combination, with the brushes, the brush-holders and their axes, of a solenoid and core, and connections to move the brush-holders, and a dash-pot to diminish the speed of movement of the core, substantially as set forth.

6. The combination, with the brush holders and the solenoid and core, of links connecting to the holders, and a screw to adjust the position of the core in relation to the solenoid, substantially as set forth.

Signed by me this 12th day of January, A. D. 1886.

NIKOLA TESLA.

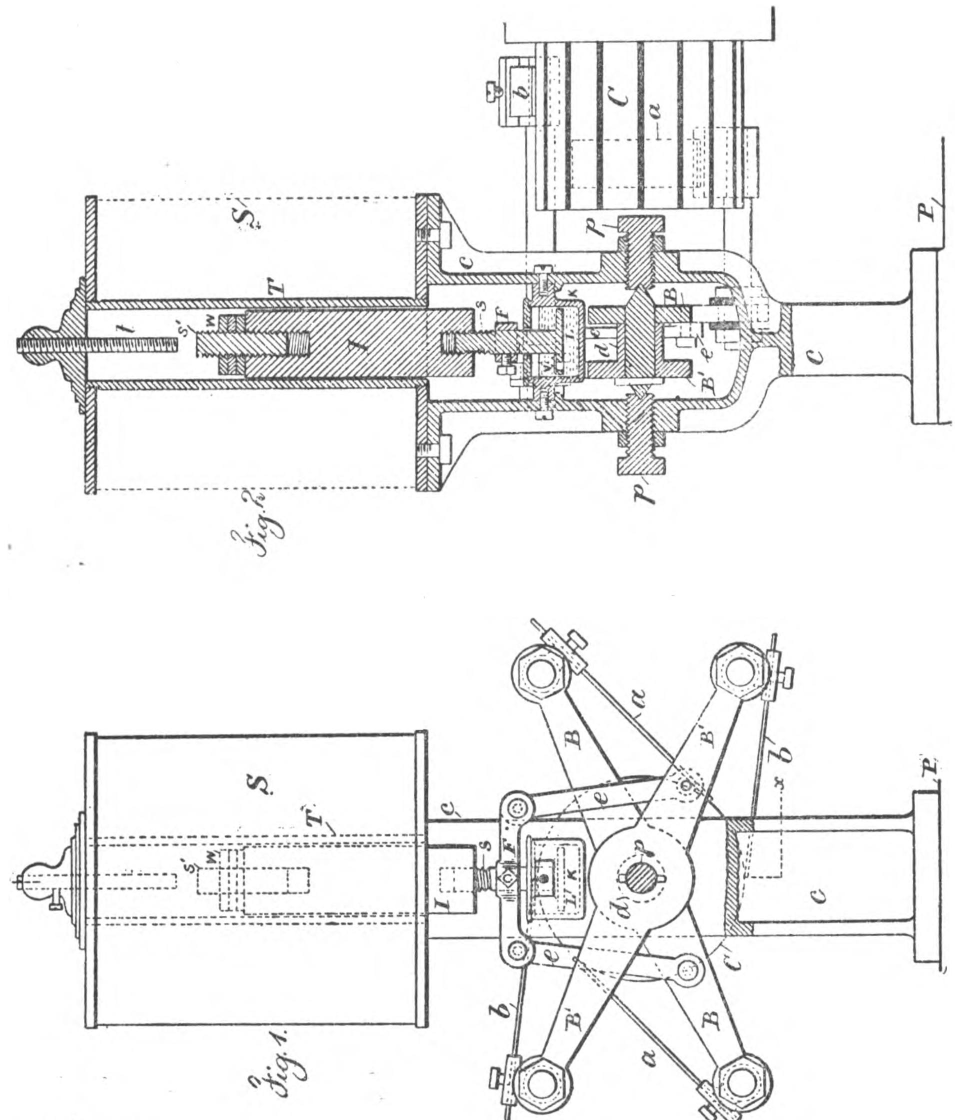
Witnesses:
GEO. T. PINCKNEY,
WILLIAM G. MOTT.

(No Model.)

N. TESLA.

REGULATOR FOR DYNAMO ELECTRIC MACHINES.

No. 350,954. Patented Oct. 19, 1886.



Witnesses
Chas. H. Smith
J. Stail

Inventor
Nikola Tesla.
per Lemuel W. Serrell atty

UNITED STATES PATENT OFFICE.

NIKOLA TESLA, OF SMILJAN LIKA, AUSTRIA-HUNGARY, ASSIGNOR TO THE TESLA ELECTRIC LIGHT AND MANUFACTURING COMPANY, OP RAHWAY, NEW JERSEY.

DYNAMO-ELECTRIC MACHINE.

SPECIFICATION forming part of Letters Patent No. 359,748, dated March 22, 1887.

Application filed January 14, 1886, Renewed December 1, 1886. Serial No. 220,370. (No model.)

To all whom it may concern:

Be it known that I, NIKOLA TESLA, of Smiljan Lika, border country of Austria-Hungary, have invented certain Improvements in Dynamo-Electric Machines, of which the following is a specification.

The main objects of my invention are to increase the efficiency of the machine and to facilitate and cheapen the construction of the same; and to this end my invention relates to the magnetic frame and the armature, and to other features of construction, hereinafter more fully explained.

My invention is illustrated in the accompanying drawings, in which Figure 1 is a longitudinal section, and Fig. 2a cross section, of the machine. Fig. 3 is a top view, and Fig. 4 a side view; of the magnetic frame. Fig. 5 is an end view of the commutator-bars, and Fig. 6 is a section of the shaft and commutator-bars. Fig. 7 is a diagram illustrating the coils of the armature and the connections to the commutator plates.

The cores *c c c c* of the field magnets may be tapering in both directions, as shown, for the purposes of concentrating the magnetism upon the middle of the pole pieces.

The connecting frame F F of the field-magnets is in the form indicated in the side view, Fig. 4, the lower part being provided with the spreading curved cast legs *e e,* so that the machine will rest firmly upon two base-bars, *r r.*

To the lower pole, S, of the field-magnet M is fastened, preferably by means of Babbitt or other fusible diamagnetic material, the base B, which is provided with bearings *b* for the armature-shaft H. The base B has a projection, P, which supports the brush holders and the regulating devices, which may be of any ordinary character, or may be such as shown in an application of like date herewith.

The armature is constructed with the view to reduce to a minimum the loss of power due to the transversal or Foucault currents and to the change of polarity, and also to shorten as much as possible the length of the inactive wire wound upon the armature-core.

It is well known that when the armature is revolved between the poles of the field-magnets currents are generated in the iron body of the armature which develop heat, and consequently cause a waste of power. Owing to the mutual action of the lines of force, the magnetic properties of iron, and the speed of the different portions of the armature-core, these currents are generated principally on and near the surface of the armature-core, diminishing in strength gradually toward the center of the core. Their quantity is under same conditions proportional to the length of the iron body in the direction in which these currents are generated. By subdividing the iron core electrically in this direction the generation of these currents can be reduced to a great extent. For instance, if the length of the armature-core is twelve inches, and by a suitable construction the same is subdivided electrically, so that there are in the generating direction six inches of iron and six inches of intervening air-spaces or insulating material, the currents will be reduced to fifty per cent.

As shown in the drawings, the armature is constructed of thin iron disks D D D, of various diameters, fastened upon the armature-shaft in a suitable manner and arranged according to their sizes, so that a series of iron bodies, *i i i,* is formed, each of which diminishes in thickness from the center toward the periphery. At both ends of the armature the inwardly-curved disks *d d,* preferably of cast iron, are fastened to the armature-shaft.

The armature-core being constructed as shown, it will be easily seen that on those portions of the armature that are the most remote from the axis, and where the currents are principally developed, the length of iron in the generating direction is only a small fraction of the total length of the armature-core, and besides this the iron body is subdivided in the generating direction, and therefore the Foucault currents are greatly reduced. Another cause of heating is the shifting of the poles of the armature-core. In consequence of the subdivision of the iron in the armature and the increased surface for radiation the risk of heating is lessened.

The iron disks D D D may be insulated or coated with some insulating paint, a very careful insulation being unnecessary, as an electrical contact between several disks can only occur on places where the generated currents are comparatively weak. An armature-core constructed in the manner described may be revolved between the poles of the field-magnets. without showing the slightest increase of temperature.

The end disks, *d d,* which are of sufficient thickness and, for the sake of cheapness, preferably of cast-iron, are curved inwardly, as indicated in the drawings. The extent of the curve is dependent on the amount of wire to be wound upon the armatures. In my present invention the wire is wound upon the armature in two superimposed parts, and the curve of the end disks, *d d,* is so calculated that the first part—that is, practically half of the wire—just fills up the hollow space to the line *x x;* or, if the wire is wound in any other manner, the curve is such that when the whole of the wire is wound the outside mass of wires, *w*, and the inside mass of wires, *w'*, are equal at each side of the plane *x x*. In this case it will be seen the passive or electrically inactive wires are of the smallest length practicable. The arrangement has further the advantage that the total lengths of the crossing wires at the two sides of the plane *x x* are practically equal.

To further equalize the armature-coils at both sides of the plates that are in contact with the brushes, the winding and connecting up is effected in the following manner: The whole wire is wound upon the armature-core in two superimposed parts, which are thoroughly insulated from each other. Each of these two parts is composed of three separated groups of coils. The first group of coils of the first part of wire being wound and connected to the commutator bars in the usual manner, this group is insulated and the second group wound; but the coils of this second group instead of being connected to the next following commutator-bars, are connected to the directly-opposite bars of the commutator. The second group is then insulated and the third group wound, the coils of this group being connected to those bars to which they would be connected in the usual way. The wires are then thoroughly insulated and the second part of wire wound and connected in the same manner. Suppose, for instance, that there are twenty-four coils—that is, twelve in each part—and consequently twenty-four commutator-plates. There will be in each part three groups, each containing four coils, and the coils will be connected as follows:

	Groups.	*Commutator-bars.*
First part of wire	First	1—5
	Second	17—21
	Third	9—13
Second part of wire	First	13—17
	Second	5—9
	Third	21—1

In constructing the armature core and winding and connecting the coils in the manner indicated, the passive or electrically-inactive wire is reduced to a minimum, and the coils at each side of the plates that are in contact with the brushes are practically equal, and in this way the electrical efficiency of the machine is increased.

The commutator-plates *t* are shown as outside the bearing *b* of the armature-shaft. The shaft H is tubular and split at the end portion, and the wires are carried through the same in any usual manner and connected to the respective commutator-plates. The commutator-plates are upon a cylinder, *u,* and insulated, and this cylinder is to be properly placed and secured by expanding the split end of the shaft by a tapering screw-plug, *v.*

I do not claim herein the cores of the field-magnets converging toward the pole-pieces; nor do I claim the method of fastening the base to the lower field-magnet, as this has been claimed in my former application on dynamo-electric machines.

What I claim is—

1. In a dynamo electric machine, the armature constructed of iron disks of various diameters arranged upon the shaft in such a manner that a series of iron bodies is formed, each diminishing in thickness from the center to the periphery, substantially as and for the purposes set forth.

2. In a dynamo electric machine, the armature-core having iron disks of various diameters, in combination with inwardly-curved end disks, for the purposes and substantially as set forth.

3. In a dynamo electric machine, an armature-core having inwardly-curved ends, in combination with the armature-coils, the crossing wires of which coils pass into the concave heads and project equally, substantially as set forth.

4. In a dynamo-electric machine, an armature having separate coils superimposed and connected to the commutator-plates in alternating groups, substantially as set forth.

5. An armature for dynamo-electric machines, having a core composed of disks of various diameters, in combination with separate superimposed coils connected to the commutator-plates in alternate groups, substantially as set forth.

6. In a dynamo electric machine, the magnetic frame composed of the cores *c c c c,* the curved pole pieces N S, and the connecting-frame with the curved and outwardly-projecting legs *e e,* substantially as described.

Signed by me this 12th day of January, A. D. 1880.

NIKOLA TESLA.

Witnesses:
GEO. T. PINCKNEY,
WALLACE L. SERRELL.

(No Model.) 3 Sheets — Sheet 1

N. TESLA.

DYNAMO ELECTRIC MACHINE.

No. 359,748. Patented Mar. 22, 1887.

Fig. 1

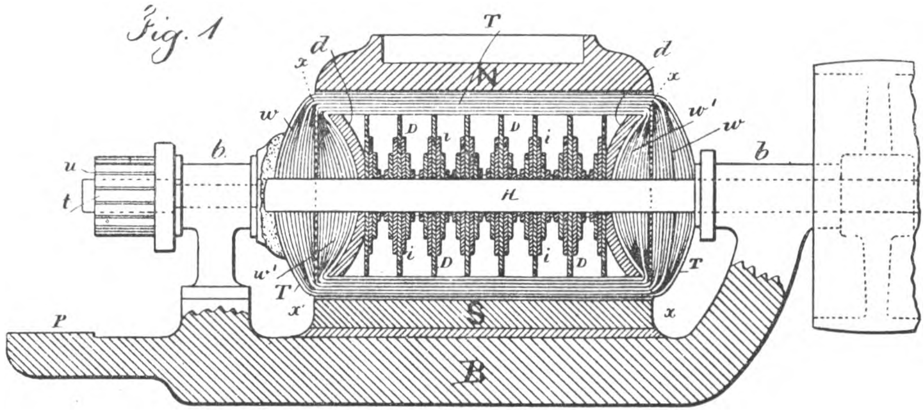
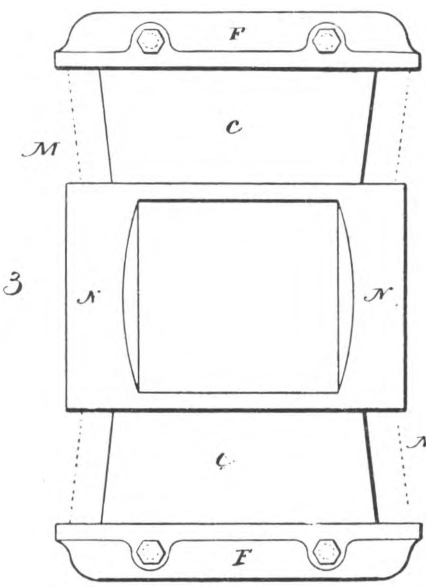


Fig 3



Witnesses

Chas. H. Smith

J. Staib

Inventor

Nikola Tesla

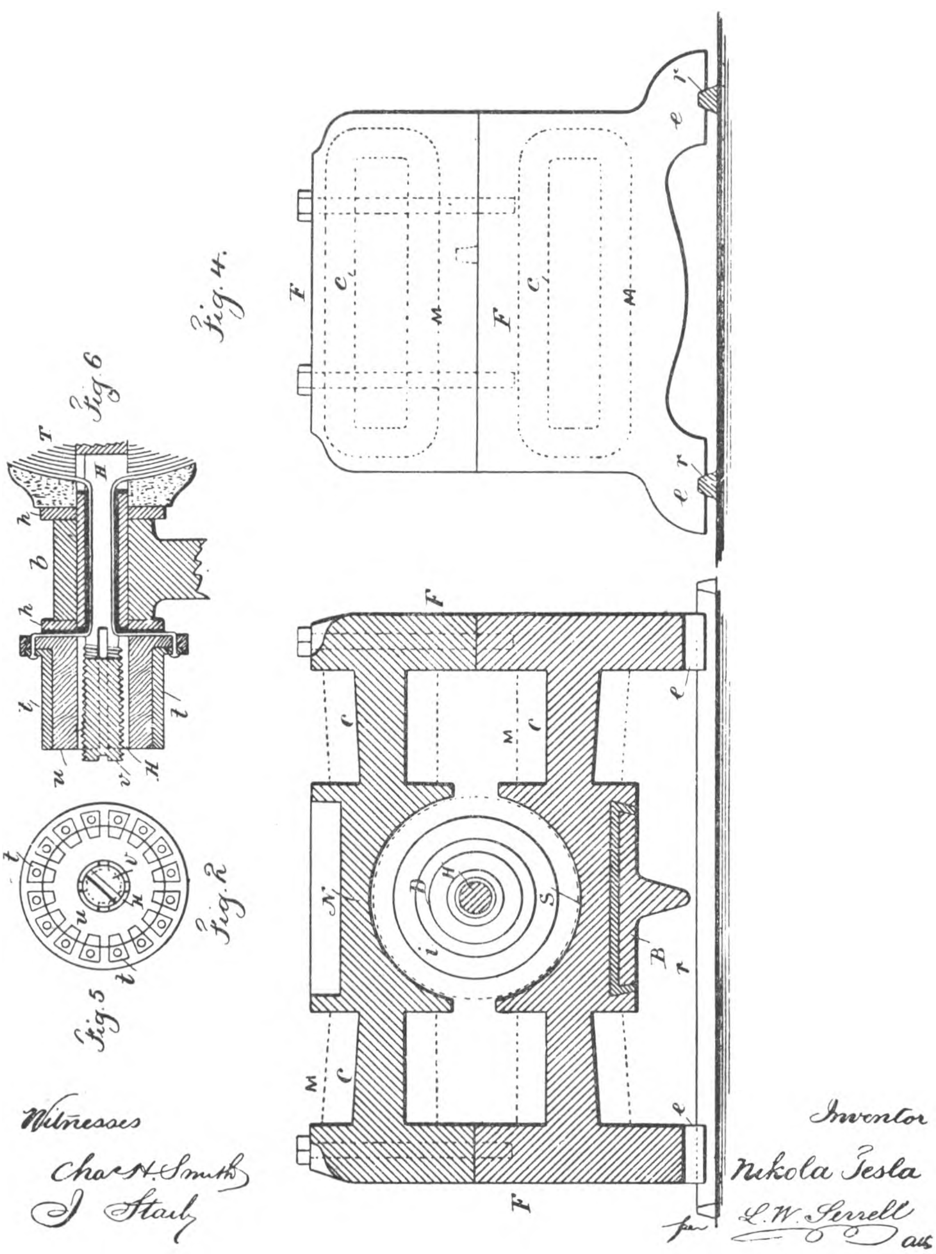
per Lemuel W. Serrell

att.

(No Model.) 3 Sheets — Sheet 2.

N. TESLA.
DYNAMO ELECTRIC-MACHINE.

No. 359,748 Patented Mar. 22, 1887.



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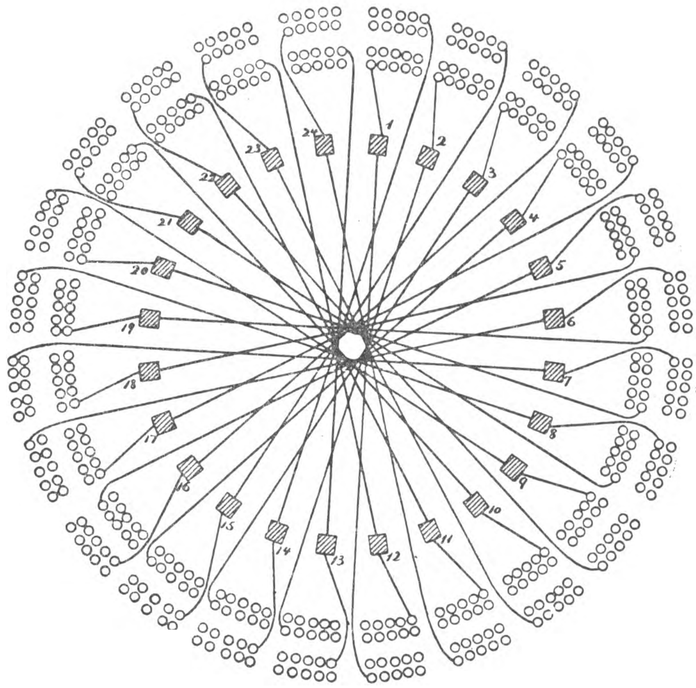
(No Model.) 3 Sheets — Sheet 3

N. TESLA.
DYNAMO ELECTRIC MACHINE.

No. 359,748, Patented Mar. 22, 1887.

Fig. 7.



Inventor

Witnesses

Chas. H. Smith
Geo. T. Pinckney

Nikola Tesla

for Lemuel W. Serrell

att.

UNITED STATES PATENT OFFICE.

NIKOLA TESLA, OF NEW YORK, N. Y., ASSIGNOR OF ONE-HALF TO CHARLES F. PECK, OF ENGLEWOOD, NEW JERSEY.

COMMUTATOR FOR DYNAMO-ELECTRIC MACHINES.

SPECIFICATION forming part of Letters Patent No. 382,845, dated May 15, 1888.

Application filed April 30, 1887. Serial No. 236,711. (No model.)

To all whom it may concern:

Be it known that I, NIKOLA TESLA, from Smiljan, Lika, border country of Austria-Hungary, at present residing in the city, county, and State of New York, have invented certain new and useful Improvements in Commutators for Dynamo-Electric Machines and Motors, of which the following is a specification, reference being had to the drawings accompanying and forming a part of the same.

This invention relates to dynamo electric machines or motors, and is an improvement in the devices for commutating and collecting the currents.

The objects of the invention are, first, to avoid the sparking and the gradual wearing away or destruction of the commutator-segments and brushes or collectors resulting therefrom; second, to obviate the necessity of readjustment of the commutator or the brushes or collectors and other consequences of the wear of the same; third, to render practicable the construction of very large dynamo-electric machines and motors with the minimum number of commutator-segments, and, fourth, to increase the efficiency and safety and reduce the cost of the machine.

In carrying out my invention in a manner to accomplish these results I construct a commutator and the collectors therefor in two parts mutually adapted to one another, and, so far as the essential features are concerned, alike in mechanical structure. Selecting as an illustration a commutator of two segments adapted for use with an armature the coils or coil of which have but two free ends, connected respectively to the said segments, the bearing-surface is the face of a disk, and is formed of two metallic quadrant-segments and two insulating-segments of the same dimensions, and the face of the disk should be smoothed off, so that the metal and insulating segments are flush. The part which takes the place of the usual brushes, or what I term the "collector", is a disk of the same character as the commutator and having a surface similarly formed with two insulating and two metallic segments. These two parts are mounted with their faces in contact and in such manner that the rotation of the armature causes the commutator to turn upon the collector, whereby the currents induced in the coils are taken off by the collector-segments and thence conveyed off by suitable conductors leading from the collector-segments. This is the general plan of the construction which I have invented. Aside from certain adjuncts, the nature and functions of which will be hereinafter set forth, this means of commutation will be seen to possess many important advantages. In the first place the short-circuiting and breaking of the armature-coil connected to the commutator-segments occur at the same instant, and from the nature of the construction this will be done with the greatest precision; secondly, the duration of both the break and that of the short circuit will be reduced to a minimum. The first results in a reduction which amounts practically to a suppression of the spark, since the break and the short circuit produce opposite effects in the armature coil. The second has the effect of diminishing the destructive effect of a spark, since this would be in a measure proportioned to the duration of the spark, while lessening the duration of the short circuit obviously increases the efficiency of the machine.

The mechanical advantages will be better understood by referring to the accompanying drawings, in which—

Figure 1 is a central longitudinal section of the end of a shaft with my improved commutator carried thereon. Fig. 2 is a view of the inner or bearing face of the collector. Fig. 3 is an end view from the armature side of a modified form of commutator. Figs. 4 and 5 are views of details of Fig. 3. Fig. 6 is a longitudinal central section of another modification, and Fig. 7 is a sectional view of the same.

A is the end of the armature-shaft of a dynamo electric machine or motor.

A' is a sleeve of insulating material around the shaft, secured in place by a screw, *a'*, or by other suitable means.

The commutator proper is in the form of a disk which is made up of four segments, D D' G G', similar to those shown in Fig. 3. Two of these segments, as D D', are of metal and are in electrical connection with the ends of the coils on the armature. The other two segments are of insulating material. The segments are held in place by a band, B, of insulating material. The disk is held in place by friction or by screws, such as *g′ g′,* Fig. 3, which secure the disk firmly to the sleeve A'.

The collector is made in the same form as the commutator. It is composed of the two metallic segments E E' and the two insulating-segments F F', bound together by a band, C. The metallic segments E E' are of the same or practically the same width or extent as the insulating segments or spaces of the commutator. The collector is secured to a sleeve, B', *by* screws g *g,* and the sleeve is arranged to turn freely on the shaft A. The end of the sleeve B' is closed by a plate, as *f,* upon which presses a pivot-pointed screw, *h,* adjustable in a spring, H, which acts to maintain the collector in close contact with the commutator and to compensate for the play of the shaft. Any convenient means is employed to hold the collector so that it may not turn with the shaft. For example, I have shown a slotted plate, K, which is designed to be attached to a stationary support, and an arm extending from the collector and carrying a clamping-screw, L, by which the collector may be adjusted and set to the desired position.

I prefer in the form shown in Figs. 1 and 2 to fit the insulating-segments of both commutator and collector loosely and to provide some means—as, for example, light springs *e e,* secured to the bands A' B', respectively, and bearing against the segments—to exert a light pressure upon them and keep them in close contact and to compensate for wear. The metal segments of the commutator may be moved forward by loosening the screw *a′.*

The circuit or line wires are led from the metal segments of the collector, being secured thereto in any convenient manner, the plan of connections being shown as applied to a modified form of the commutator in Fig. 6. The commutator and the collector in thus presenting two flat and smooth bearing surfaces prevent by mechanical action the occurrence of sparks, and this is more effectively accomplished as is here done—that is to say, by the interposition of an insulating body between the separating plates or segments of the commutator and collector—than by any other mechanical devices of which I am aware.

The insulating segments are made of some hard material capable of being polished and formed with sharp edges. Such materials as glass, marble, or soapstone may be advantageously used. The metal segments are preferably of copper or brass; but they may have a facing or edge of durable material—such as platinum or the like—where the sparks are liable to occur.

In Fig. 3 a somewhat modified form of my invention is shown, a form designed to facilitate the construction and replacing of the parts. In this form the commutator and collector are made in substantially the same manner as previously described, except that the bands B C may be omitted, The four segments of each part, however, are secured to their respective sleeves by screws *g′ g′* and one edge of each segment is cut away, so that small plates *a b* may be slipped into the spaces thus formed. Of these plates *a a* are of metal, and are in contact with the metal segments D D', respectively. The other two, *b b,* are of glass or marble, and they are all preferably square, as shown in Figs. 4 and 5, so that they may be turned to present new edges should any edge become worn by use. Light springs *d* bear upon these plates and press those in the commutator toward those in the collector, and insulating-strips *c c* are secured to the periphery of the disks to prevent the blocks from being thrown out by centrifugal action. These plates are, of course, useful at those edges of the segments only where sparks are liable to occur, and, as they are easily replaced, they are of great advantage. I prefer to coat them with platinum or silver.

In Figs. 6 and 7 is shown the construction which I use when, instead of solid segments, a fluid is employ ed. In this case the commutator and collector are made of two insulating-disks, S T, and in lieu of the metal segments a space is cut out of each part, as at R R', corresponding in shape and size to a metal segment. The two parts are fitted smoothly and the collector T held by the screw *h* and spring H against the commutator S. As in the other cases, the commutator revolves while the collector remains stationary. The ends of the coils are connected to binding-posts *s s,* which are in electrical connection with metal plates *t t* within the recesses in the two parts S T. These chambers or recesses are filled with mercury, and in the collector part are tubes W W, with screws *w w,* carrying springs X and pistons X', which compensate for the expansion and contraction of the mercury under varying temperatures, but which are sufficiently strong not to yield to the pressure of the fluid due to centrifugal action, and which serve as binding posts.

In all the above cases I have described commutators adapted for a single coil, and the device is particularly adapted to such purposes. The number of segments may be increased, however, or more than one commutator used with a single armature, as will be well understood.

Although I have shown the bearing surfaces as planes at right angles to the shaft or axis, it is evident that in this particular the construction may be very greatly modified without departure from the invention.

Without confining myself, therefore, to the details of construction which I have shown in illustration of the invention, what I claim as new is—

1. In a dynamo electric machine, the combination, with a commutator form d with conducting terminals or segments with intervening insulating-spaces, of a collector adapted to bear upon the surface of the commutator

and formed with conducting terminals or segments equal in extent to the insulating space between the commutator-segments, as set forth.

2. The combination, with a commutator built or formed of alternate blocks or segments of conducting and insulating material, of a collector adapted to bear upon the surface of the commutator and formed of conducting blocks or segments of a width or extent equal to that of the insulating segments of the commutator and separated by interposed blocks or segments of insulating material, as described.

3. The combination, with a commutator formed as a disk with alternate terminals or segments of conducting and insulating material, of a collector similarly formed and mounted with its face in contact with that of the commutator, as set forth.

4. The combination, with a commutator having a bearing-surface formed of alternate sections of conducting and insulating material, of a collector with a similar and symmetrically-formed bearing-surface and means for applying spring pressure to force the two bearing-surfaces together, as set forth.

5. The combination, with a commutator and a collector the bearing surfaces of which are identical in respect to the disposition of the conducting and insulating parts, of means for applying spring-pressure to maintain the two bearing-surfaces in contact and means for holding the collector against rotary movement, as set forth.

Signed this 21st day of April, 1887.

NIKOLA TESLA.

Witnesses:

ROBT. F. GAYLORD,
FRANK E. HARTLEY.

P-26

(No Model.)

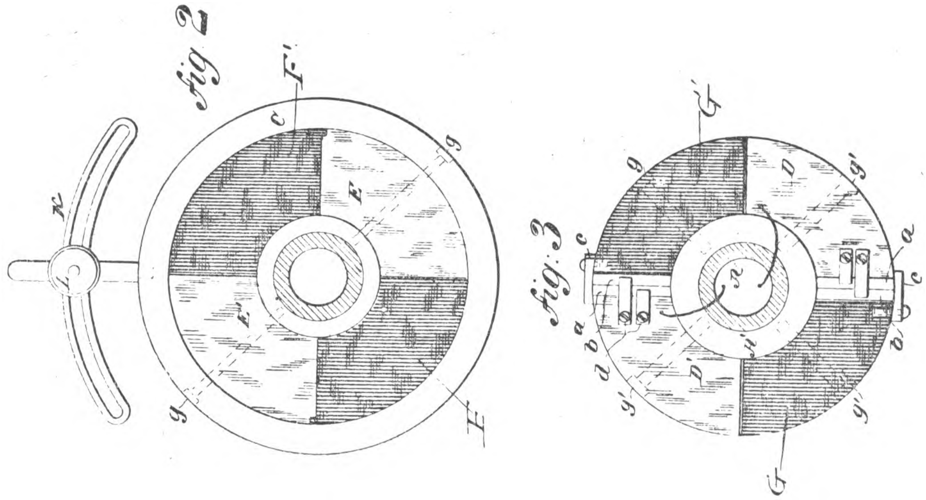
2 Sheets — Sheet 1

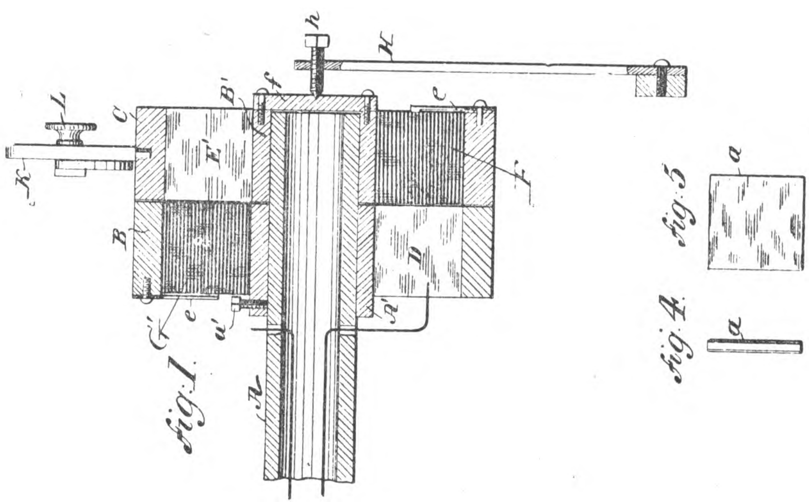
N. TESLA.

COMMUTATOR FOR DYNAMO ELECTRIC MACHINES

No. 382,845.

Patented May 15, 1888.





WITNESSES:

Robt. F. Gaylord.
Robt. P. Harlow.

INVENTOR

Nikola Tesla

BY

Duncan, Curtis & Page

ATTORNEYS

(No Model.)

2 Sheets — Sheet 2.

N. TESLA.

COMMUTATOR FOR DYNAMO ELECTRIC MACHINES.

No. 382,845. Patented May 15, 1888.

Fig. 6.

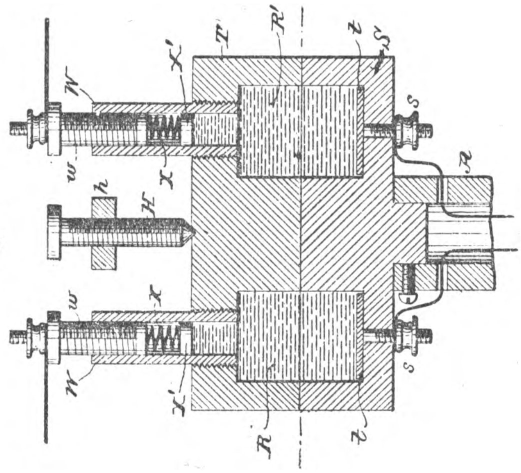
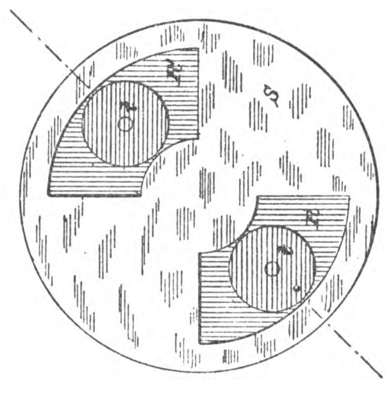


Fig. 7.



WITNESSES:
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UNITED STATES PATENT OFFICE.

NIKOLA TESLA, OF NEW YORK. N. Y., ASSIGNOR OF ONE HALF TO CHARLES F. PECK, OF ENGLEWOOD, NEW JERSEY

ELECTRO-MAGNETIC MOTOR.

SPECIFICATION forming part of Letters Patent No. 381,968, dated May 1, 1888

Application filed October 12, 1887. Serial No. 252,133. (No model.)

To all whom it may concern:

Be it known that I, NIKOLA TESLA, from Smiljan Lika, border country of Austria-Hungary, residing at New York, N. Y., have invented certain new and useful Improvements in Electro-Magnetic Motors, of which the following is a specification, reference being had to the drawings accompanying and forming a part of the same.

The practical solution of the problem of the electrical conversion and transmission of mechanical energy involves certain requirements which the apparatus and systems heretofore employed have not been capable of fulfilling. Such a solution, primarily, demands a uniformity of speed in the motor irrespective of its load within its normal working limits. On the other hand, it is necessary, to attain a greater economy of conversion than has heretofore existed, to construct cheaper and more reliable and simple apparatus, and, lastly, the apparatus must be capable of easy management, and such that all danger from the use of currents of high tension, which are necessary to an economical transmission, may be avoided.

My present invention is directed to the production and improvement of apparatus capable of more nearly meeting these requirements than those heretofore available, and though I have described various means for the purpose, they involve the same main principles of construction and mode of operation, which may be described as follows: A motor is employed in which there are two or more independent circuits through which alternate currents are passed at proper intervals, in the manner hereinafter described, for the purpose of effecting a progressive shifting of the magnetism or of the "lines of force" in accordance with the well known theory, and a consequent action of the motor. It is obvious that a proper progressive shifting of the lines of force may be utilized to set up a movement or rotation of either element of the motor, the armature, or the field magnet, and that if the currents directed through the several circuits of the motor are in the proper direction no commutator for the motor will be required; but to avoid all the usual commutating appliances in the system I prefer to connect the motor-circuits directly with those of a suitable alternate current generator. The practical results of such a system, its economical advantages, and the mode of its construction and operation will be described more in detail by reference to the accompanying diagrams and drawings.

Figures 1 to 8 and 1^a to 8^a, inclusive, are diagrams illustrating the principle of the action of my invention. The remaining figures are views of the apparatus in various forms by means of which the invention may be carried into effect, and which will be described in their order.

Referring first to Fig. 9, which is a diagrammatic representation of a motor, a generator, and connecting-circuits in accordance with my invention, M is the motor, and G the generator for driving it. The motor comprises a ring or annulus, R, preferably built up of thin insulated iron rings or annular plates, so as to be as susceptible as possible to variations in its magnetic condition. This ring is surrounded by four coils of insulated wire symmetrically placed, and designated by C C C' C'. The diametrically-opposite coils are connected up so as to co-operate in pairs in producing free poles on diametrically-opposite parts of the ring. The four free ends thus left are connected to terminals T T T' T', as indicated. Near the ring, and preferably inside of it, there is mounted on an axis or shaft, *a,* a magnetic disk, D, generally circular in shape, but having two segments cut away, as shown. This disk is mounted so as to turn freely within the ring R. The generator G is of any ordinary type, that shown in the present instance having field-magnets N S and a cylindrical armature core, A, wound with the two coils B B'. The free ends of each coil are carried through the shaft *a'* and connected, respectively, to insulated contact rings *b b b' b'*. Any convenient form of collector or brush bears on each ring and forms a terminal by which the current to and from a ring is conveyed. These terminals are connected to the terminals of the motor by the wires L and L' in the manner indicated, whereby two complete circuits are formed—one including, say, the coils B of the generator C' C' of the motor, and the other the remaining coils B' and C C of the generator and the motor.

It remains now to explain the mode of operation of this system, and for this purpose I refer to the diagrams, Figs. 1 to 8, and 1ª to 8ª, for an illustration of the various phases through which the coils of the generator pass when in operation, and the corresponding and resultant magnetic changes produced in the motor. The revolution of the armature of the generator between the field-magnets N S obviously produces in the coils B B' alternating currents, the intensity and direction of which depend upon well-known laws. In the position of the coils indicated in Fig. 1 the current in the coil B is practically *nil,* whereas the coil B' at the same time is developing its maximum current, and by the means indicated in the description of Fig. 9 the circuit including this coil B' may also include, say, the coils C C of the motor, Fig. 1ª The result, with the proper connections, would be the magnetization of the ring R', the poles being on the line N S. The same order of connections being observed between the coil B and the coils C', the latter, when traversed by a current, tend to fix the poles at right angles to the line N S of Fig. 1ª. It results, therefore, that when the generator-coils have made one eighth of a revolution, reaching the position shown in Fig. 2, both pairs of coils C and C' will be traversed by currents and act in opposition, in so far as the location of the poles is concerned. The position of the poles will therefore be the resultant of the magnetizing forces of the coils—that is to say, it will advance along the ring to a position corresponding to one-eighth of the revolution of the armature of the generator. In Fig. 3 the armature of the generator has progressed to one quarter of a revolution. At the point indicated the current in the coil B is maximum, while in B' it is *nil,* the latter coil being in its neutral position. The poles of the ring R in Fig. 3 will, in consequence, be shifted to a position ninety degrees from that at the start, as shown. I have in like manner shown the conditions existing at each successive eighth of one revolution in the remaining figures. A short reference to these figures will suffice for an understanding of their significance. Figs. 4 and 4ª illustrate the conditions which exist when the generator armature has completed three eighths of a revolution. Here both coils are generating current; but the coil B', having now entered the opposite field, is generating a current in the opposite direction, having the opposite magnetizing effect; hence the resultant pole will be on the line N S, as shown. In Fig. 5 one-half of one revolution of the armature of the generator has been completed, and the resulting magnetic condition of the ring is shown in Fig. 5'. In this phase coil B is in the neutral position while coil B' is generating its maximum current, which is in the same direction as in Fig. 4. The poles will consequently be shifted through one half of the ring. In Fig. 6 the armature has completed five-eighths of a revolution. In this position coil B' develops a less powerful current, but in the same direction as before. The coil B, on the other hand, having entered a field of opposite polarity, generates a current of opposite direction. The resultant, poles will therefore be in the line N S, Fig. 6ª, or, in other words, the poles of the ring will be shifted along five-eighths of its periphery. Figs. 7 and 7ª in the same manner illustrate the phases of the generator and ring at three-quarters of a revolution, and Figs. 8 and 8ª the same at seven-eighths of a revolution of the generator armature. These figures will be readily understood from the foregoing. When a complete revolution is accomplished, the conditions existing at the start are re established and the same action is repeated for the next and all subsequent revolutions, and, in general, it will now be seen that every revolution of the armature of the generator produces a corresponding shifting of the poles or lines of force around the ring. This effect I utilize in producing the rotation of a body or armature in a variety of ways—for example, applying the principle above described to the apparatus shown in Fig. 9. The disk D, owing to its tendency to assume that position in which it embraces the greatest possible number of the magnetic lines, is set in rotation, following the motion of the lines or the points of greatest attraction.

The disk D in Fig. 9 is shown as cut away on opposite sides; but this, I have found, is not essential to effecting its rotation, as a circular disk, as indicated by dotted lines, is also set in rotation. This phenomenon I attribute to a certain inertia or resistance inherent in the metal to the rapid shifting of the lines of force through the same, which results in a continuous tangential pull upon the disk, causing its rotation. This seems to be confirmed by the fact that a circular disk of steel is more effectively rotated than one of soft iron, for the reason that the former is assumed to possess a greater resistance to the shifting of the magnetic lines.

In illustration of other forms of my invention, I shall now describe the remaining figured of the drawings.

Fig. 10 is a view in elevation and part vertical section of a motor. Fig. 12 is a top view of the same with the field in section and a diagram of connections. Fig. 11 is an end or side view of a generator with the fields in section. This form of motor may be used in place of that shown above. D is a cylindrical or drum armature core, which, for obvious reasons, should be split up as far as practicable to prevent the circulation within it of currents of induction. The core is wound longitudinally with two coils, E and E', the ends of which are respectively connected to insulated contact-rings *d d d' d',* carried by the shaft *a,* upon which the armature is mounted. The armature is set to revolve within an iron shell, R', which constitutes the field-magnet, or other element of the motor. This shell is preferably formed with a slot or opening, *r,* but it may be continuous, as shown by the dotted lines, and in this event it is preferably made of steel. It is also desirable that this shell should be divided up similarly to the armature and for similar reasons. As a generator for driving this motor I may use the device shown in Fig. 11. This represents an annular or ring armature, A, surrounded by four coils, F F F' F', of which those diametrically opposite are connected in series, so that four free ends are left, which are connected to the insulated contact-rings *b b b' b'.* The ring is suitably mounted on a shaft, *a*', between the poles N S. The contact-rings of each pair of generator-coils are connected to these of the motor, respectively, by means of contact-brushes and the two pairs of conductors L L and L' L', as indicated diagrammatically in Fig. 12. Now it is obvious from a consideration of the preceding figures that the rotation of the generator-ring produces currents in the coils F F', which, being transmitted to the motor-coils, impart to the core of the latter magnetic poles constantly shifting or whirling around the core. This effect sets up a rotation of the armature owing to the attractive force between the shell and the poles of the armature, but inasmuch as the coils in this case move relative to the shell or field magnet the movement of the coils is in the opposite direction to the progressive shifting of the poles.

Other arrangements of the coils of both generator and motor are possible, and a greater number of circuits may be used, as will be seen in the two succeeding figures:

Fig. 13 is a diagrammatic illustration of a motor and a generator constructed and connected in accordance with my invention. Fig. 14 is an end view of the generator with its field-magnets in section. The field of the motor M is produced by six magnetic poles, G' G', secured to or projecting from a ring or frame, H. These magnets or poles are wound with insulated coils, those diametrically opposite to each other being connected in pairs so as to produce opposite poles in each pair. This leaves six free ends, which are connected to the terminals T T T' T' T'' T''. The armature, which is mounted to rotate between the poles, is a cylinder or disk, D, of wrought-iron, mounted on the shaft *a.* Two segments of the same are cut away, as shown. The generator for this motor has in this instance an armature, A, wound with three coils, K K' K'', at sixty degrees apart. The ends of these coils are connected, respectively, to insulated contact-rings *e e e' e' e'' e''.* These rings are connected to those of the motor in proper order by means of collecting brushes and six wires, forming three independent, circuits. The variations in the strength and direction of the currents transmitted through these circuits and traversing the coils of the motor produces steadily-progressive shifting of the resultant attractive force exerted by the poles G' upon the armature D, and consequently keep the armature rapidly rotating. The peculiar advantage of this disposition is in obtaining a more concentrated and powerful field. The application of this principle to systems involving multiple circuits generally will be understood from this apparatus.

Referring, now, to Figs. 15 and 16, Fig. 15 is a diagrammatic representation of a modified disposition of my invention. Fig. 1.6 is a horizontal cross section of the motor. In this case a disk, D, of magnetic metal, preferably cut away at opposite edges, as shown in dotted lines in Fig. 15, is mounted so as to turn freely inside two stationary coils, N' N'', placed at right angles to one another. The coils are preferably wound on a frame, O, of insulating material, and their ends are connected to the fixed terminals T T T' T'. The generator G is a representative of that class of alternating-current machines in which a stationary induced element is employed. That shown consists of a revolving permanent or electro magnet, A, and four independent stationary magnets, P F, wound with coils, those diametrically opposite to each other being connected in series and having their ends secured to the terminals *t t t' t'.* From these terminals the currents are led to the terminals of the motor, as shown in the drawings. The mode of operation is substantially the same as in the previous cases, the currents traversing the coils of the motor having the effect to turn the disk D. This mode of carrying out the invention has the advantage of dispensing with the sliding contacts in the system.

In the forms of motor above described only one of the elements, the armature or the field-magnet, is provided with energizing-coils. It remains, then, to show how both elements may be wound with coils. Reference is therefore had to Figs. 17, 18, and 19. Fig. 17 is an end view of such a motor. Fig. 18 is a similar view of the generator with the field-magnets in section, and Fig. 19 is a diagram of the circuit-connections. In Fig. 17 the field-magnet of the motor consists of a ring, R, preferably of thin insulated iron sheets or bands with eight pole pieces, G', and corresponding recesses, in which four pairs of coils, V, are wound. The diametrically opposite pairs of coils are connected in series and the free ends connected to four terminals, *w*, the rule to be followed in connecting being the same as hereinbefore explained. An armature, D, with two coils, E E', at right angles to each other, is mounted to rotate in side of the field-magnet R. The ends of the armature-coils are connected to two pairs of contact-rings, *d d d' d',* Fig. 19. The generator for this motor may be of any suitable kind to produce currents of the desired character. In the present instance it consists of a field-magnet, N S, and an armature, A, with two coils at right angles, the ends of which are connected to four contact-rings, *b b b' b',* carried by its shaft. The circuit connections are established between the rings on the generator-shaft and those on the motor shaft by collecting brushes and wires, as previously explained. In order to properly energize the field-magnet of the motor, however, the connections are so made with the armature coils or wires leading thereto that while the points of greatest attraction or greatest density of magnetic lines of force upon the armature are shifted in one direction those upon the field-magnet are made to progress in an opposite, direction. In other respects the operation is identically the same as in the other cases cited. This arrangement results in an increased speed of rotation. In Figs. 17 and 19, for example, the terminals of each set of field coils are connected with the wires to the two armature-coils in such way that the field coils will maintain opposite poles in advance of the poles of the armature.

In the drawings the field coils are in shunts to the armature, but they may be in series or in independent circuits.

It is obvious that the same principle may be applied to the various typical forms of motor hereinbefore described.

Having now described the nature of my invention and some of the various ways in which it is or may be carried into effect, I would call attention to certain characteristics which the applications of the invention possess and the advantages which the invention secures.

In my motor, considering for convenience that represented in Fig. 9, it will be observed that since the disk D has a tendency to follow continuously the points of greatest attraction, and since these points are shifted around the ring once for each revolution of the armature of the generator, it follows that the movement of the disk D will be synchronous with that of the armature A. This feature by practical demonstrations I have found to exist in all other forms in which one revolution of the armature of the general or produces a shifting of the poles of the motor through three hundred and sixty degrees.

In the particular construction shown in fig. 15, or in others constructed on a similar plan, the number of alternating impulses resulting from one revolution of the generator armature is double as compared with the preceding cases, and the polarities in the motor are shifted around twice by one revolution of the generator-armature. The speed of the motor will, therefore, be twice that of the generator. The same result is evidently obtained by such a disposition as that shown in Fig. 17, where the poles of both elements are shifted in opposite directions.

Again, considering the apparatus illustrated by Fig. 9 as typical of the invention, it is obvious that since the attractive effect upon the disk D is greatest when the disk is in its proper relative position to the poles developed in the ring R—that is to say, when its ends or poles immediately follow those of the ring—the speed of the motor for all the loads within the normal working limits of the motor will be practically constant. It is clearly apparent that the speed can never exceed the arbitrary limit as determined by the generator, and also that within certain limits at least the speed of the motor will be independent of the strength of the current.

It will now be more readily seen from the above description how far the requirements of a practical system of electrical transmission of power are realized in my invention. I secure, first, a uniform speed under all loads within the normal working limits of the motor without the use cf any auxiliary regulator: second, synchronism between the motor and generator; third, greater efficiency by the more direct application of the current, no commutating devices being required on either the motor or generator; fourth, cheapness and simplicity of mechanical construction and economy in maintenance; fifth, the capability of being very easily managed or controlled; and, sixth, diminution of danger from injury to persons and apparatus.

These motors way be run in series, multiple arc or multiple series, under conditions well understood by those skilled in the art.

The means or devices for carrying out the principle may be varied to a far greater extent than I have been able to indicate; but I regard as within my invention, and I desire to secure by Letters Patent in general, motors containing two or more independent circuits through which the operating-currents are led in the manner described. By "independent" I do not mean to imply that the circuits are necessarily isolated from one another, for in some instances there might be electrical connections between them to regulate or modify the action of the motor without necessarily producing a new or different action.

I am aware that the rotation of the armature of a motor wound with two energizing-coils at right angles to each other has been effected by an intermittent shifting of the energizing effect of both coils through which a direct current by means of mechanical devices has been transmitted in alternately opposite directions; but this method or plan I regard as absolutely impracticable for the purposes for which my invention is designed—at least on any extended scale—for the reasons, mainly, that a great waste of energy is necessarily involved unless the number of energizing circuits is very great, and that the interruption and reversal of a current of any considerable strength by means of any known mechanical devices is a matter of the greatest difficulty and expense.

In this application I do not claim the method of operating motors which is herein involved, having made separate application for such method.

I therefore claim the following:

1. The combination, with a motor containing separate or independent circuits on the armature or field magnet, or both, of an alternating-current generator containing induced

circuits connected independently to corresponding circuits in the motor, whereby a rotation of the generator produces a progressive shifting of the poles of the motor, as herein described.

2. In a system for the electrical transmission of power, the combination of a motor provided with two or more independent magnetizing coils and an alternating current generator containing induced coils corresponding to the motor coils, and circuits connecting directly the motor and generator coils in such order that the currents developed by the generator will be passed through the corresponding motor coils, and thereby produce a progressive shifting of the poles of the motor, as herein set forth.

3. The combination, with a motor having an annular or ring shaped field magnet and a cylindrical or equivalent armature, and independent coils on the field magnet or armature, or both, of an alternating current generator having correspondingly independent coils, and circuits including the generator coils and corresponding motor coils in such manner that the rotation of the generator causes a progressive shifting of the poles of the motor in the manner set forth.

4. In a system for the electrical transmission of power, the combination of the follow sing instrumentalities, to wit: a motor composed of a disk or its equivalent mounted within a ring or annular field-magnet, which is provided with magnetizing coils connected in diametrically-opposite pairs or groups to independent terminals, a generator having induced coils or groups of coils equal in number to the pairs or groups of motor-coils, and circuits connecting the terminals of said coils to the terminals of the motor, respectively, and in such order that the rotation of the generator and the consequent production of alternating currents in the respective circuits produces a progressive shifting of the poles of the motor, as hereinbefore described.

NIKOLA TESLA.

Witnesses:

FRANK E. HARTLEY,

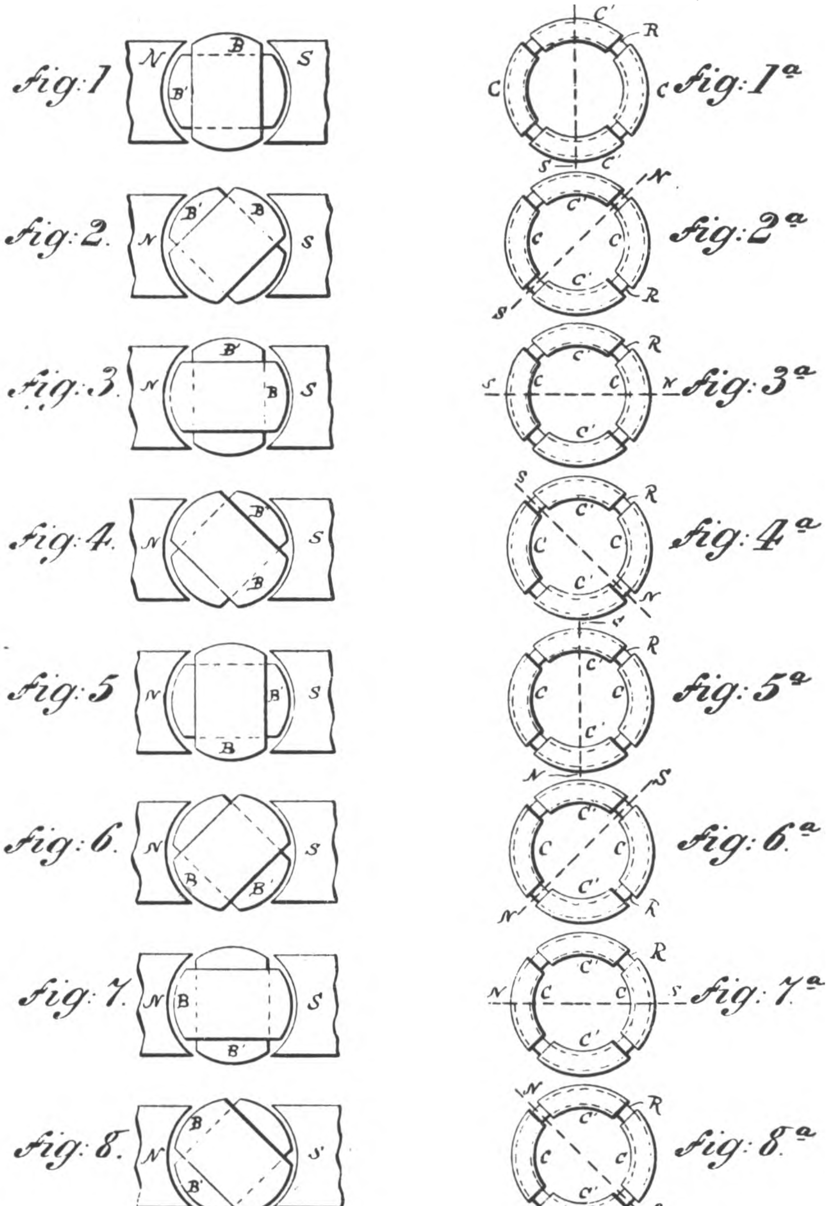
FRANK B. MURPHY.

(No Model.) 4 Sheets — Sheet 1.

N. TESLA.

ELECTRO MAGNETIC MOTOR.

No. 381,968. Patented May 1, 1888.



WITNESSES:

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Frank B. Murphy.

INVENTOR

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ATTORNEYS.

P-34

(No Model.)

4 Sheets — Sheet 2.

N. TESLA.

ELECTRO MAGNETIC MOTOR.

No. 381,968. Patented May 1, 1888.

Fig: 9.

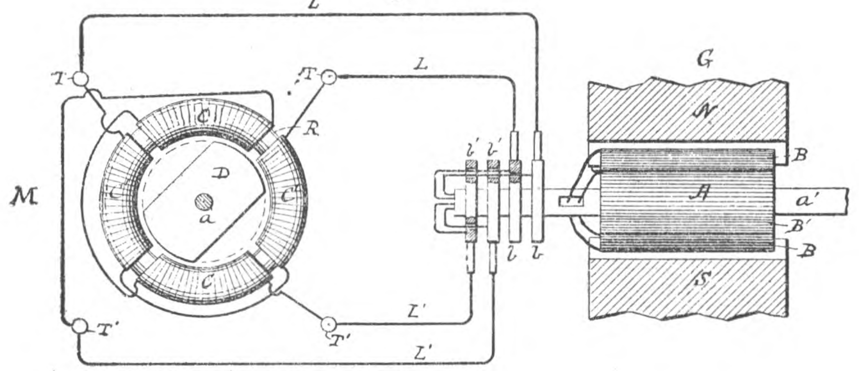


Fig: 10.

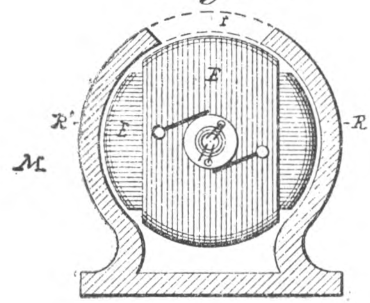


Fig: 11.

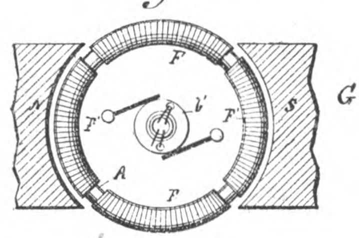
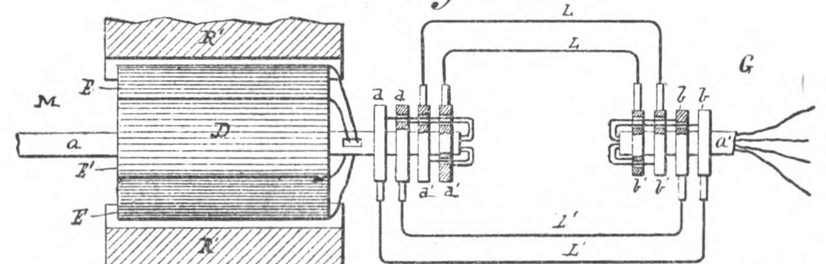


Fig: 12.



WITNESSES:

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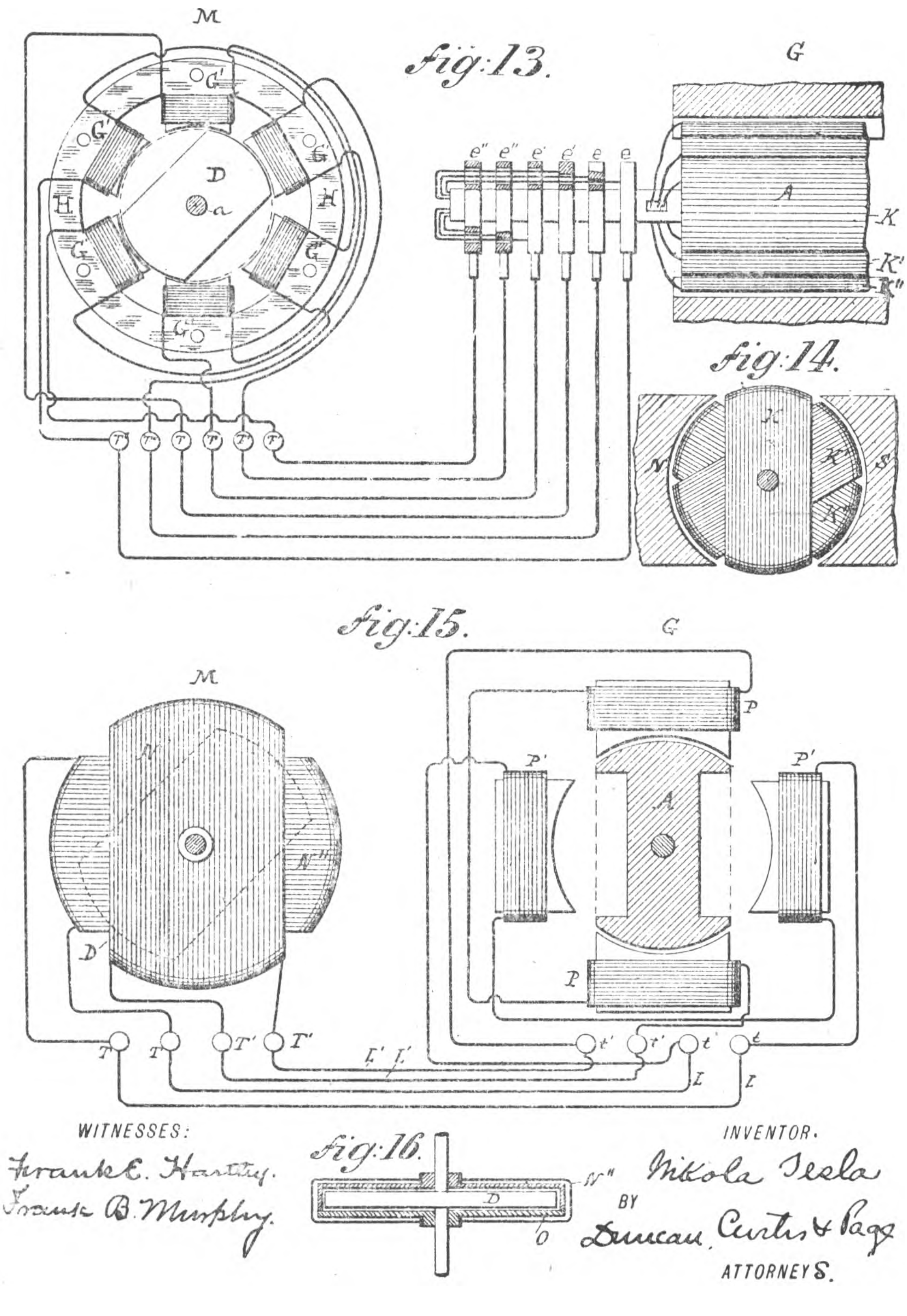
(No Model.)

4 Sheets — Sheet 3.

N. TESLA

ELECTRO MAGNETIC MOTOR.

No. 381,968. Patented May 1, 1888.



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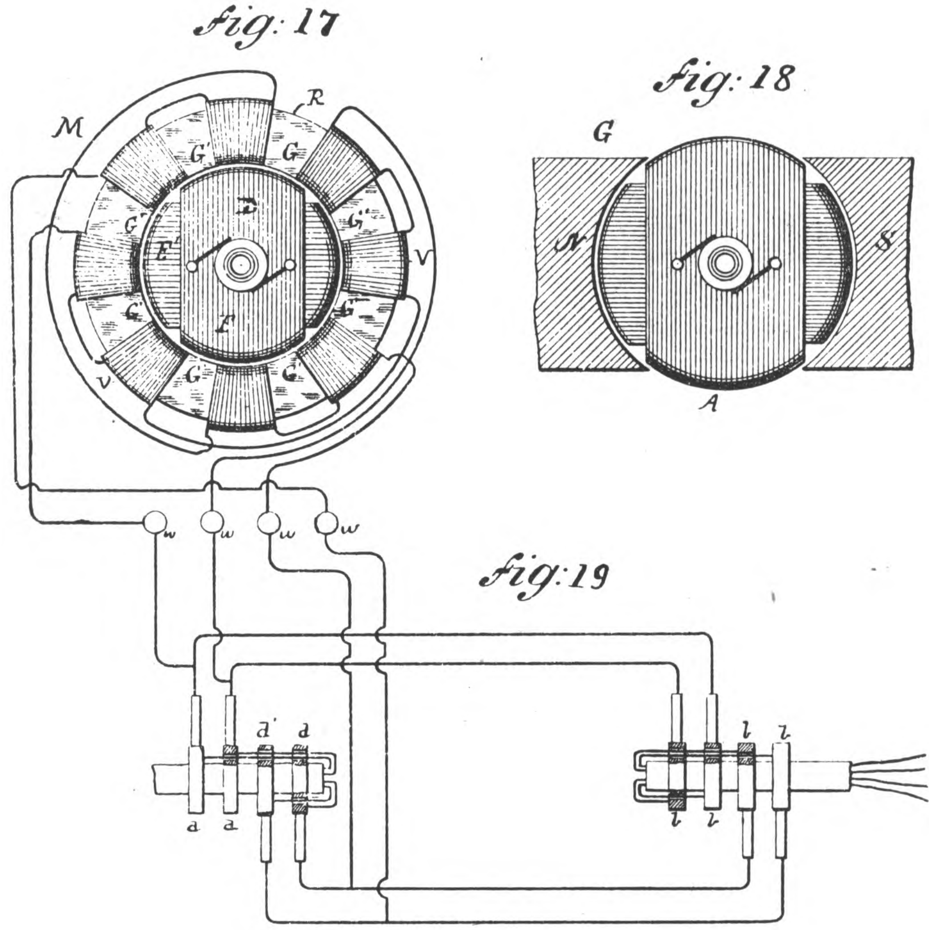
(No Model.) 4 Sheets — Sheet 4

N. TESLA
ELECTRO MAGNETIC MOTOR.

No. 381,968 Patented May 1, 1888.



WITNESSES

Frank E. Hartley

Frank B. Murphy.

INVENTOR

Nikola Tesla,

BY

Duncan Curtis & Page

ATTORNEYS.

UNITED STATES PATENT OFFICE.

NIKOLA TESLA, OF NEW YORK, N. Y., ASSIGNOR OF ONE HALF TO CHARLES F. PECK, OF ENGLEWOOD, NEW JERSEY.

ELECTRO-MAGNETIC MOTOR.

SPECIFICATION forming part of Letters Patent No. 381,969, dated May 1, 1888.

Application filed November 30, 1987. Serial No. 956,563. (No models.)

To all whom it may concern:

Be it known that I, NIKOLA TESLA, from Smiljan Lika, border country of Austria Hungary, now residing in New York, in the county and State of New York, have invented certain new and useful Improvements in Electro-Magnetic Motors, of which the following is a specification, reference being had to the drawings accompanying and forming a part of the same.

In an application filed by me October 12, 1887, No. 252,132, I have shown and described a novel form of electro-magnetic motor and a mode of operating the same, which may be generally described as follows: The motor is wound with coils forming independent energizing circuits on either the armature or field magnet, or both, (it is sufficient for present purposes to consider the case in which the coils are on the armature alone,) and these coils are connected up with corresponding circuits on an alternating current generator. As the result of this, currents of alternately opposite direction are sent through the energizing coils of the motor in such manner as to produce a progressive shifting or rotation of the magnetic poles of the armature. This movement of the poles of the armature obviously tends to rotate the armature in the opposite direction to that in which the movement of the poles takes place, owing to the attractive force between said poles and the field magnets, and the speed of rotation increases from the start until it equals that of the generator, supposing both motor and generator to be alike.

As the poles of the armature are shifted in a direction opposite to that in which the armature rotates, it will be apparent that when the normal speed is attained the poles of the armature will assume a fixed position relative to the field-magnet, and that in consequence the field-magnets will be energized by magnetic induction, exhibiting two distinct poles, one in each of the pole pieces. In starting the motor, however, the speed of the armature being comparatively slow, the pole-pieces are subjected to rapid reversals of magnetic polarity; but as the speed increases these reversals become less and less frequent, and finally cease when the movement of the armature become synchronous with that of the generator. This being the case, the field cores and the pole-pieces of the motor become a magnet, but by induction only.

I have found that advantageous results are secured by winding the field-magnets with a coil or coils and passing a continuous current through them, thus maintaining a permanent field, and in this feature my present invention consists.

I shall now describe the apparatus which I have devised for carrying out this invention and explain the mode of using or operating the same.

Figure 1 is an end view in elevation of my improved motor. Fig. 2 is a part horizontal central section, and Fig. 3 is a diagrammatic representation of the motor and generator combined and connected for operation.

Let A A in Fig. 1 represent the legs or pole-pieces of a field-magnet, around which are coils B B, included in the circuit of a continuous-current generator, C, which is adapted to impart magnetism to the said poles in the ordinary manner.

D D' are two independent coils wound upon a suitable cylindrical or equivalent armature-core, which, like all others used in a similar manner, should be split or divided up into alternate magnetic and insulating parts in the usual way. This armature is mounted in non-magnetic cross-bars E E, secured to the poles of the field-magnet. The terminals of the armature-coils D D' are connected to insulated sliding contact-rings *a a b b,* carried by the armature shaft, and brushes *c c'* bear upon these rings to convey to the coils the currents which operate the motor.

The generator for operating this motor is or may be of precisely identical construction; and for convenience of reference I have marked in Fig. 3 its parts, as follows: F F, the field-magnets, energized by a continuous current passing in its field-coils, G G; H H', the coils carried by the cylindrical armature; *d d e e,* the friction or collecting rings, carried by the armature shaft and forming the terminals of the armature-coils; and *f f'*, the collecting-brushes which deliver, the currents developed in the armature-coils to the two circuits *g g',* which connect the generators with the motor.

The operation of this system will be understood from the foregoing. The action of the generator, by causing a progressive shifting of the poles in the motor-armature, sets up in the latter a rotation opposite in direction to that in which the poles move. If, now, the continuous current ba directed, through the field coils, so as to strongly energize the magnet A A, the speed of the motor, which depends upon that of the generator, will not be increased, but the power which produces its rotation wilt be increased in proportion to the energy supplied through the coils B B.

It is characteristic of this motor that its direction of rotation is not reversed by reversing the direction of the current through its field coils, for the direction of rotation depends not upon the polarity of the field, but upon the direction in which the poles of the armature are shifted. To reverse the motor, the connections of either of the circuits *g g'* must be reversed.

I have found that if the field-magnet of the motor be strongly energized by its coils B B and the circuits through the armature coils closed, assuming the generator to be running at a certain speed, the motor will not start; but if the field be but slightly energized or in general in such condition that the magnetic influence of the armature preponderates in determining its magnetic condition the motor will start and, with sufficient current, will reach its maximum or normal speed. For this reason it is desirable to keep at the start and until the motor has attained its normal speed, or nearly so, the field circuit open or to permit but little current to pass through it. I have found, however, if the fields of both the generator and motor be strongly energized that starting the generator starts the motor, and that the speed of the motor is increased in synchronism with the generator. Motors constructed and operated on this principle maintain almost absolutely the same speed for all loads within their normal working-limits; and in practice I have observed that if the motor be overloaded to such an extent as to check its speed the speed of the generator. If its motive power be not too great, is diminished synchronously with that of the motor.

I have in other applications shown how the construction of these or similar motors may be varied in certain well-known ways—as, for instance, by rotating the field about a stationary armature or rotating conductors within the field; but I do not illustrate these features further herein, as with the illustration which I have given I regard the rest as within the power of a person, skilled in the art to construct.

The present form of motor is cheap, simple, reliable, and easy to maintain. It requires the simplest type of generator for its operation, and when properly constructed shows a high efficiency.

I do not claim herein the method of transmitting power which this system involves, having made it the subject of another application for patent.

What I claim is—

The combination, with a motor having independent energizing or armature circuits, of an alternating-current generator with corresponding induced circuits connected with the motor for effecting a progressive shifting of the poles of the motor armature, and a source of continuous current for energizing the field of said motor, as set forth.

NIKOLA. TESLA

Witnesses:

FRANK B. MURPHY,

FRANK E. HARTLEY.

(No Model.)

2 Sheets—Sheet 1.

N. TESLA.

ELECTRO MAGNETIC MOTOR.

No. 381,969.

Patented May 1, 1888.

Fig: 1.

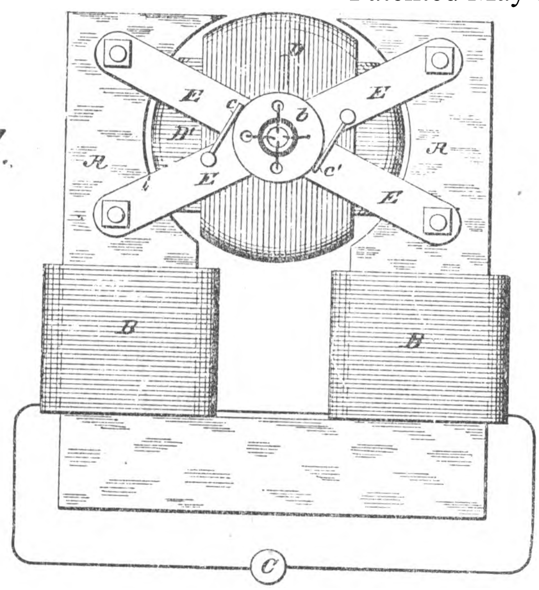
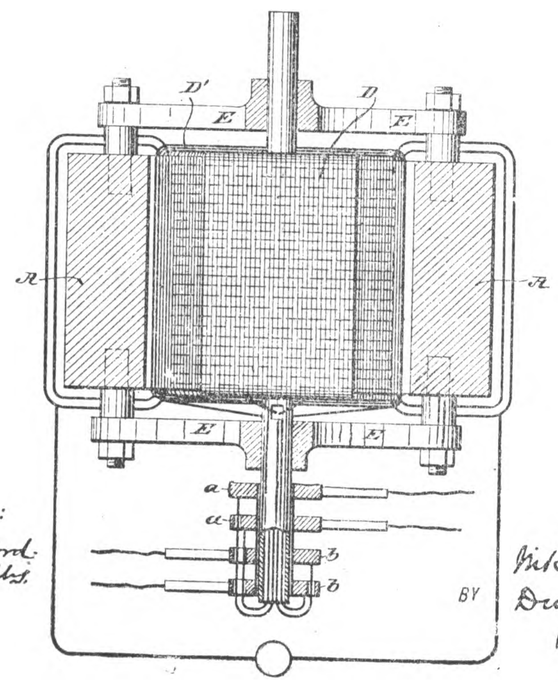


Fig: 2.



WITNESSES:
Robt. F. Gaylord.
Frank B. Murphy.

INVENTOR.
Nikola Tesla
BY
Duncan Curtis & Page
ATTORNEYS.

P-40

(No Model.)

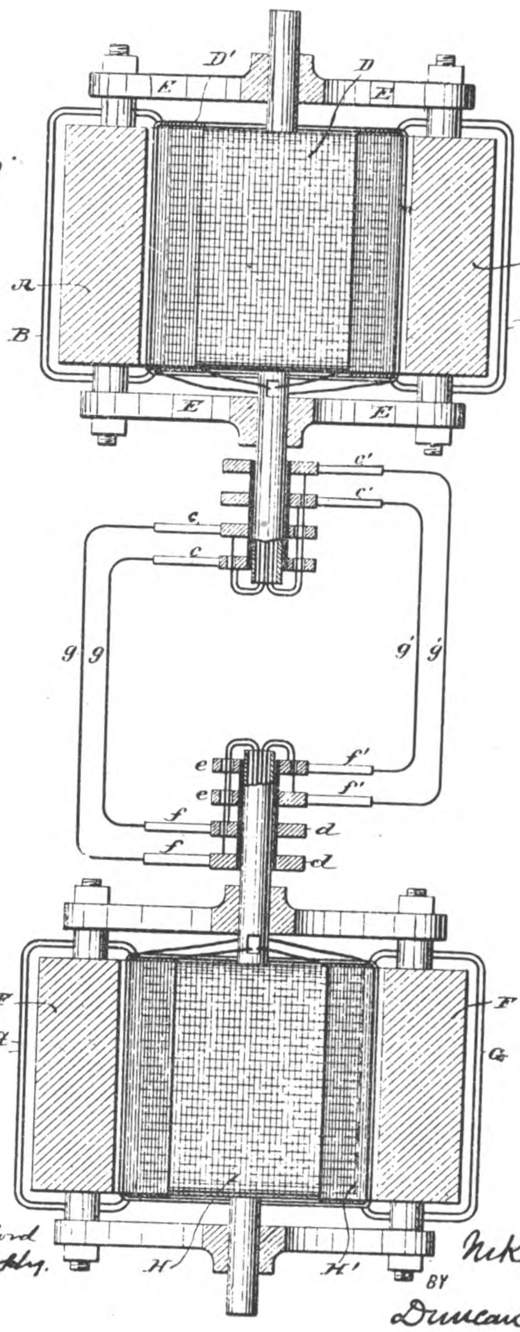
N. TESLA

2 Sheets—Sheet 2

ELECTRO MAGNETIC MOTOR.

No 381,969. Patented May 1, 1888.

Fig: 3



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ATTORNEYS.

UNITED STATES PATENT OFFICE.

NIKOLA TESLA, OF NEW YORK, N.Y., ASSIGNOR OF ONE-HALF TO CHARLES F. PECK, OF ENGLEWOOD, NEW JERSEY.

ELECTRO-MAGNETIC MOTOR.

SPECIFICATION forming part of Letters Patent No. 382,279, dated May 1, 1888.

Application filed November 30, 1887. Serial No. 256,561. (No model.)

To all whom it may concern:

Be it known that I, NIKOLA TESLA, a subject of the Emperor of Austria, from Smiljan, Lika, border country of Austria-Hungary, now residing at New York, in the county and State of New York, have invented certain new and useful Improvements in Electro-Magnetic Motors, of which the following is a specification, reference being had to the drawings accompanying and forming a part of the same.

In a former application, filed October 12, 1887, No. 252,132, I have shown and described a mode or plan of operating electric motors by causing a progressive shifting of the poles of one or both of the parts or elements of a motor—that is to say, of either the field magnet or magnets or armature, or both. I accomplish this by constructing a motor with two or more independent energizing-circuits, on the field-magnets, for example, and I connect these up with corresponding induced or generating circuits in an alternating-current generator, so that alternating currents are caused to traverse the motor-circuits. By so doing the poles of the field-magnet of the motor are progressively shifted, and by their attraction upon a rotary armature set up a rotation in the latter in the direction of the movement of the poles. In this case, however, the rotation is produced and maintained by the direct attraction of the magnetic elements of the motor. I have discovered that advantageous results may be secured in this system by utilizing the shifting of the poles primarily to setup currents in a closed conductor located within the influence of the field of the motor, so that the rotation may result from the reaction of such currents upon the field.

To illustrate more fully the nature of the invention I refer to the accompanying drawings.

Figure 1 represents in side elevation, the operative parts or elements of a motor embodying the principles of my invention, and in section the generator for operating the same. Fig. 2 is a horizontal central section of the motor in Fig. 1, the circuits being shown partly in diagram. Fig. 3 is a modified form of motor in side elevation. Fig. 4 is a central horizontal cross-section of Fig. 3.

In Figs. 1 and 2, A is an annular core of soft iron, preferably laminated or formed of insulated sections, so as to be susceptible to rapid variations of magnetism. This core is wound with four coils, C C C' C', the diametrically-opposite coils being connected in the same circuit, and the two free ends of each pair being brought to the terminals *t* and *t'*, respectively, as shown. Within this annular field-magnet A is mounted a soft-iron cylinder or disk, D, on an axis, *a*, in bearings *b b*, properly supported by the frame-work of the machine. The disk carries two coils, E E', of insulated wire, wound at right angles to one another, and having their respective ends joined, so that each coil forms a separate closed circuit.

In illustration of the action or mode of operation of this apparatus, let it be assumed that the annular field-magnet A is permanently magnetized, so as to present two free poles diametrically opposite. If suitable mechanical provision be now made for rotating the field-magnet around the disk, the apparatus exemplifies the conditions of an ordinary magneto-generator, and currents would be set up in the coils or closed conductors E E' on the disk D. Evidently these currents would be the most powerful at or near the points of the greatest density of the lines of force, and they would, as in all similar cases, tend, at least theoretically, to establish magnetic poles in the disk D at right angles to those in the annular field-magnet A. As a result of the well-known reaction of these polarities upon each other, a more or less powerful tendency in the disk to rotate in the same direction as that of the field-magnet would be established. If, on the other hand, the ring or annular field-magnet A be held stationary and its magnetic poles progressively shifted by passing through its coils C C' properly-alternated currents, it is obvious that similar results will follow, for the passage of the currents causing the shifting or whirling of the poles of the field-magnet A induces currents in the closed circuits of the armature coils E E', with the result of setting up a rotation of the disk D in the same direction of such shifting. Inasmuch as the currents are always induced or generated in the coils E E' in the same manner, the poles of the disk or cylinder follow continuously the poles of the annular field-magnet, maintaining, at least theoretically, the same relative positions. This results in an even and perfect action of the apparatus.

In order that the system as a whole may be better understood, I shall now describe the mode or plan devised by me for producing the currents that effect the progressive shifting of the poles of the motor.

In Fig. 1, B B' are the poles or pole nieces of an alternating-current generator. They are permanently magnetized and of opposite polarity. F is a cylindrical or other armature containing the independent coils G G'. These coils are wound at right angles, so that while one is crossing the strongest portion of the field of force the other is at the neutral point. The coils G G' terminate in the two pairs of insulated collecting rings *f* and *f'*, upon which bear the brushes *g g'*. Four wires connect the motor-terminals *t* and *t'* with the brushes *g* and *g'*, respectively. When the generator is rotated, the coil G will at the certain point shown in the drawings be generating its maximum current, while coil G' is neutral. Let it be assumed that this current, is conveyed from the rings *f f* to the terminals *t t* and through the coils C C. Its effect will be to establish poles in the ring midway between the two coils. By the farther rotation of the generator the coil G' is brought within the influence of the field and begins to produce a current, which grows stronger as the said coil approaches the maximum points of the field, while the current produced in the coil G diminishes as the said coil recedes from those points. The current from the coil G', being conveyed to the terminals *t' t'* and through coils C' C', has a tendency to establish poles at right angles to those set up by the coils C C; but, owing to the greater effect of the current in coils C C the result is merely to advance the poles from the position in which they would remain if due to the magnetizing influence of coils C C alone. This progression continues for a quarter-revolution until coil G G becomes neutral and coil G' G' produces its maximum current. The action described is then repeated, the poles having been shifted through one half of the field, or a half-revolution. The second half revolution is accomplished in a similar way, the same polarity being maintained in the shifting poles by the movement of the generator-coils alternately through fields of opposite polarity.

The same principle of operation may be applied to motors of various forms, and I have shown one of such modified forms in Figs. 3 and 4 of the drawings. In these figures, M M' are field-magnets secured to or forming part of a frame, F', mounted on a base, P. These magnets should be laminated or composed of a number of electrically-insulated magnetic sections, to prevent the circulation of induced currents and to render them capable of rapid magnetic changes. These magnetic cores or poles are wound with insulated coils C C', the diametrically opposite coils being connected together in series and their free ends brought to terminals *t t'*, respectively. Between the poles there is mounted, in bearings in the cross-pieces G'', a cylindrical iron core, D, which, in order to prevent the formation of eddying currents, and the loss consequent thereon, is subdivided in the usual way. - Insulated conductors or coils are applied to the cylinder D longitudinally, and for these I may employ copper plates E E', which are secured to the sides and ends of the cylindrical core in well-known ways. These plates or conductors may form one or preferably several independent circuits around the core. In the drawings two of such circuits are shown, formed respectively by the conductors E and E', which are insulated from each other. It is advantageous also to slot these plates longitudinally, to prevent the formation of eddy currents and waste of energy.

From what has now been given the operation of this apparatus will be readily understood. To the binding-posts *t t'* are connected the proper circuits from the generator to cause a progressive shifting of the resultant, magnetic poles produced by the magnets M upon the armature. Thus currents are induced in the closed circuits on the core, which, energizing the core strongly, maintain a powerful attraction, between the same and the field, which causes a rotation of the armature in the direction in which the resultant poles are shifted.

The particular advantage of the construction illustrated in Figs. 3 and 4 is that a concentrated and powerful field, is obtained and a remarkably powerful tendency to rotation in the armature secured. The same results may be obtained in the form illustrated in Figs. 1 and 2, however, by forming polar projections on the field and armature cores.

When these motors are not loaded, but running free, the rotation of the armature is nearly synchronous with the rotation of the poles of the field, and under these circumstances very little current is perceptible in the coils E E'; but if a load is added the speed tends to diminish and the currents in coils E E' are augmented, so that the rotary effort is increased proportionately.

Obviously the principle of this invention is capable of many modified applications, most of which follow as a matter of course from the constructions described. For instance, the armature-coils, or those in which the currents are set up by induction, may be held stationary and the alternating currents from the generator conducted through the rotating inducing or field coils by means of suitable sliding contacts. It is also apparent that the induced coils may be movable and the magnetic parts of the motor stationary; but I have illustrated these modifications fully in the application to which reference has herein been made.

In the case of motors wound with independent field and armature circuits and operated by shifting their poles, as described in my said prior application, I may by short circuiting the armature-coils apply the present invention in order to obtain greater power on starting.

An advantage and characteristic feature of motors constructed and operated in accordance with this invention is their capability of almost instantaneous reversal by a reversal of one of the energizing currents from the generator. This will be understood from a consideration of the working conditions. Assuming the armature to be rotating in a certain direction following the movement of the shifting poles, then reverse the direction of the shifting, which may be done by reversing the connections of one of the two energizing circuits. If it be borne in mind that in a dynamo-electric machine the energy developed is very nearly proportionate to the cube of the speed, it is evident that at such moment an extraordinary power is brought to play in reversing the motor. In addition to this the resistance of the motor is very greatly reduced at the moment of reversal, so that a much greater amount of current passes through the energizing circuits.

The phenomenon alluded to—viz., the variation of the resistance of the motor apparently like that in ordinary motors—I attribute to the variation in the amount of self-induction in the primary or energizing circuits.

These motors present numerous advantages, chief among which are their simplicity, reliability, economy in construction and maintenance, and their easy and dangerless management. As no commutators are required on either the generators or the motors, the system is capable of a very perfect action and involves but little loss.

I do not claim herein the mode or plan of producing currents in closed conductors in a magnetic field which is herein disclosed, except in its application to this particular purpose; but

What I claim is—

1. The combination, with a motor containing independent inducing or energizing circuits and closed induced circuits, of an alternating-current generator having induced or generating circuits corresponding to and connected with the energizing-circuits of the motor, as set forth.

2. An electro magnetic motor having its field-magnets wound with independent coils and its armature with independent closed coils, in combination with a source of alternating currents connected to the field coils and capable of progressively shifting the poles of the field-magnet, as set forth.

3. A motor constructed with an annular field-magnet wound with independent coils and a cylindrical or disk armature wound with closed coils, in combination with a source of alternating currents connected with the field-magnet coils and acting to progressively shift or rotate the poles of the field, as herein set forth.

NIKOLA TESLA.

Witnesses:
FRANK B. MURPHY,
FRANK E. HARTLEY.

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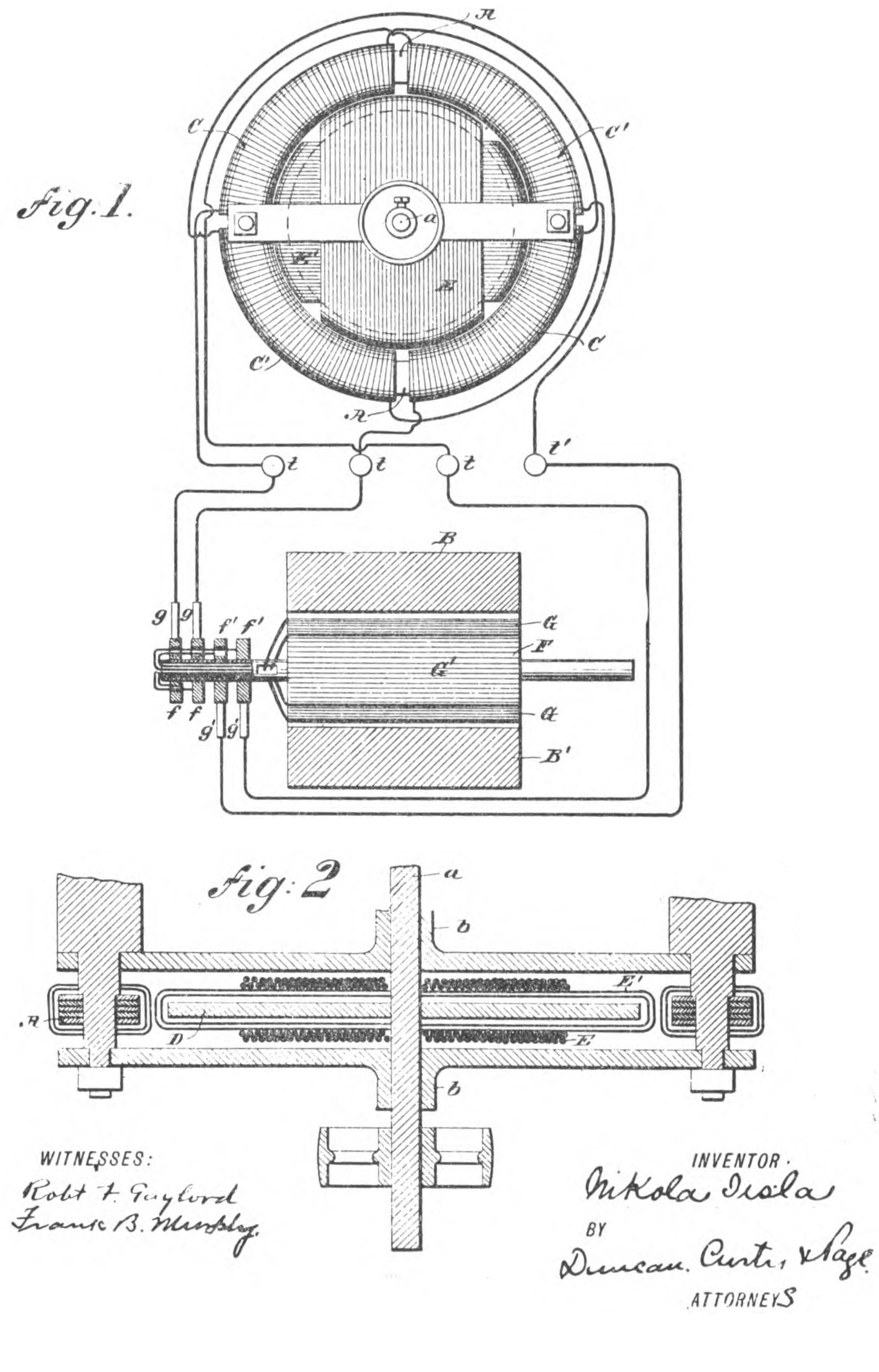
(No Model.) 2 Sheets-Sheet 1.

N. TESLA.

ELECTRO MAGNETIC MOTOR.

No. 382,279. Patented May 1, 1888.



(No Model.) 2 Sheets—Sheet 2.

N. TESLA.

ELECTRO MAGNETIC MOTOR.

No. 382,279. Patented May 1, 1888.

Fig: 3.

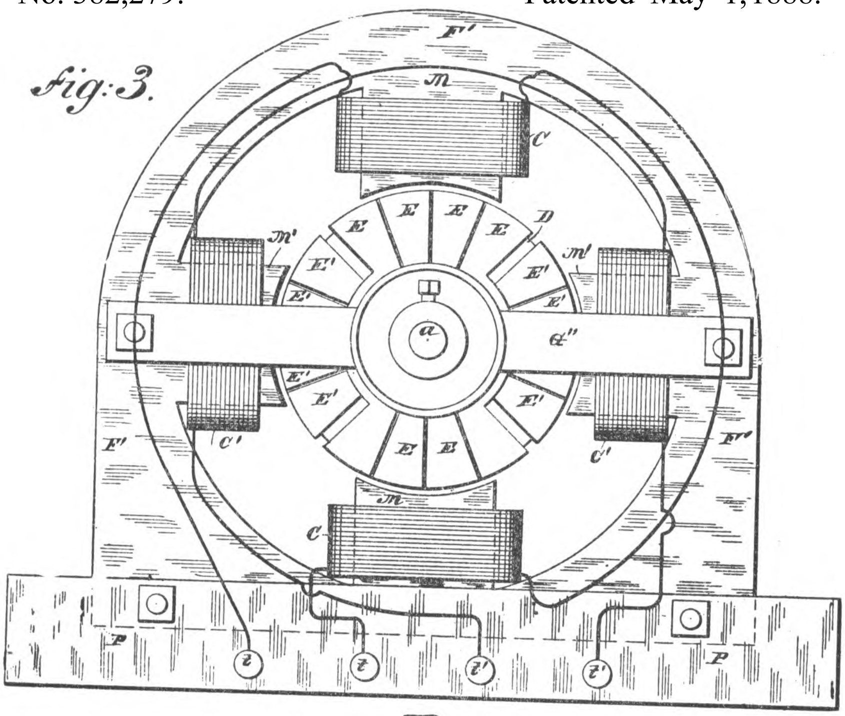
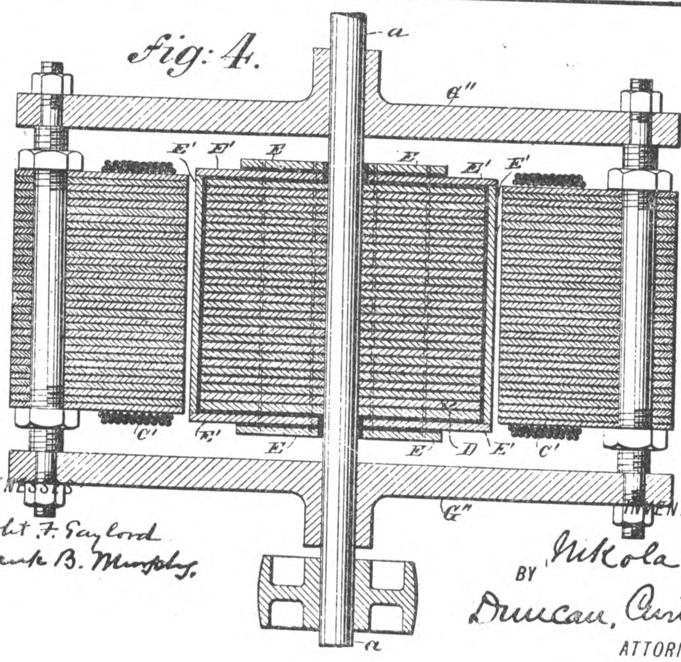


Fig: 4.



UNITED STATES PATENT OFFICE.

NIKOLA TESLA, OF NEW YORK, N. Y., ASSIGNOR TO THE TESLA ELECTRIC COMPANY. OF SAME PLACE.

DYNAMO-ELECTRIC MACHINE.

SPECIFICATION forming part of Letters Patent No. 390.414, dated October 2, 1889.

Application filed April 23, 1888. Serial No 271,626 (No model.)

To all whom it may concern:

Be it known that I, NIKOLA TESLA, a subject of the Emperor of Austria, from Smiljan, Lika, border country of Austria-Hungary, now residing at New York, in the county and State of New York, have invented certain new and useful Improvements in Dynamo-Electric Machines, of which the following is a specification, reference being had to the drawings accompanying and forming a part of the same.

In certain patents granted to Charles F. Peck and myself—notably in Patents No. 381,968 and No. 382,280, May 1, 1888—I have shown and described a plan of constructing and operating motors, transformers, and the like, by alternating currents conveyed through two or more independent circuits from a generator having such relation to the motors or transformers as to produce therein a progressive movement of the magnetic poles or lines of force. In the said applications the descriptions and illustrations of the generators were confined to those types of alternating current machine in which the current generating coils are independent or separate; but I have found that the ordinary forms of continuous current dynamos now in use may be readily and cheaply adapted to my system, or utilized both as continuous and alternating current generators with but slight changes in their construction. The mode of effecting this forms the substance of my present application.

Generally stated, the plan pursued by me in carrying out this invention is as follows: On the shaft of a given generator, either in place of or in addition to the regular commutator, I secure as many pairs of insulated collecting-rings as there are circuits to be formed. Now, it will be understood that in the operation of any dynamo electric generator the currents in the coils in their movement through the field of force undergo different phases—that is to say, at different positions of the coils the currents have certain directions and certain strengths—and that in my improved motors or transformers it is necessary that the currents in the energizing-coils should undergo a certain order of variations in strength and direction. Hence, the further step—viz, the connection between the induced or generating coils of the machine and the contact-rings from which the currents are to be taken off—will be determined solely by what order of variations of strength and direction in the currents is desired for producing a given result in the electrical translating device. This may be accomplished in various ways; but in the drawings I have given typical instances only of the best and most practicable ways of applying the invention to three of the best-known types of machines, in order to illustrate the principle and to enable any one skilled in the art to apply the invention in any other case or under any modified conditions which the circumstances of particular cases may require.

Figure 1 is a diagram illustrative of the mode of applying the invention to the well known type of closed or continuous circuit machines. Fig. 2 is a similar diagram containing an armature with separate coils connected diametrically, or what is generally called an "open-circuit" machine. Fig. 3 is a diagram showing the application of the invention to a machine the armature-coils of which have a common joint.

Referring to Fig. 1, let A represent one of my improved motors or transformers, which, for convenience, I shall designate a "converter", which consists of an annular core, B, wound with four independent coils, C and D, those diametrically opposite being connected together so as to co-operate in pairs in establishing free poles in the ring, the tendency of each pair being to fix the poles at ninety degrees from the other. There may be an armature, E, within the ring, which is wound with coils closed upon themselves. The object is to pass through coils C D currents of such relative strength and direction as to produce a progressive shifting or movement of the points of maximum magnetic effect around the ring, and to thereby maintain a rotary movement of the armature. I therefore secure to the shaft F of the generator four insulated contact-rings, *a b c d,* upon which I cause to bear the collecting-brushes *a′ b′ c′ d′*, connected by wires G G H H, respectively, with the terminals of coils C and D.

Assume, for sake of illustration, that the coils D D are to receive the maximum and coils C C at the same instant the minimum current, so that the polar line be midway between the coils D D, the rings *a b* would therefore be connected to the continuous armature coil at its neutral points with respect to the field or the point corresponding with that of the ordinary commutator brushes, and between which exists the greatest difference of potential, while rings *c d* would be connected to two points in the coil, between which exists no difference of potential. The best re suits will be obtained by making these connections. at points equidistant from one another, as shown. These connections are easiest made by using wires L between the rings and the loops or wires J, connecting the coil I to the segments of the commutator K. When the converters are made in this manner, it is evident that the phases of the currents in the sections of the generator coil will be reproduced in the converter coils. For example, after turning through an arc of ninety degrees the conductors L L, which before conveyed the maximum current, will receive the minimum current by reason of the change in the position of their coils, and it is evident that for the same reason the current in said coils has gradually fallen from the maximum to the minimum in passing through the arc of ninety degrees. In this special plan of connections the rotation of the magnetic poles of the converter will be synchronous with that of the armature coils of the generator, and the result will be the same, whether the energizing circuits are derivations from a continuous armature coil or from independent coils, as in my previous devices.

I have shown in Fig. 1, in dotted lines, the brushes M M in their proper normal position. In practice these brushes may be removed from the commutator and the field of the generator excited by an external source of cur rent; or the brushes may be allowed to remain on the commutator and to take off a converted current to excite the field, or to be used for other purposes.

In a certain well known class of machines the armature contains a number of coils the terminals of which connect to commutator-segments, the coils being connected across the armature in pairs. This type of machine is represented in Fig. 2. In this machine each pair of coils goes through the same phases as the coils in some of the generators I have shown, and it is obviously only necessary to utilize them in pairs or sets to operate one of my converters by extending the segments of the commutators belonging to each pair of coils and causing a collecting brush to bear on the continuous portion of each segment. In this way two or more circuits may be taken off from the generator, each including one or more pairs or sets of coils, as may be desired.

In Fig. 2 I I represent the armature-coils, T T the poles of the field-magnet, and F the shaft carrying the commutators, which are extended to form continuous portions *a b c d.* The brushes bearing on the continuous portions for taking off the alternating currents are represented by *a' b' c' d'.* The collecting brushes, or those which may be used to take off the direct current, are designated by M M. Two pairs of the armature coils and their commutators are shown in the figure as being utilized; but all may be utilized in a similar manner.

There is another well known type of machine in which three or more coils, A' B' C', on the armature have a common joint, the free ends being connected to the segments of a commutator. This form of generator is illustrated in Fig. 3. In this case each terminal of the generator is connected directly or in derivation to a continuous ring, *a b c,* and collecting brushes *a' b' c',* bearing thereon, take off the alternating currents that operate the motor. It is preferable in this case to employ a motor or transformer with three energizing coils, A" B" C", placed symmetrically with those of the generator, and the circuits from the latter are connected to the terminals of such coils either directly—as when they are stationary—or by means of brushes *c'* and contact rings *e.* In this, as in the other eases, the ordinary commutator may be used on the generator, and the current taken from it utilized for exciting the generator field magnets or for other purposes.

These examples serve to illustrate the principle of the invention. It will be observed that in any case it is necessary only to add the continuous contact or collecting rings and to establish the connections between them and the appropriate coils.

It will be understood that this invention is applicable to other types of machine—as, for example, those by which the induced coils are stationary and the brushes and magnet revolve; but the manner of its application is obvious to one skilled in the art.

Having now described my invention, what I claim is—

1. The combination, with a converter having independent energizing-coils, of a continuous or direct current dynamo or magneto machine, and intermediate circuits permanently connected at suitable points to the induced or generating coils of the generator, as herein set forth.

2. The combination, with a converter provided with independent energizing-circuits, of a continuous or direct current generator provided with continuous collecting rings connected in derivation to the armature-coils to form the terminals of circuits corresponding to those of the converter, as herein set forth.

NIKOLA TESLA

Witnesses:

ROBT. F. GAYLORD,

FRANK B. MURPHY.

P-48

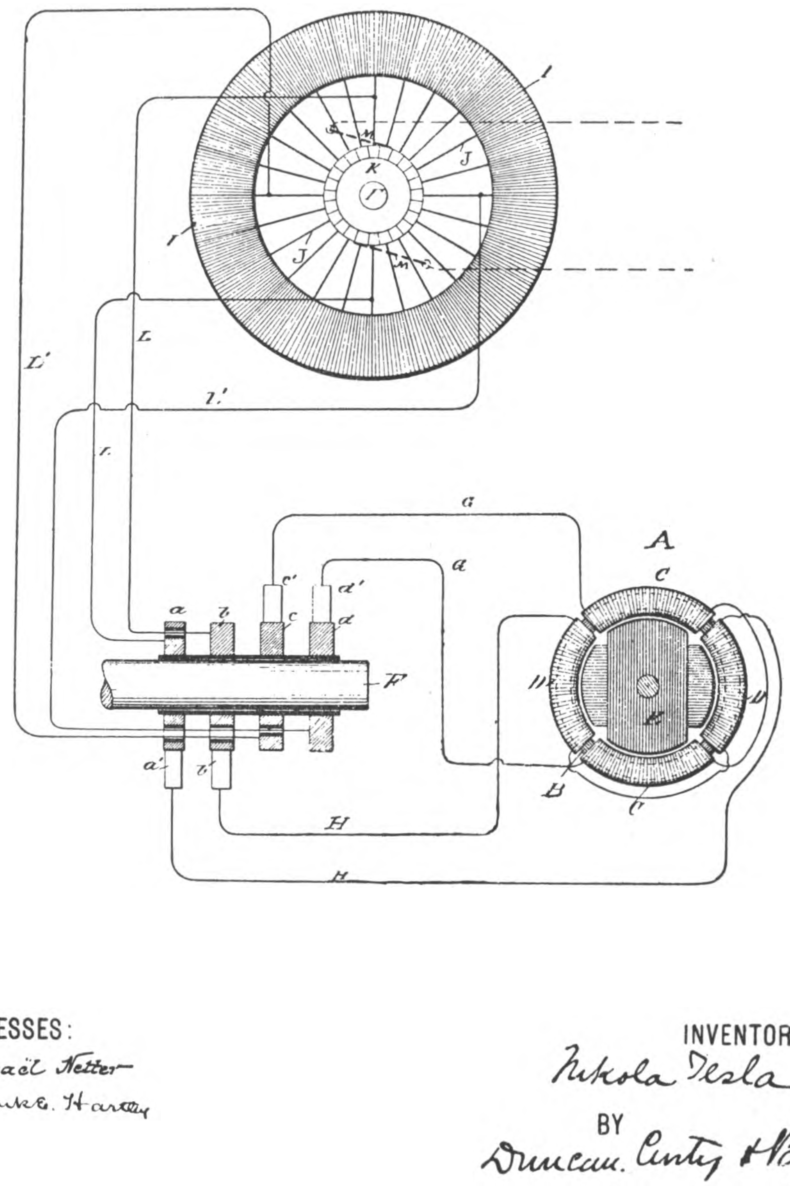
(No Model.) 2 Sheets—Sheet 1

N. TESLA.

DYNAMO ELECTRIC MACHINE.

No. 390,414. Patented Oct. 2, 1888.

Fig. 1



WITNESSES:

Raphaël Netter

Frank E. Hartley

INVENTOR

Nikola Tesla

BY

Duncan, Curtis & Page

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(No Model.) 2 Sheets—Sheet 2.

N. TESLA

DYNAMO ELECTRIC MACHINE.

No. 390.414 Patented Oct. 2, 1888.

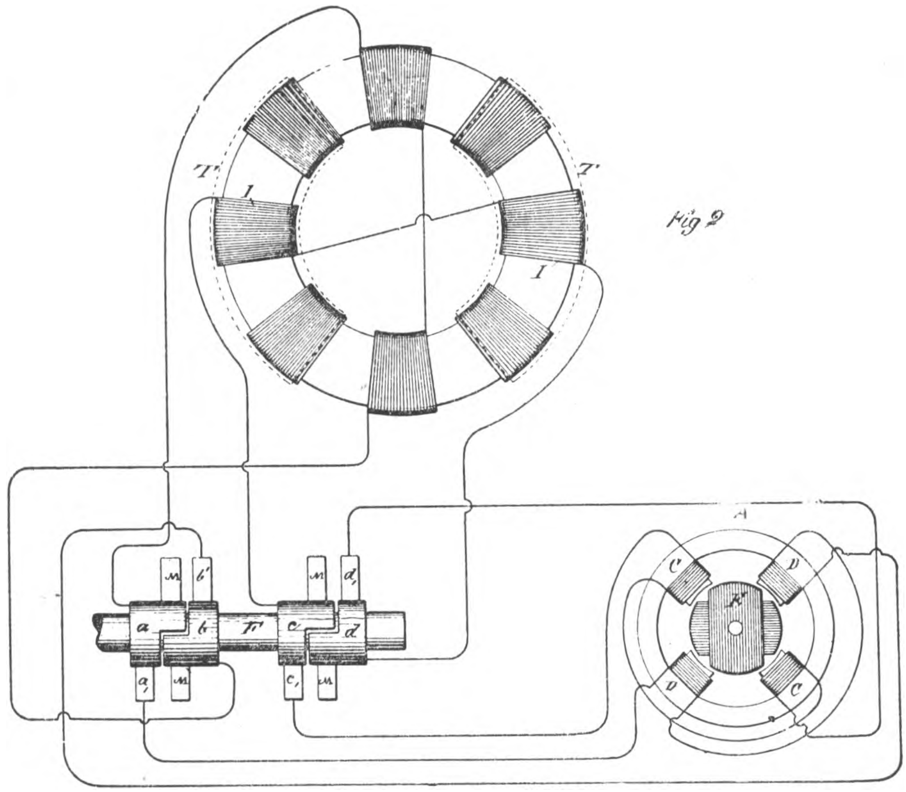

Fig 2

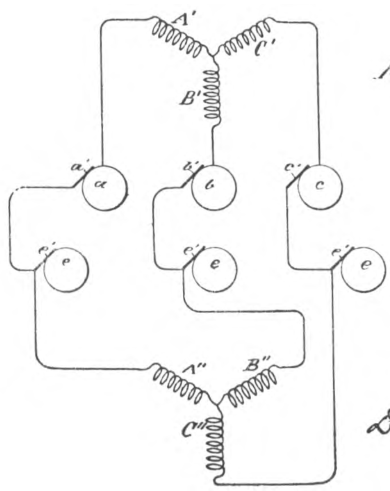

Fig. 3

WITNESSES:
Raphaël Netter
Frank E. Hartley

INVENTOR
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UNITED STATES PATENT OFFICE.

NIKOLA TESLA, OF NEW YORK, N. Y., ASSIGNOR TO THE TESLA ELECTRIC COMPANY, OK SAME PLACE.

REGULATOR FOR ALTERNATIVE-CURRENT MOTORS.

SPECIFICATION forming part of Letters Patent No. 390,820. dated October 9. 1888.

Application filed April 21, 1888. Serial No. 271,682. (No model.)

To all whom it may concern.

Be it known that I, NIKOLA TESLA, a subject of the Emperor of Austria, from Smiljan, Lika, border country of Austria Hungary, now residing in New York, in the county and State of New York, have invented certain new and useful Improvements in Regulators for Alternating Current Motors, of which the following is a specification, reference being had to the drawings accompanying and forming part of the same.

My invent ion is an improvement in systems for the electric transmission of power; and it consists in a means of regulating the speed and power of the motor or motors. The system for use with which the invention is more particularly designed is one in which the motors, or what may be in certain cases their equivalents—the electrical transformers—have two or more independent energizing-circuits, which, receiving current from corresponding sources, act to set up a progressive movement or shifting of the magnetic poles of the motors; but the invention is also applicable to other purposes, as will hereinafter appear. I employ the regulator for the purpose of varying the speed of these motors.

The regulator proper consists of a form of converter or transformer with one element capable of movement with respect to the other, whereby the inductive relations may be altered, either manually or automatically, for the pur pose of varying the strength of the induced current. I prefer to construct this device in such manner that the induced or secondary element may be movable with respect to the other; and the improvement, so far as relates merely to the construction of the device itself, consists, essentially, in the combination, with two opposite magnetic poles, of an armature wound with an insulated coil and mounted on a shaft, whereby it may be turned to the desired extent within the field produced by the poles. The normal position of the core of the secondary element is that in which it most completely closes the magnetic circuit between the poles of the primary element, and in this position its coil is in its most effective position for the inductive action upon it of the primary coils; but by turning the movable core to either side the induced currents delivered by its coil become weaker until, by a movement of the said core and coil through ninety degrees, there will be no current delivered.

The construction of this device, broadly, I do not claim as of my invention; but this, together with the manner of applying and using the same, which forms the subject of my invention, I will now explain by reference to the accompanying drawings.

Figure 1 is a view in side elevation of the regulator. Fig. 2 is a broken section on line *x x* of Fig. 1. Fig. 3 is a diagram illustrating the preferred manner of applying the regulator to ordinary forms of motors, and Fig. 4 is a similar diagram illustrating the application of the device to my improved alternating-current motors.

The regulator may be constructed in many ways to secure the desired result; but in the best form of which I am now aware it is shown in Figs. 1 and 2.

A represents a frame of iron, and I would here state that the plan which is now invariably followed of dividing up all iron cores which are subjected to the influence of alternating currents should be adopted in the construction of this device

B B are the cores of the inducing or primary coils C C, said cores being integral with or bolted to the frame A in any well known way.

D is a shaft mounted in the side bars, D', and on which is secured a sectional iron core, E, wound with an induced or secondary coil, F, the convolutions of which are parallel with the axis of the shaft. The ends of the core are rounded off, so as to fit closely in the space between the two poles and permit the core E to be turned. A handle, G, secured to the projecting end of the shaft D, is provided for this purpose.

Any means may be employed for maintaining the core and secondary coil in any given position to which it is turned by the handle.

The operation or effect of the device will be understood by reference to the diagrams illustrating the manner of its application.

In Fig. 3, let H represent an ordinary alternating current generator, the field magnets of which are excited by a suitable source of current, I. Let J designate an ordinary form of electro-magnetic motor provided with an armature, K, commutator L, and field-magnets M. It is well known that such a motor, if its field-magnets cores be divided up into insulated sections, may be practically operated by an alternating current; but in using my regulator with such a motor I include one element of the motor only—say the armature-coils—in the main circuit of the generator, making the connections through the brushes and the commutator in the usual way. I also include one of the elements of the regulator—say the stationary coils—in the same circuit, and in the circuit with the secondary or movable coil of the regulator I connect up the field-coils of the motor. I prefer to use flexible conductors to make the connections from the secondary coil of the regulator, as I thereby avoid the use of sliding contacts or rings without interfering with the requisite movement of the core E.

If the regulator be in its normal position, or that in which its magnetic circuit is most nearly closed, it delivers its maximum induced current, the phases of which so correspond with those or the primary current that the motor will run as though both field and armature were excited by the main current.

To vary the speed of the motor to any rate between the minimum and maximum rates, the core E and coils F are turned in either direction to an extent which produces the desired result, for in its normal position the convolutions of coil F embrace the maximum number of lines of force, all of which act with the same effect upon said coil; hence it will deliver its maximum current; but by turning the coil F out of its position of maximum effect the number of lines of force embraced by it is diminished. The inductive effect is there fore impaired, and the current delivered by coil F will continue to dimmish in proportion to the angle at which the coil F is turned until, after passing through an angle of ninety degrees, the convolutions of the coil will beat right angles to those of coils C C, and the inductive effect reduced to a minimum.

Incidentally to certain constructions, other causes may influence the variation in the strength of the induced currents. For example, in the present case it will be observed that by the first movement of coil F a certain portion of its convolutions are carried beyond the line of the direct influence of the lines of force, and that the magnetic path or circuit for said lines is impaired; hence the inductive effect would be reduced. Next, that after moving through a certain angle, which is obviously determined by the relative dimensions of the bobbin or coil F, diagonally opposite portions of the coil will be simultaneously included in the field, but in such positions that the lines which produce a current-impulse in one portion of the coil in a certain direction will produce in the diagonally-opposite portion a corresponding impulse in the opposite direction; hence portions of the current will neutralize one another.

As before stated, the mechanical construction of the device may be greatly varied; but the essential conditions of the invention will be fulfilled in any apparatus in which the movement of the elements with respect to one another effects the same results by varying the inductive relations of the two elements in a manner similar to that described.

It may also be stated that the core E is not indispensable to the operation of the regulator; but its presence is obviously beneficial. This regulator, how ever, has another valuable property in its capability of reversing the motor, for if the coil F be turned through a half-revolution the position of its convolutions relatively to the two coils C C and the lines of force is reversed, and consequently the phases of the current will be reversed. This will produce a rotation of the motor in an opposite direction. This form of regulator is also applied with great advantage to my system of utilizing alternating currents, in which the magnetic poles of the field of a motor are progressively shifted by means of the combined effects upon the field of magnetizing-coils included in independent circuits, through which pass alternating currents in proper order and relations to each other.

In illustration, let P represent one of my generators having two independent coils, P' and P", on the armature, and T a diagram of a motor having two independent energizing-coils or sets of coils, R R'. One of the circuits from the generator, as S' S', includes one set, R' R', of the energizing-coils of the motor, while the other circuit, as S S, includes the primary coils of the regulator. The secondary coil of the regulator includes the other coils, R R, of the motor.

While the secondary coil of the regulator is in its normal position it produces its maximum current, and the maximum rotary effect is imparted to the motor; but this effect will be diminished in proportion to the angle at which the coil F of the regulator is turned. The motor will also be reversed by reversing the position of the coil with reference to the coils C C, and thereby reversing the phases of the current produced by the generator. This changes the direction of the movement of the shifting poles which the armature follows.

One of the main advantages of this plan of regulation is its economy of power. When the induced coil is generating, its maximum current, the maximum amount of energy in the primary coils is absorbed; but as the induced coil is turned from its normal position the self-induction of the primary coils reduces the expenditure of energy and saves power.

It is obvious that in practice either coils C C or coil F may be used as primary or secondary, and it is well understood that their relative proportions may be varied to produce any desired difference or similarity in the inducing and induced currents.

I am aware that it is not new to vary the secondary current of an induction-coil by moving one coil with respect to the other, and thereby varying the inductive relations normally existing between the two. This I do not claim.

What I claim is—

1. The combination, with a motor having independent energizing circuits, of an alternating current regulator, consisting, essentially, of inducing and induced coils movable with respect to one another, whereby the strength of the induced currents may be varied, the induced coils being included in and adapted to supply the current for one of the motor-circuits, as set forth.

2. The combination, with a motor adapted to be run or operated by alternating currents and provided with independent energizing-coils, of a regulator consisting of stationary inducing coils and an induced coil capable of being rotated, whereby it may be turned to a greater or less angle to the primary coils, or its position with respect thereto reversed, the induced coil or coils being included in and adapted to supply the current for one of the motor circuits, as set forth.

NIKOLA TESLA.

Witnesses:

ROBT. F. GAYLORD,

FRANK B. MURPHY.

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(No Model.) 2 Sheets—Sheet 1.

N. TESLA.

REGULATOR FOR ALTERNATE CURRENT MOTORS.

No 390,820. Patented Oct. 9, 1888.

Fig. 2

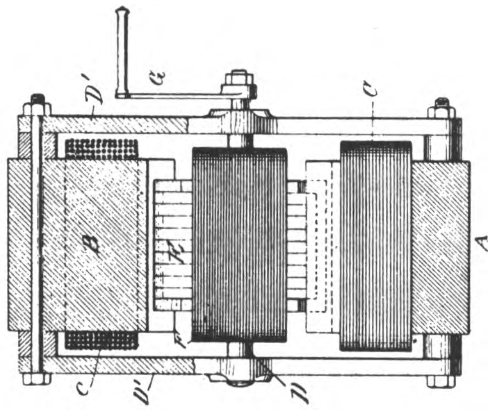
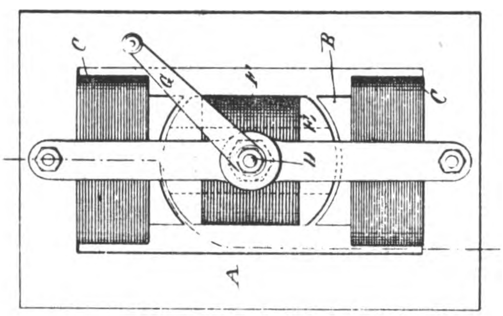


Fig. 1



WITNESSES:
Raphaël Netter
Robt. F. Gaylord

INVENTOR
Nikola Tesla,
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ATTORNEYS

P-54

(No Model.) 2 Sheets—Sheet 2.

N. TESLA.

REGULATOR FOR ALTERNATE CURRENT MOTORS.

No. 390,820. Patented Oct. 9, 1888.

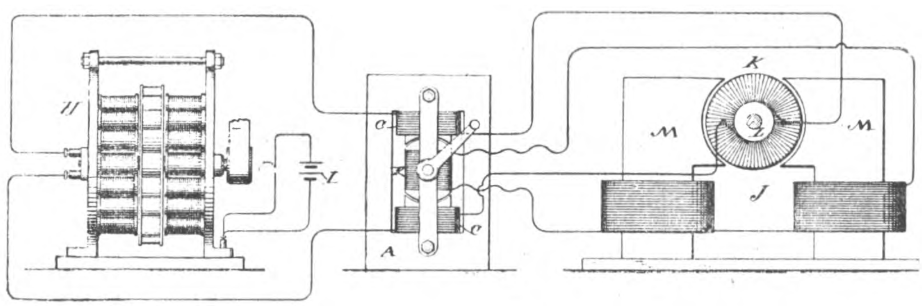
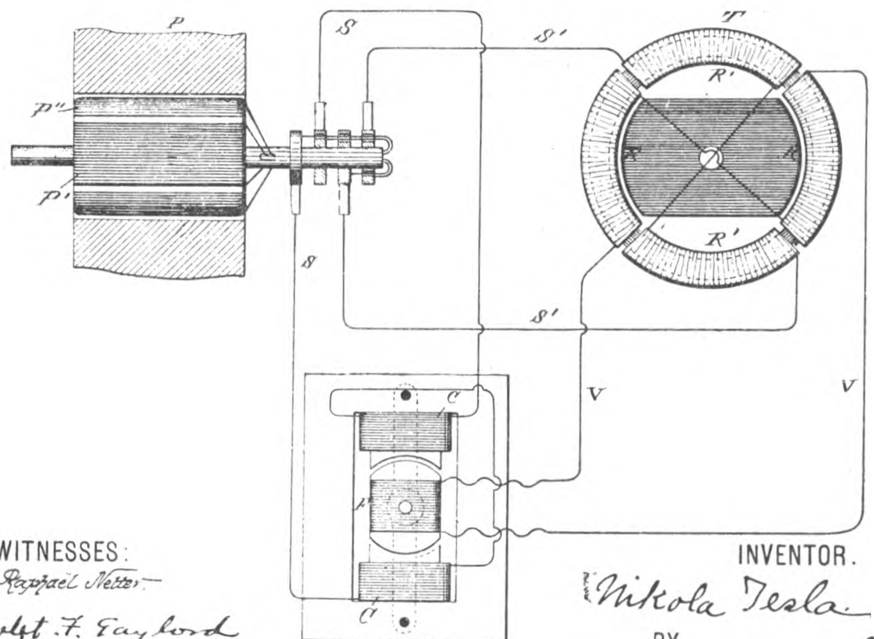


Fig. 4



WITNESSES:
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INVENTOR.
Nikola Tesla
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ATTORNEYS.

UNITED STATES PATENT OFFICE.

NIKOLA TESLA, OF NEW YORK, N. Y., ASSIGNOR TO THE TESLA ELECTRIC COMPANY, OF SAME PLACE.

DYNAMO-ELECTRIC MACHINE.

SPECIFICATION forming part of Letters Patent No. 390,721, dated October 9, 1888.

Application filed April 28, 1888. Serial No. 272,153. (No model.)

To all whom it may concern:

Be it known that I, NIKOLA TESLA, a subject of the Emperor of Austria, from Smiljan, Lika, border country of Austria-Hungary, now residing at New York, in the county and State of New York, have invented certain new and useful Improvements in Electric Generators, of which the following is a specification, reference being had to the drawing accompanying and forming a part of the same.

My present invention relates, chiefly, to the alternating-current system invented by me and described in prior patents, notably Nos. 381,968 and 382,280, of May 1, 1888, in which the motors or transformers, Or generally the converters, are operated by a progressive shifting or movement of their magnetic poles produced by the co-operative action of independent magnetizing-coils through which pass alternating currents in proper order and direction. In my said, system, as I have heretofore shown, I employed a generator of alternating currents in which there were independent induced or generating coils corresponding to the energizing coils of the converter, and the relations of the generator and converters were generally such that the speed of rotation of the magnetic poles of the converter equaled that of the armature of the generator.

To secure the greatest efficiency, it is necessary to run the machines at a high speed, and this is true not only of those generators and motors which are particularly adapted for use in my system, but of others. The practicability of running at very high speeds, however, particularly in the case of large generators, is limited by mechanical conditions, in seeking to avoid which I have devised various plans for operating the system under efficient conditions, although running the generator at a comparatively low rate of speed.

My present invention consists of another way of accomplishing this result, which in certain respects presents many advantages. According to the invention, in lieu of driving the armature of the generator at a high rate of speed, I produce a rotation of the magnetic poles of one element of the generator and drive the other at a different speed, by which similar results are obtained to those secured by a rapid rotation of one of the elements.

I shall describe this invention by reference to the diagram drawing hereto annexed.

The generator which supplies the current for operating the motors or transformers consists in this instance of a subdivided ring or annular core wound with four diametrically-opposite coils, E E'. Within the ring is mounted a cylindrical armature core wound longitudinally with two independent coils, F F', the ends of which lead, respectively, to two pairs of insulated contact or collecting rings, D D' G G', on the armature shaft. Collecting-brushes *d d' g g'* bear upon these rings, respectively, and convey the currents through the two independent line circuits M M'. In the main line there may be included one or more motors or transformers, or both. If motors be used, they are constructed in accordance with my invention with independent coils or sets of coils J J', included, respectively, in the circuits M M'. These energizing-coils are wound on a ring or annular field or on pole pieces thereon, and produce by the action of the alternating currents passing through them a progressive shifting of the magnetism from pole to pole. The cylindrical armature H of the motor is wound with two coils at right angles, which form independent closed circuits.

If transformers be employed, I connect one set of the primary coils, as N N, wound on a ring or annular core, to one circuit, as M', and the other primary coils, N' N', to the circuit M. The secondary coils K K' may then be utilized for running groups of incandescent lamps P P'.

With the generator I employ an exciter. This consists of two poles, A A, of steel permanently magnetized, or of iron excited by a battery or other generator of continuous currents, and a cylindrical armature-core mounted on a shaft, B, and wound with two longitudinal coils, C C'. One end of each of these coils is connected to the collecting-rings *b c,* respectively, while the other ends are both connected to a ring, *a.* Collecting-brushes *b' c'* bear on the rings *b c*, respectively, and conductors L L convey the currents therefrom through the coils E and E' of the generator. L' is a common return wire to brush *a'*. Two independent circuits are thus formed, one including coils O of the exciter and E E of the generator, the other coils C' of the exciter and E' E' of the generator. It results from this that the operation of the exciter produces a progressive movement of the magnetic poles of the annular field core of the generator, the shifting or rotary movement of said poles being synchronous with the rotation of the exciter armature. Considering the operative conditions of a system thus established, it will be found that when the exciter is driven so as to energize the field of the generator the armature of the latter, if left free to turn, would rotate at a speed practically the same as that of the exciter. If under such conditions the coils F F' of the generator armature be closed upon themselves or short-circuited, no currents, at least theoretically, will be generated in the said armature-coils. In practice I have observed the presence of slight currents, the existence of which is attributable to more or less pronounced fluctuations in the intensity of the magnetic poles of the generator ring. So, if the armature-coils F F' be closed through the motor, the latter will not be turned as long as the movement of the generator-armature is synchronous with that of the exciter or of the magnetic poles of its field. If, on the contrary, the speed of the generator armature be in any way checked, so that the shifting or rotation of the poles of the field becomes relatively more rapid, currents will be induced in the armature coils. This obviously follows from the passing of the lines of force across the armature conductors. The greater the speed of rotation of the magnetic poles relatively to that of the armature the more rapidly the currents developed in the coils of the latter will follow one another, and the more rapidly the motor will revolve in response thereto, and this continues until the armature-generator is stopped entirely, as by a brake, when the motor, if properly constructed, runs at the same speed with which the magnetic poles of the generator rotate.

The effective strength of the currents developed in the armature-coils of the generator is dependent upon the strength of the currents energizing the generator and upon the number of rotations per unit of time of the magnetic poles of the generator; hence the speed of the motor armature will depend in all cases upon the relative speeds of the armature of the generator and of its magnetic poles. For example, if the poles are turned two thousand times per unit of time and the armature is turned eight hundred, the motor will turn twelve hundred times, or nearly so. Very slight differences of speed may be indicated by a delicately-balanced motor.

Let it now be assumed that power is applied to the generator armature to turn it in a direction opposite to that in which its magnetic poles rotate. In such case the result would be similar to that produced by a generator the armature and field-magnets of which are rotated in opposite directions, and by reason of these conditions the motor-armature will turn at a rate of speed equal to the sum of the speeds of the armature and magnetic poles of the generator, so that a comparatively low speed of the generator-armature will produce a high speed in the motor.

It will be observed in connection with this system that on diminishing the resistance of the external circuit of the generator-armature by checking the speed of the motor or by adding translating devices in multiple arc in the secondary circuit or circuits of the transformer the strength of the current in the armature-circuit is greatly increased. This is due to two causes: first, to the great differences in the speeds of the motor and generator, and, secondly, to the fact that the apparatus follows the analogy of a transformer, for, in proportion as the resistance of the armature or secondary circuits is reduced, the strength of the currents in the field or primary circuits of the generator is increased and the currents in the armature augmented correspondingly. For similar reasons the corrects in the armature-coils of the generator increase very rapidly when the speed of the armature is reduced when running in the same direction as the magnetic poles or conversely.

It will be understood from the above description that the generator-armature may be run in the direction of the shifting of the magnetic poles, but more rapidly, and that in such case the speed of the motor will be equal to the difference between the two rates.

In many applications to electrical conversion and distribution this system possesses great advantages both in economy, efficiency, and practicability.

What I claim is—

1, The combination, with an alternating current generator having independent energizing or field and independent induced or armature coils, of an alternating-current exciter having generating or induced coils corresponding to and connected with the energizing-coils of the generator, as set forth.

2. In an alternating-current generator, the combination of the elements named and cooperatively associated in the following manner: a field-magnet wound with independent coils each connected with a source of alternating currents, whereby the magnetic poles produced by said coils will be progressively shifted or moved through the field, and an armature-core wound with independent coils, each having terminals from which currents are delivered to the independent external circuits.

3. The system of electrical distribution consisting of the combination, with an alternating-current generator having independent energizing-coils and an armature wound with independent induced coils, of an alternating-current exciter having induced coils corresponding to and connected with the energizing-coils of the generator, and one or more electrical converters having independent inducing or energizing coils connected with the corre-

sponding armature coils of the generator, as herein set forth.

4. The combination, with an alternating current generator having a field-magnet wound with independent energizing-coils and an armature adapted to be rotated within the field produced by said magnet, of an exciter having induced or generating coils corresponding to and connected with the energizing coils of the generator, as set forth.

NIKOLA TESLA.

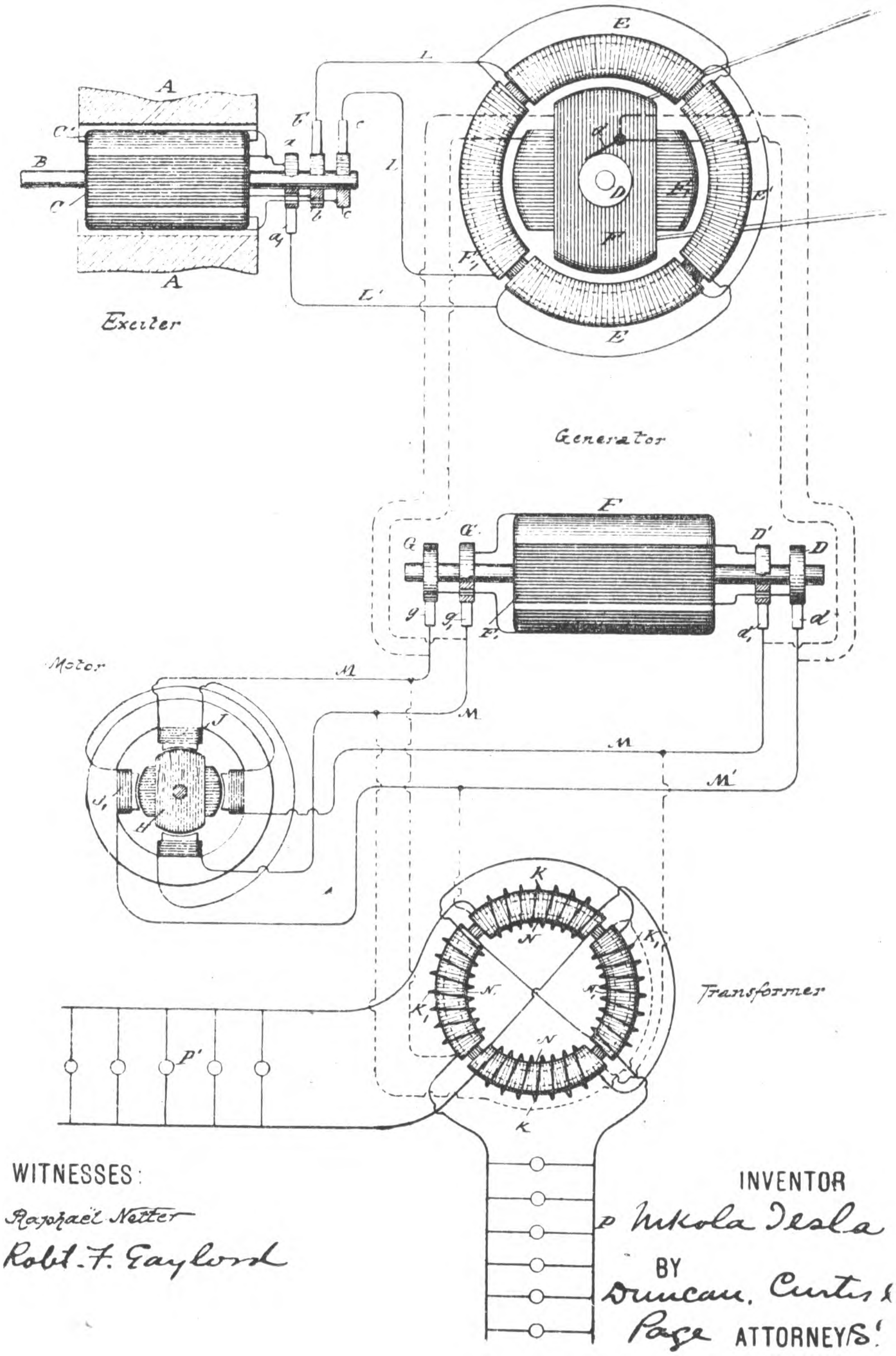
Witnesses:
ROBT. F. GAYLORD,
PARKER W. PAGE.

P-58

(No Model.)

N. TESLA
DYNAMO ELECTRIC MACHINE.

No. 390,721 Patented Oct. 9, 1888.



WITNESSES:

Raphael Netter

Robt. F. Gaylord

INVENTOR

Nikola Tesla

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Duncan, Curtis & Page ATTORNEYS.

UNITED STATES PATENT OFFICE.

NIKOLA TESLA, OF NEW YORK, N. V., ASSIGNOR TO THE TESLA ELECTRIC COMPANY, OF SAME PLACE.

DYNAMO-ELECTRIC MACHINE OR MOTOR.

SPECIFICATION forming part of Letters Patent No. 390,415, dated October 2, 1888.

Application filed May 15, 1888. Serial No. 273,994 (No model.)

To all whom it may concern:

Be it known that I, NIKOLA TESLA, A subject of the Emperor of Austria, from Smiljan, Lika, border country of Austria-Hungary, now residing at New York, in the county and State of New York, have invented certain new and useful Improvements in Dynamo Electric Machines and Motors, of which the following is a specification, reference being had to the drawings accompanying and forming a part of the same.

This invention is an improvement in the construction of dynamo or magneto electric machines or motors, the improvement consisting in a novel form of frame and field magnet which renders the machine more solid and compact as a structure, which requires fewer parts, and which involves less trouble and expense in its manufacture.

The invention is applicable to generators and motors generally, not only to those which I have described in former patents, and which have independent circuits adapted for use in my patented alternating current system, but to other continuous or alternating current machines, such as have heretofore been more generally used.

In the drawings hereto annexed, which illustrate my improvements, Figure 1 shows the machine in side elevation. Fig. 2 is a vertical sectional view of the field magnets and frame and an end view of the armature: and Fig. 3 is a plan view of one of the parts of the frame and the armature, a portion of the latter being cut away.

I cast the field-magnets and frame in two parts. These parts are identical in size and shape, and each consists of the solid plates or ends A B, from which project inwardly the cores C D and the side bars or bridge-pieces, E F. The precise shape of these parts is largely a matter of choice—that is to say, each casting, as shown, forms an approximately rectangular frame; but it may obviously be more or less oval, round, or square without departure from the invention. I also prefer to reduce the width of the side bars, E F, at the center and to so proportion the parts that when the frame is put together the spaces between the pole pieces will be practically equal to the arcs which the surfaces of the poles occupy.

The bearings G for the armature shaft are cast in the side bars, E F. The field-coils are either wound on the pole pieces or preferably, wound on a form and then slipped on over the ends of the pole-pieces. The lower part or casting is secured to a suitable base after being finished off. The armature K on its shaft is then mounted in the bearings of the lower casting and the other part of the frame placed in position, dowel-pins L or any other means being used to secure the two parts in proper position.

In order to secure an easier fit I cast the side bars, E F, and end pieces, A B, so that slots M are formed when the two parts are put together.

This machine possesses many advantages. For example, I magnetize the cores alternately, as indicated by the characters N S, and it will be seen that the magnetic circuit between the poles of each part of a easting is completed through the solid iron side bars. The bearings for the shaft are located at the neutral points of the field, so that the armature core is not affected by the magnetic condition of the field.

My improvement is not, restricted to the use of four pole-pieces, as it is evident that, each pole piece could be divided or more than four formed by the shape of the casting.

What I claim is—

1. A dynamo or magneto electric machine or motor the frame of which is built up of two castings, each consisting of end plates with pole pieces extending inwardly there from and connecting side bars, as set forth.

2. A frame for generators or motors built up of two superposed castings, each consisting of a rectangular frame with pole pieces extending inwardly from its ends, as set forth.

3. A frame and field magnet for generators and motors built up of two rectangular castings having pole-pieces extending inwardly from their ends, the faces of said pole-pieces being curved to afford clearance for the armature and provided with energizing coils, as set forth.

NIKOLA TESLA.

Witnesses:

ROBT. F. GAYLORD,

FRANK E. HARTLEY.

P-60

(No Model.)

N. TESLA.

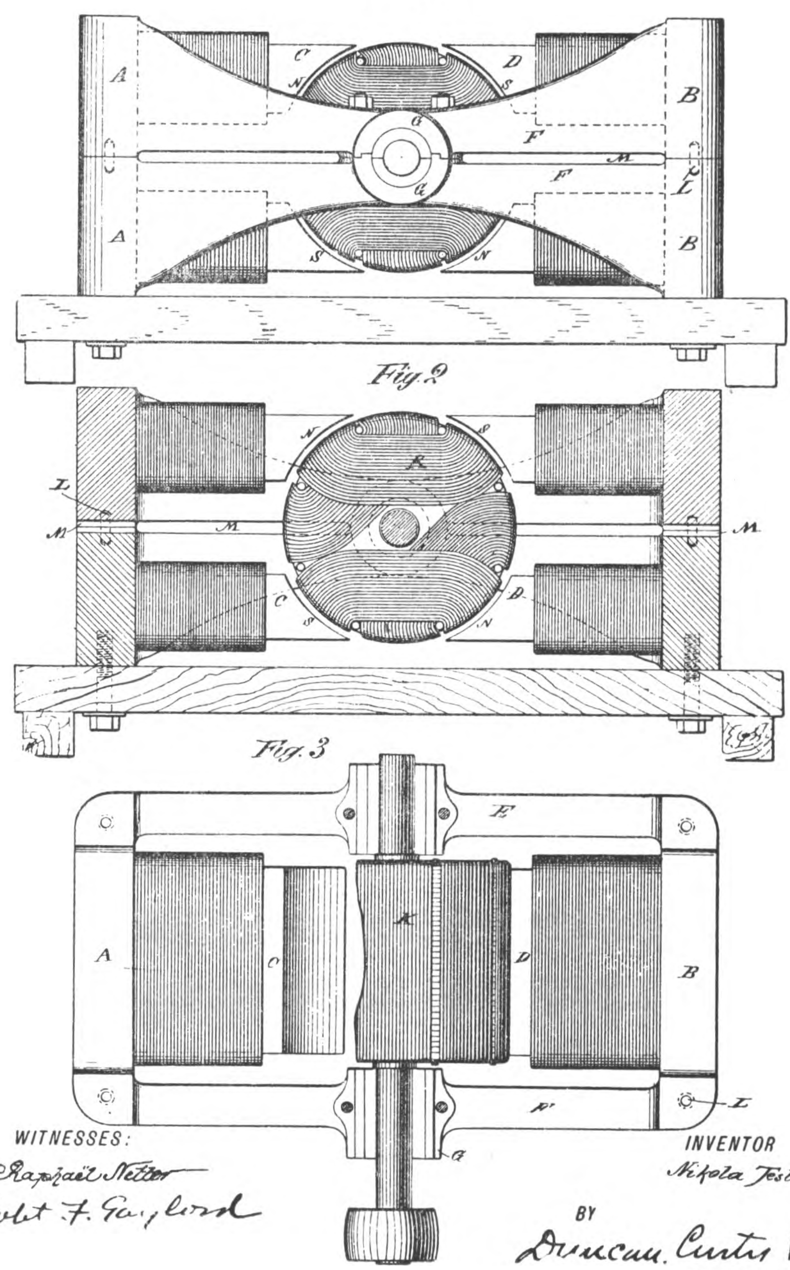
DYNAMO ELECTRIC MACHINE OR MOTOR.

No. 390,415. Patented Oct. 2, 1888.

Fig. 1

Fig. 2

Fig. 3



WITNESSES:

Raphaël Netter

Robt. F. Gaylord

INVENTOR

Nikola Tesla

BY

Duncan, Curtis & Page

ATTORNEYS

UNITED STATES PATENT OFFICE.

NIKOLA TESLA, OF NEW YORK. N. Y., ASSIGNOR TO THE TESLA ELECTRIC COMPANY, OF SAME PLACE

ALTERNATING MOTOR.

SPECIFICATION forming part of Letters Patent No. 555,190, dated February 25, 1896.

Application filed May 16, 1888. Serial No. 273,993. (No model.)

To all whom it may concern:

Be it known that I, NIKOLA TESLA, a citizen of the United States, residing at New York, in the county and State of New York, have invented certain new and useful Improvements in Electromagnetic Motors, of which the following is a specification, reference being had to the drawings accompanying and forming a part of the same.

In former patents granted to me—notably, Patents Nos. 381,968 and 382,280, of May 1, 1888—I have shown and described a system for the electrical transmission of power characterized by the following particulars: The motor contains independent energizing-circuits and the generator has corresponding induced or current-generating circuits which are connected by independent line-circuits with those of the motor, the said circuits being independent in the sense only that the distinctive relations of the currents produced, transmitted and utilized in each are preserved to produce their proper conjoint effect. The disposition of the generator coils or circuits is such that, the currents developed therein and transmitted therefrom to the motor will have a certain difference of phase—for example, so that the maximum periods of the currents generated in one of such circuits coincide with the minimum periods of the currents produced in the other circuit, and the corresponding energizing-circuits of the motor are so arranged that the two currents cooperate to effect a progressive shifting of the magnetic poles or the points of maximum magnetic effect in the motor, in consequence of which a rotation of its movable element is maintained.

My present invention pertains to this system of electrical transmission of power, its novel and distinguishing feature, however, being a special means for generating or producing in the two motor-circuits the alternating current necessary for the operation of the motor, for while in the instances referred to I produce both currents directly by a magneto-electric machine in the present instance I generate or produce in but one of the circuits of the motor directly an alternating current, and by means of such current induce in the other energizing-motor circuit the other alternating current necessary for its operation.

When the two currents are both produced in the magneto-electric machine, it will be observed that the two line or transmitting circuits will of necessity extend the entire distance from the generator to the motor; but by the plan herein provided one line-circuit only is required, as the circuit from the generator and the other are brought into inductive relation to each other in the motor itself.

The following is illustrative of a means by which I secure this result in accordance with my present invention: I employ as a motor, for example, a subdivided annular field-magnet within which is mounted a suitable armature, at a cylinder or disk, wound with two coils at right angles, each of which forms a closed circuit. On opposite sides of the annular field-magnet I wind two coils of insulated wire of a size adapted to carry the current from the generator. Over these coils, or close to them, in any of the well-understood ways, I wind secondary coils. I also wind on the annular field-magnet midway between the first-mentioned coils a pair of coils which I connect up in circuit with the secondary coils.

The last pair of coils I make of finer wire than the main or line and secondary coils, and with a greater number of convolutions, that they may have a greater relative magnetizing effect than either of the others.

By connecting up the main coils in circuit with a generator of alternating currents, the armature of the motor will be rotated. I have assumed that this action is explained by the following theory: A current-impulse on the line passing through the main coils establishes the magnetic poles of the annular field-magnet at points midway between said coils; but this impulse produces in the secondary coils a current differing in phase from the first, which, circulating through the second pair of energizing-coils, tends to establish the pole at points ninety degrees removed from their first position, with the result of producing a movement or shifting of the poles in obedience to the combined magnetizing effect of the two sets of coils. This shifting, continued by each successive current-impulse, establishes what may be termed a "rotary effort," and operates to maintain the armature in rotation

In the drawings annexed I have shown, in Figure 1, an alternating-current generator connected with a motor shown diagrammatically and constructed in accordance with ray invention, and in Fig. 2 a diagram of a modified form of motor.

A designates any ordinary form of alternating-current generator, and B B the line-wires for connecting, the same with the motor.

C is the annular field-magnet of the motor.

D D are two main coils wound on opposite sides of the ring or annular field and connected up with the line and having a tendency to magnify the ring C with opposite poles midway between the two coils.

E E are two other magnetizing-coils wound midway between the coils D D, but having a stronger magnetizing influence for a current of given strength than, coils D D.

F F are the secondary coils, which are associated with the main coils D D. They are in circuits which include the coils E E, respectively, the connections being made in such order that currents induced in coils F and circulating in coils E will act in opposition to those in coils E in so far only as the location of the magnetic poles in the ring C is concerned.

The armature may be of any of the forms used by me in my alternating-current system, and is shown as wound with two closed coils G H at right angles to each other.

In order to prolong the magnetizing effect of the induced currents in producing a shifting of the poles, I have carried the principle of the construction exhibited in Fig. 1 further, thereby obtaining a stronger and better rotary effect.

Referring to Fig. 2, O is an annular field-magnet having three pairs or oppositely-located sets of polar projections K L M. Upon one pair of these projections, as K, the main energizing coils D are wound. Over these are wound the secondary coils E. On the next polar projections L L are wound the second energizing-coils F, which are in circuit with coils E. Tertiary-induced coils E' are then wound over the coils F, and on the remaining polar projections M the third energizing-coils F' are wound and connected up in the circuit of the tertiary coils E'.

The cylindrical or disk armature core N in thin motor has polar projections wound with coils O, forming closed circuits. My object in constructing the motor in this way is to effect more perfectly the shifting of the points of maximum magnetic effect. For assuming the operation of the motor to be due to the action above set forth, the first effect of a current-impulse in this motor will be to magnetize the pole-pieces K K; but the current thereby induced in coils E magnetizes the pole-pieces L, and the current induced in turn in coils E' magnetizes the pole-pieces M. The pole-pieces are not magnetized, at least to their full extent, simultaneously by this means; but there is enough of a retardation or delay to produce a rotary effect or influence upon the armature. The application of this principle is not limited to the special forms of motor herein shown, as any of the double-circuit alternating current motors invented by me and described in former Letters Patent to me may be adapted to the same purpose.

This invention, moreover, is not limited to the specific means herein shown for inducing in one energizing-circuit of the motor the currents necessary for co-operating with the primary current of the generator for producing the progressive shifting of the poles or points of maximum magnetic effect.

I believe that I am the first to produce any kind of a motor adapted to be operated by alternating currents and characterized by any arrangement of independent circuits brought into inductive relation so as to produce a rotary effort or effect due to the conjoint action of alternating currents from a source of supply in one of the motor-circuits and alternating currents induced by the first-named currents in the other circuit, and this without reference to the specific character or arrangement of the said two circuits in the motor,

What I therefore claim as my invention is—

1. In an electromagnetic motor, the combination of independent energizing-circuits, one adapted to be connected with a source of alternating current, the other arranged in inductive relation to the said first circuit whereby the motor will be operated by the resultant action of the two circuits, as set forth.

2. The combination in an electromagnetic motor, with an alternating coil or conductor and a closed-circuit conductor in inductive relation thereto, of an armature mounted so as to be within the field produced by the coil and closed conductor, as set forth.

3. The combination in an electromagnetic-motor, with energizing-coils adapted to be connected with the generator of induced coils and independent energizing-coils in circuit therewith and arranged to produce a shifting movement of the points of maximum magnetic effect of the motor, as set forth.

4. The combination in an electromagnetic motor of a series of independent energizing-coils or sets of coils and induced coils wound on all the energizing-coils or sets of coils but the last of the series, the first energizing-coil or set of coils being included in circuit with a generator and each succeeding energizing-coil or set of coils being in circuit with the induced coils of the next preceding energizing-coils of the series.

5. In a system for the electrical transmission of power the combination of an alternating-current generator, a motor with an energizing coil or coils connected with the generator, secondary coils in inductive relation to said energizing-coils, and energizing-coils in circuit therewith arranged in substantially

the manner set forth to produce a movement or rotation of the points of maximum magnetic effect of the motor, as set forth.

6. In an electromagnetic motor the combination of independent energizing-circuits, one for connection with a source of alternating currents, the other in inductive relation to the first, whereby a rotary movement or projection of the field-poles will be produced by the conjoint action of the two and an armature mounted within the influence of the field produced by the energizing-circuits and containing closed coils or circuits, as set forth.

NIKOLA TESLA

Witnesses

ROBT F. GAYLORD,

FRANK E. HARTLEY

P-64

(No Model.)

N. TESLA.

ALTERNATING MOTOR.

No. 555,190. Patented Feb. 25, 1896.

Fig. 1

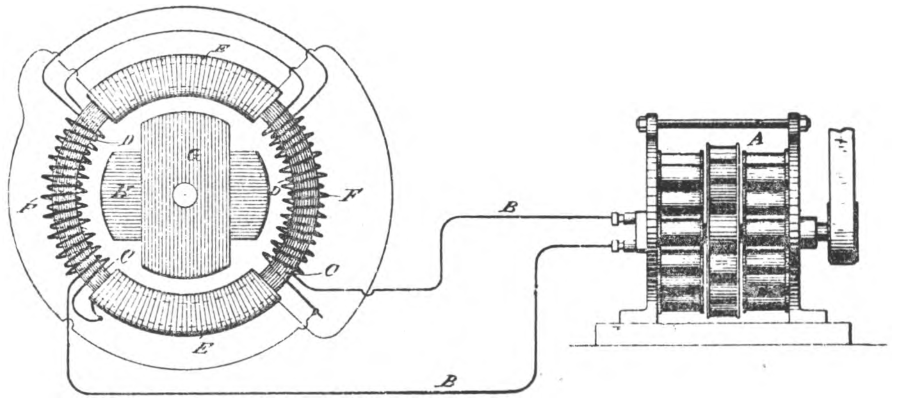
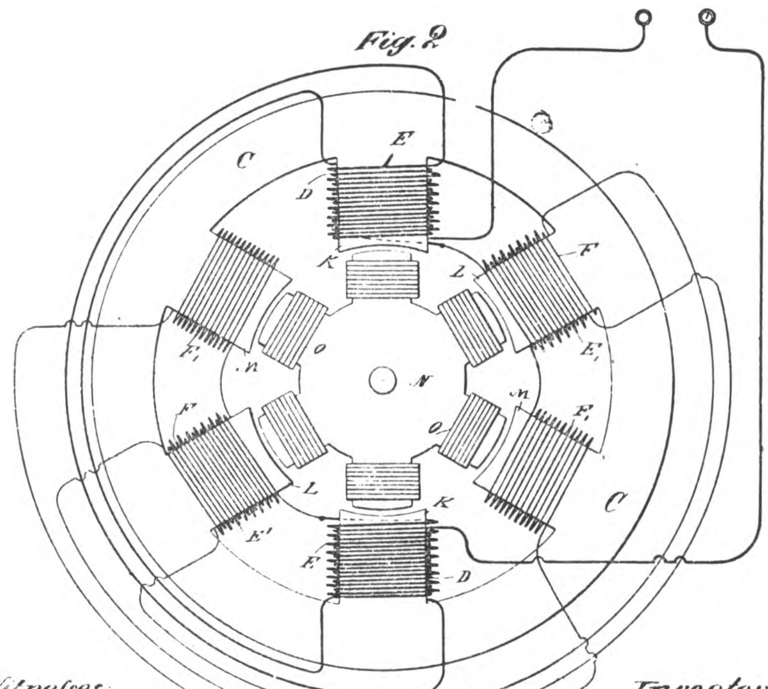


Fig. 2



Witnesses:
Raphaël Netter
Robt. F. Gaylord

Inventor
Nikola Tesla
by
Duncan, Curtis & Page
Attorneys

UNITED STATES PATENT OFFICE.

NIKOLA TESLA, OF NEW YORK, N. Y., ASSIGNOR TO THE TESLA ELECTRIC COMPANY. OF SAME PLACE.

ELECTROMAGNETIC MOTOR.

SPECIFICATION forming part of Letters Patent No. 524,426, dated August 14, 1894.

Application filed October 20, 1888. Serial No. 288,677. (No model.)

To all whom, it may concern:

Be it known that I, NIKOLA TESLA, a subject of the Emperor of Austria-Hungary, from Smiljan, Lika, border country of Austria-Hungary, and a resident of New York, in the county and State of New York, have invented certain new and useful Improvements in Electromagnetic Motors, of which the following is a specification, reference being had to the drawings accompanying and forming a part of the same.

In previous patents of the United States notably in those numbered 381,968 and 382,280, dated May 1, 1888, I have shown and described a system of transmitting power by means of electro-magnetic generators and motors. The distinguishing feature of this system was shown, to be the progressive movement or shifting of the magnetic poles or points of maximum attraction of a motor, due to the action or effect of alternating currents passed through independent energizing circuits in the motor. To secure this result the two currents must have different phases, the best results being obtained when the two currents differ by a quarter phase, or in other words when the periods of maximum potential of one current coincide with the minimum periods of the other, and conversely. I have also discovered that a single alternating current may be utilized to produce a progression or shifting of the magnetic poles of a motor if the field magnets of the same be of different magnetic susceptibility in different parts so that the magnetic phases of the same will differ. That is to say, if the field magnets are of such character that their different portions will be differently magnetized—in respect to time—by the same current impulse, and so disposed that the difference of magnetic phase will maintain a rotary or progressive shifting of the points of maximum magnetic effect. This may be accomplished in various ways, as may best be explained by reference to the accompanying drawings, in which—

Figure 1, is a diagrammatic view of a motor constructed in accordance with my invention and a generator connected therewith. Fig. 2, is an end view of a modified form of armature for said motor.

Let A designate an ordinary type of alternating current generator in the circuit of which is to be connected a motor or motors, according to my present invention. I construct such motor or motors in the following manner: On a shaft *a* I mount an armature C, which for convenience of illustration is presumed to be a soft iron plate or disk with two cut-away portions or a bar with rounded ends. Around this armature I place say four poles, D D E E, of soft iron, and, as is usual in all alternating current machines, built up of insulated plates or sections to prevent the heating that would otherwise occur. Each of these cores is surrounded by an energizing coil F and all of these coils are connected to the main circuit from the generator A in series or in any other manner to receive simultaneously the current impulses delivered by the generator. If the cores are all of the same shape or mass, or composition, and the coils are all wound in the same or alternately opposite directions, no rotation would be produced by the passage through the coils of a current, whether alternating or direct, since the attractive forces of the poles upon the soft iron armature would be developed simultaneously and would counterbalance or neutralize each other. But to secure rotation I make, for example, the cores D D short with their coils close to their inner ends and the cores E E long, with their coils removed from the inner ends. By this means I secure a difference in the magnetic phases which the poles exhibit, for while the short cores will respond to the magnetizing effect of an alternation or impulse of current in the coils in a certain time, a greater interval of time will elapse before the same magnetic intensity will be developed at the ends of the longer cores, and in practice I have found that this difference in phase may be utilized to produce the rotation of the armature. The effect being virtually to produce a shifting of the points of maximum magnetic effect similar to that which takes place when two alternating energizing currents, differing in phase are used, as explained in the patents above referred to. The essential difference being that in my patented system the rotation is effected by a time difference of electrical phase, while in the present case it is due to a difference in magnetic phases

The same or similar results are obtainable by other means. For example, to secure the requisite difference of magnetic phase, I may make two of the cores as E E of greater mass than cores D D, whereby their period of saturation will be greater than of cores D D, or I may make the cores E E of hard iron or steel and the cores D D of soft iron, in which case the cores E E offering greater resistance to magnetic changes, will not exhibit their magnetism as soon after the passage of a current as the cores D D. Or if the cores of one set of poles, as D, D, be removed, the attractive force of the coils or solenoids would be exerted instantly while the magnetic cores E E would lag or have a different phase.

The special form of the motor is largely a matter of choice, nor is the invention limited to the number of poles nor to the special form of armature shown. For example, I may employ such an armature as that shown in Fig 2, which is a cylinder or disk C wound with coils G closed upon themselves. This adds materially to the efficiency of the motor for the reason that currents are induced in the closed coils and magnetize the iron cylinder in a manner similar to that described in my Patent No 383,279 of May 1, 1888.

Without limiting myself, therefore, in the particulars herein before specified, what I claim as my invention is—

1. In an alternating current motor the combination with energizing coils adapted to be, connected with an external circuit of cores of different magnetic susceptibility so as to exhibit differences of magnetic phase under the influence of an energizing current, as herein set forth.

2. The combination in an alternating current motor with a rotary armature of magnetic poles, and coils adapted to be connected with the external circuit surrounding the same, the said cores being constructed of different size or material whereby their magnetic phase will differ in time as set forth.

3. The combination in an electromagnetic motor with a rotary armature of magnetic cores of different length or mass and energizing coils surrounding the same and adapted to be connected with a single source of alternating currents, as set forth.

4. The combination in an electro magnetic motor with a rotary armature of short magnetic cores as D D and long magnetic cores as E E, and energizing coils surrounding the same, those on the cores E E being placed at a distance from the inner ends of the said cores, as herein set forth.

5. The combination in an electro-magnetic motor with energizing coils adapted to be connected with a source of alternating currents, and cores of different magnetic susceptibility, of an armature wound with coils closed upon themselves, as herein set forth.

6. The combination in an electro-magnetic motor with a rotary armature of field cores of different magnetic susceptibility and energizing coils thereon connected in series and adapted to be connected with a source of alternating currents, as set forth.

NIKOLA TESLA.

Witnesses
GEO. N. MONRO,
A. PATTERSON

(No Model.)

N. TESLA.
ELECTROMAGNETIC MOTOR.

No. 524,426 Patented Aug. 14, 1894.

Fig. 1

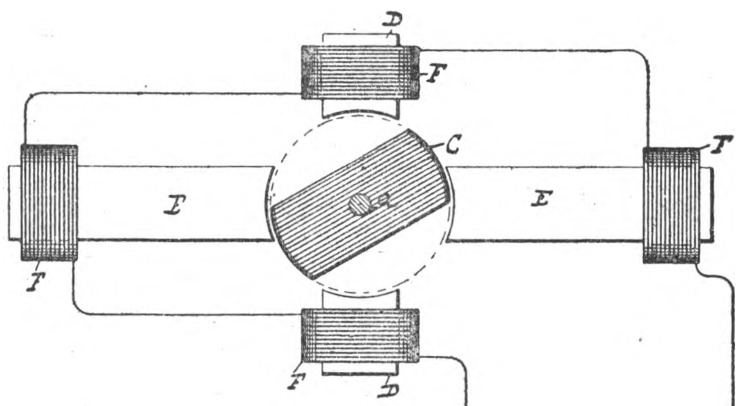
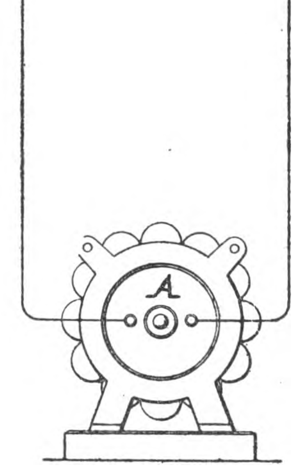
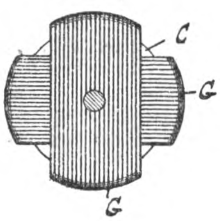



Fig. 2



WITNESSES:
Frank E. Hartley
Frank B. Murphy

Nikola Tesla INVENTOR
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UNITED STATES PATENT OFFICE.

NIKOLA TESLA, OF NEW YORK, N.Y., ASSIGNOR TO THE TESLA ELECTRIC COMPANY, OF SAME PLACE.

ELECTRO-MAGNETIC MOTOR.

SPECIFICATION forming part of Letters Patent No. 405,858, dated June 25, 1889.

Application filed January 8, 1889. Serial Ho. 295,745. (No model.)

To all whom it may concern:

Be it known that I, NIKOLA TESLA, from Smiljan, Lika, border country of Austria-Hungary, a subject of the Emperor of Austria, residing at New York, in the county and State of New York, have invented certain new and useful Improvements in Electro-Magnetic Motors, of which the following is a specification, reference being had to the drawings accompanying and forming a part of the same.

In order to define more clearly the relations which the motor forming the subject of my present application bears to others of the class to which it pertains, I will recapitulate briefly the forms of alternating-current motors invented by me and described more in detail in my prior patents and applications. Of these there are two principal types or forms: first, those containing two or more energizing-circuits through which are caused to pass alternating currents differing from one another in phase to an extent sufficient to produce a continuous progression or shifting of the poles or points of greatest magnetic effect, in obedience to which the movable element of the motor is maintained in rotation; second, those containing poles or parts of different magnetic susceptibility, which under the energizing influence of the same current or two currents coinciding in phase will exhibit differences. in their magnetic periods or phases. In the first class of motors the torque is due to the magnetism established in different portions of the motor by currents from the same or from independent sources, and exhibiting time differences in phase. In the second class the torque results from the energizing effects of a current upon parts of the motor which differ in magnetic susceptibility—in other words, parts which respond to the same relative degree to the action of a current, not simultaneously, but after different intervals of time. In my present invention, however, the torque, instead of being solely the result of a time difference in the magnetic periods or phases of the poles or attractive parts to whatever cause due, is produced by an angular displacement of the parts which, though movable with respect to one another, are magnetized simultaneously, or approximately so, by the same currents. This principle of operation I have embodied practically in a motor in which I obtain the necessary angular displacement between the points of greatest magnetic attraction in the two elements of the motor—the armature and field—by the direction of the lamination of the magnetic cores of said elements, and the best means of accomplishing this result of which I am at present aware I have shown in the accompanying drawings.

Figure 1 is a side view of the motor with a portion of its armature-core exposed. Fig. 2 is an end or edge view of the same. Fig. 3 is a central cross-section of the same, the armature being shown mainly in elevation.

Let A A designate two plates built up of thin sections or laminæ of soft iron insulated more or less from one another and held together by bolts *a* or any other suitable means and secured to a base B. The inner faces of these plates contain recesses or grooves in which a coil or coils D are secured obliquely to the direction of the laminations. Within the coils D is a disk E, preferably composed of a spirally-wound iron wire or ribbon or a series of concentric rings and mounted on a shaft F, having bearings in the plates A A. Such a device when acted upon by an alternating current is capable of rotation and constitutes a motor, the operation of which I explain in the following manner: A current or current-impulse traversing the coils D tends to magnetize the cores A A and E, all of which are within the influence of the magnetic field of the coils. The poles thus established would naturally lie in the same line at right angles to the coils D, but in the plates A they are deflected by reason of the direction of the laminations and appear at or near the extremities of said plates. In the disk, however, where these conditions are not present, the poles or points of greatest attraction are on a line at right angles to the plane of the coils; hence there will be a torque established by this angular displacement of the poles or magnetic lines, which starts the disk in rotation, the magnetic lines of the armature and field tending toward a position of parallelism. This rotation is continued and maintained by the reversals of the current in coils D D, which change alternately the polarity of the field-cores A A. This rotary tendency or effect will be greatly increased by winding the disk with conductors G, closed upon themselves and having a radial direction, whereby the magnetic intensity of the poles of the disk will be greatly increased by the energizing effect of the currents induced in the coils G by the alternating currents in coils D. The plan of winding and the principle of operation have been fully explained in my patent, No. 382,279, of May 1, 1888

The cores of the disk and field may or may not be of different magnetic susceptibility—that is to say, they may both be of the same kind of iron, so as to be magnetized at approximately the same instant by the coils D; or one may be of soft iron and the other of hard, in order that a certain time may elapse between the periods of their magnetization. In either case rotation will be produced; but unless the disk is provided with the closed energizing-coils it is desirable that the above-described difference of magnetic susceptibility be utilized to assist in its rotation.

The cores of the field and armature may be made in various ways, as will be well understood, it being only requisite that the laminations in each be in such direction as to secure the necessary angular displacement of the points of greatest attraction. Moreover, since the disk may be considered as made up of an infinite number of radial arras, it is obvious that what is true of a disk holds, under well-understood conditions, for many other forms of armature, and my invention in this respect is in no sense limited to the specific form of armature shown

It will be understood that the specific ways of carrying out this invention are almost without number, and that, therefore, I do not limit myself to the precise form of motor which I have herein shown

I believe that I am the first to produce rotation of an armature, at least such as could be utilized for any general or practicable purposes, by means of an alternating current passing through a single coil or several coils acting as one, and which have a direct magnetizing effect upon the cores of both armature and field, and this I claim in its broadest sense

I further believe that I am the first to impart directly, by means of an alternating current, magnetism to the cores of the two elements of a motor, and by the direction of the lamination of one or both of the same to produce an angular displacement of the poles or lines of magnetic force of the cores, respectively.

What I therefore claim is—

1. An electro-magnetic motor consisting of a field-magnet, a rotary armature, and a single coil adapted to be connected to a source of alternating currents and to impart magnetism to both the armature and the field-magnet with angular displacement of the maximum points, as set forth.

2. In an electro-magnetic motor, the combination, with a coil adapted to be connected with a source of alternating currents, of a field magnet and rotary armature the cores of which are in such relation to the coil as to be energized thereby and subdivided or laminated in such manner as to produce an angular displacement of their poles or the magnetic lines therein, as set forth

3. In an electro-magnetic motor, the combination, with a coil adapted to be connected with a source of alternating currents, of field-magnets with laminations lying obliquely to the plane of said coil and a circular or disk armature mounted to rotate between the field-magnets, both field and armature being under the magnetizing influence of the coil, as set forth.

4. In an electro-magnetic motor, the combination, with a coil adapted to be connected with a source of alternating currents, of field-magnets with laminations lying obliquely to the plane of the coil and a circular or disk armature with spiral or concentric laminations mounted between the field-magnets, both field and armature being under the magnetizing influence of the coil, as set forth.

5. In an electro-magnetic motor, the combination, with a coil adapted to be connected to a source of alternating currents, of a field-magnet and a rotary armature with closed coils thereon, both the field and the armature being under the magnetizing influence of said coil and laminated to produce an angular displacement of the poles of the two cores.

NIKOLA TESLA

Witnesses

EDWARD T. EVANS.

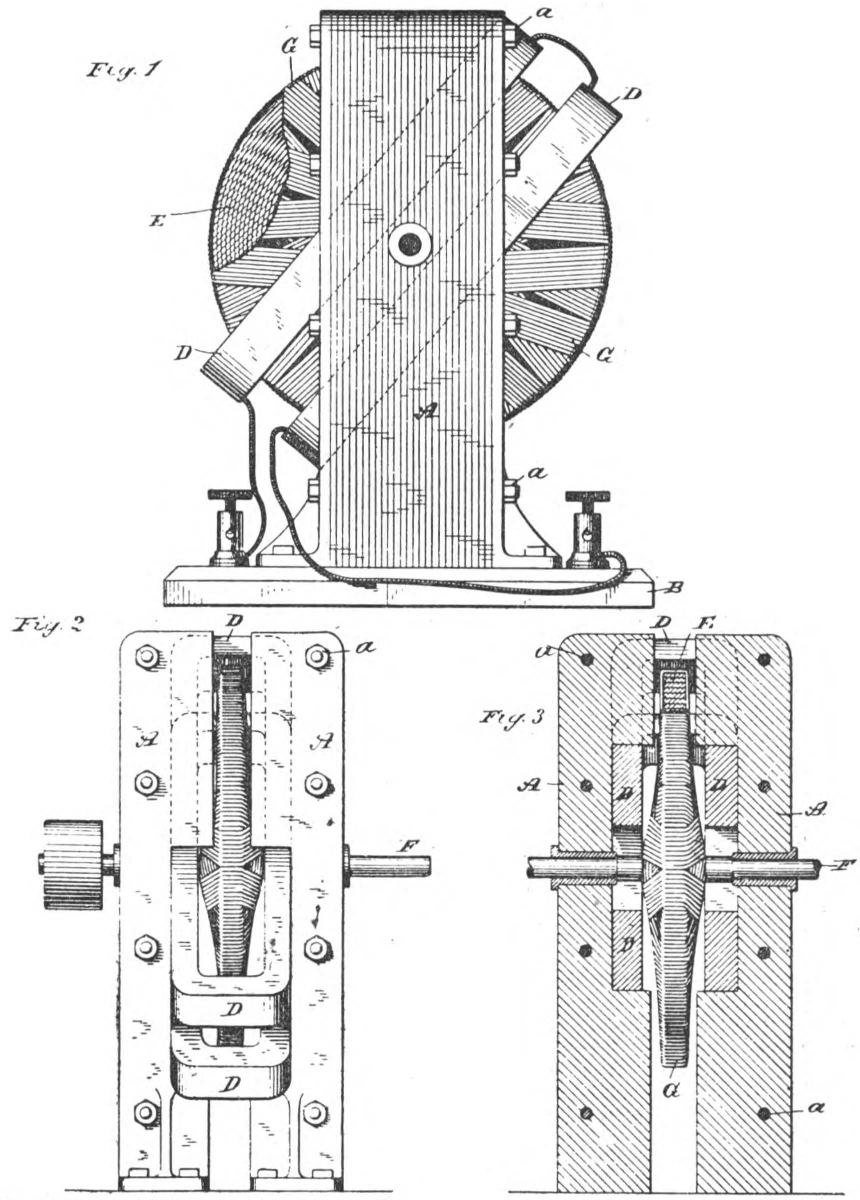
GEORGE N. MONRO.

P-70

(No Model.)

N. TESLA.
ELECTRO MAGNETIC MOTOR.

No. 405,858. Patented June 25, 1889.



WITNESSES

Raphael Netter

Robt. F. Gaylord

INVENTOR

Nikola Tesla

BY

Duncan, Curtis & Page

ATTORNEYS

UNITED STATES PATENT OFFICE.

NIKOLA TESLA, OF NEW YORK. N. Y

METHOD OF OPERATING ELECTRO-MAGNETIC MOTORS.

SPECIFICATION forming part of Letters Patent No. 401,520, dated April 16, 1889.

Application filed February 18, 1889. Serial No. 300,220. (No model.)

To all whom it may concern:

Be it known that I, NIKOLA TESLA, a subject of the Emperor of Austria, from Smiljan, Lika, border country of Austria-Hungary, and residing at New York, in the county and State of New York, have invented certain new and useful Improvements in Methods of Operating Electro-Magnetic Motors, of which the following is a specification, reference being had to the drawings accompanying and forming a part of the same.

As is well known, certain forms of alternating-current machines have the property, when connected in circuit with an alternating-current generator, of running as a motor in synchronism therewith; but, while the alternating current will run the motor after it has attained a rate of speed synchronous with that of the generator, it will not start it. Hence, in all instances heretofore where these "synchronizing-motors," as they are termed, have been run some means have been adopted to bring the motors up to synchronism with the generator, or approximately so, before the alternating current of the generator is applied to drive them. In some instances mechanical appliances have been utilized for this purpose. In others special and complicated forms of motor have been constructed. I have discovered a much more simple method or plan of operating synchronizing-motors, which requires practically no other apparatus than the motor itself. In other words, by a certain change in the circuit-connections of the motor I convert it at will from a double-circuit motor, or such as I have described in prior patents and applications, and which will start under the action of an alternating current into a synchronizing-motor, or one which will be run by the generator only when it has reached a certain speed of rotation synchronous with that of the generator. In this manner I am enabled to very greatly extend the applications of my system and to secure all the advantages of both forms of alternating-current motor.

The expression "synchronous with that of the generator", is used herein in its ordinary acceptation—that is to say, a motor is said to synchronize with the generator when it preserves a certain relative speed determined by its number of poles and the number of alternations produced per revolution of the generator. Its actual speed, therefore, may be faster or slower than that of the generator; but it is said to be synchronous so long as it preserves the same relative speed.

In carrying out my invention I construct a motor which has a strong tendency to synchronism with the generator. The construction which I prefer for this is that in which the armature is provided with polar projections. The field-magnets are wound with two sets of coils, the terminals of which are connected to a switch mechanism, by means of which the line-current may be carried directly through the said coils or indirectly through paths by which its phases are modified. To start such a motor, the switch is turned onto a set of contacts which includes in one motor-circuit a dead resistance, in the other an inductive resist nice, and, the two circuits being in derivation, it is obvious that the difference in phase of the current in such circuits will set up a rotation of the motor. When the speed of the motor has thus been brought to the desired rate, the switch is shifted to throw the main current directly through the motor-circuits, and although the currents in both circuits will now be of the same phase the motor will continue to revolve, becoming a true synchronous motor. To secure greater efficiency, I wind the armature or its polar projections with coils closed on themselves. There are various modifications and important features of this method or plan; but the main principle of the invention will be understood from the foregoing.

In the drawings, to which I now refer, I have illustrated by the diagrams the general features of construction and operation which distinguish my invention, Figure 1 being drawn to illustrate the details of the plan above set forth, and Figs. 2 and 3 modifications of the same.

Referring to Fig. 1, let A designate the field-magnets of a motor, the polar projections of which are wound with coils B C included in independent circuits, and D the armature with polar projections wound with coils E closed upon themselves, the motor in these respects being similar in construction to those described in my patent, No. 382,279, dated May 1, 1888, but having, by reason of the polar projections on the armature-core or other similar and well-known features, the properties of a synchronizing-motor.

L L' represent the conductors of a line from an alternating-current generator G.

Near the motor is placed a switch the action of which is that of the one shown in the drawings, which is constructed as follows: F F' are two conducting plates or arms, pivoted at their ends and connected by an insulating cross-bar, H, so as to be shifted in parallelism. In the path of the bars F F' is the contact 2, which forms one terminal of the circuit through coils C, and the contact 4, which is one terminal of the circuit through coils B. The opposite end of the wire of coils C is connected to the wire L or bar F', and the corresponding end of coils B is connected to wire L' and bar F; hence if the bars be shifted so as to bear on contacts 2 and 4 both sets of coils B C will be included in the circuit L L' in multiple arc or derivation. In the path of the levers F F' are two other contact-terminals, 1 and 3. The contact 1 is connected to contact 2 through an artificial resistance, I, and contact 3 with contact 4 through a self-induction coil, J, so that when the switch-levers are shifted onto the points 1 and 3 the circuits of coils B and C will be connected in multiple arc or derivation to the circuit L L', and will include the resistance and self-induction coil, respectively. A third position of the switch is that in which the levers F and F' are shifted out of contact with both sets of points. In this case the, motor is entirely out of circuit.

The purpose and manner of operating the motor by these devices are as follows: The normal position of the switch, the motor being out of circuit, is off the contact-points. Assuming the generator to be running, and that it is desired to start the motor, the switch is shifted until its levers rest upon points 1 and 3. The two motor-circuits are thus connected with the generator-circuit; but by reason of the presence of the resistance I in one and the self-induction coil J in the other the coincidence of the phases of the current is disturbed sufficiently to produce a progression of the poles, which starts the motor in rotation. When the speed of the motor has run up to synchronism with the generator, or approximately so, the switch is shifted over onto the points 2 and 4, thus cutting out the coils I and J, so that the currents in both circuits have the same phase; but the motor now runs as a synchronous motor, which is well known to be a very desirable and efficient means of converting and transmitting power.

It will be understood that when brought up to speed the motor will run with only one of the circuits B or C connected with the main or generator circuit, or the two circuits may be connected in series. This latter plan is preferably when a current having a high number of alternations per unit of time is employed to drive the motor. In such case the starting of the motor is more difficult and the dead and inductive resistances must take up a considerable proportion of the electro-motive force of the circuits. Generally I so adjust the conditions that the electro-motive force used in each of the motor-circuits is that which is required to operate the motor when its circuits are in series. The plan which I follow in this case is illustrated in Fig. 2. In this diagram the motor has twelve poles and the armature has polar projections D wound with closed coils E. The switch used is of substantially the same construction as that shown in the previous figure. There are, however, five contacts, which I have designated by the figures 5, 6, 7, 8, and 9. The motor-circuits B C, which include alternate field-coils, are connected to the terminals in the following order: One end of circuit C is connected to contact 9 and to contact 5 through a dead resistance, I. One terminal of circuit B is connected to contact 7 and to contact 6 through a self-induction coil, J. The opposite terminals of both circuits are connected to contact S.

One of the levers, as F, of the switch is made with an extension, *f,* or otherwise, so as to cover both contacts 5 and 6 when shifted into the position to start the motor. It will be observed that when in this position and with lever F' on contact 8 the current divides between the two circuits B C, which from their difference in electrical character produce a progression of the poles that starts the motor in rotation. When the motor has attained the proper speed, the switch is shifted so that the levers cover the contacts 7 and 9, thereby connecting circuits Band C in series. I have found that by this disposition the motor is maintained in rotation in synchronism with the generator. This principle of operation, which consists in converting by a change of connections or otherwise a double-circuit motor or one operating by a progressive shifting of the poles into an ordinary synchronizing-motor may be carried out in many other ways. For instance, instead of using the switch shown in the previous figures, I may use a temporary ground circuit between the generator and motor, in order to start, the motor, in substantially the manner indicated in Fig. 3. Let G in this figure represent an ordinary alternating-current generator with, say, two poles, M M', and an armature wound with two coils, N N', at right angles and connected in series. The motor has, for example, four poles wound with coils B C, which are connected in series and an armature with polar projections D wound with closed coils E E. From the common joint or union between the two circuits of both the generator and the motor an earth-connection is established, while the terminals or ends of the said circuits are connected to the line. Assuming that the motor is a synchronizing-motor or one that has the capability of running in synchronism with the generator, but not of starting, it may be started by the above-described apparatus by closing the ground connection from both generator and motor. The system thus becomes one with a two-circuit generator and motor, the ground forming a common return for the currents in the two circuits L and L'. When by this arrangement of circuits the motor is brought to speed, the ground-connection is broken between the motor or generator, or both, and ground, switches P P' being employed for this purpose. The motor then runs as a synchronizing-motor.

In describing those features which constitute my invention I have omitted illustrations of the appliances used in conjunction with the electrical devices of similar systems—such, for instance, as driving-belts, fixed and loose pulleys for the motor, and the like; but these are matters well understood.

In describing my invention by reference to specific constructions I do not wish to be understood as limiting myself to the constructions shown; and in explanation of my intent in this respect I would say that I may in such forms of apparatus as I have shown in Figs. 1 and 2 include the dead resistance and self-induction coil in either circuit, or use only a dead resistance or a self-induction coil, as in the various ways shown in my application, No. 293,052, filed December 8, 1888. I may also use any form of switch, whether manual or automatic, that will by its manipulation or operation effect the required change of connections, and in order to secure the necessary difference of phase in the two motor-circuits on starting I may employ any of the known means for this purpose.

I believe that I am the first to operate electro-magnetic motors by alternating currents in any of the ways herein suggested, or described—that is to say, by producing a progressive movement or rotation of their poles or points of greatest magnetic attraction by the alternating currents until they have reached a given speed, and then by the same currents producing a simple alternation of their poles, or, in other words, by a change in the order or character of the circuit-connections to convert a motor operating on one principle to one operating on another, for the purpose described.

I do not claim herein of itself the method of or apparatus for operating a motor which forms a part of this invention and which involves the principle of varying or modifying the currents passing through the energizing-circuits, so as to produce between such currents a difference of phase, as these matters are described and claimed by me in other applications, but with the object of securing, broadly, the method as a whole which I have herein set forth.

What I claim is—

1. The method of operating an alternating-current motor herein described by first progressively shifting or rotating its poles or points of greatest attraction and then, when the motor has attained a given speed, alternating the said poles, as described.

2. The method of operating an electro-magnetic motor herein described, which consists in passing through independent energizing-circuits of the motor alternating currents differing in phase and then, when the motor has attained a given speed, alternating currents coinciding in phase, as described.

3. The method of operating an electro-magnetic motor herein described, which consists in starting the motor by passing alternating currents differing in phase through independent energizing-circuits and then, when the motor has attained a given speed, joining the energizing circuits in series and passing an alternating current through the same.

4. The method of operating a synchronizing-motor, which consists in passing an alternating current through independent energizing-circuits of the motor and introducing into such circuits a resistance and self-induction coil, whereby a difference of phase between the currents in the circuits will be obtained, and then, when the speed of the motor synchronizes with that of the generator, withdrawing the resistance and self-induction coil, as set forth.

NIKOLA TESLA.

Witnesses:
GEO. M. MONRO,
WM. H. LEMON.

P-74

(No Model.)

N. TESLA.

METHOD OF OPERATING ELECTRO MAGNETIC MOTORS.

No. 401,520. Patented Apr. 16, 1889.

Fig. 1

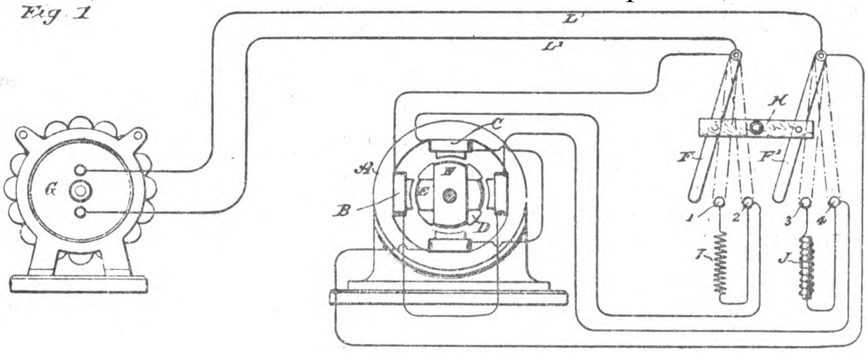


Fig. 2

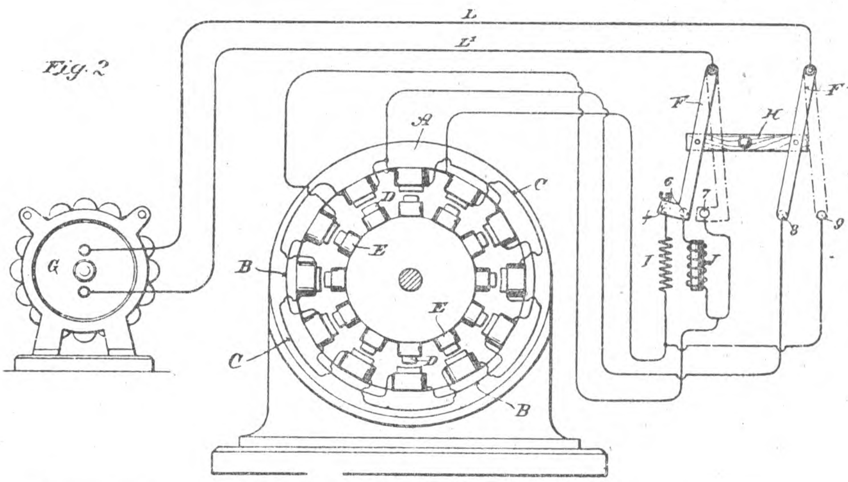
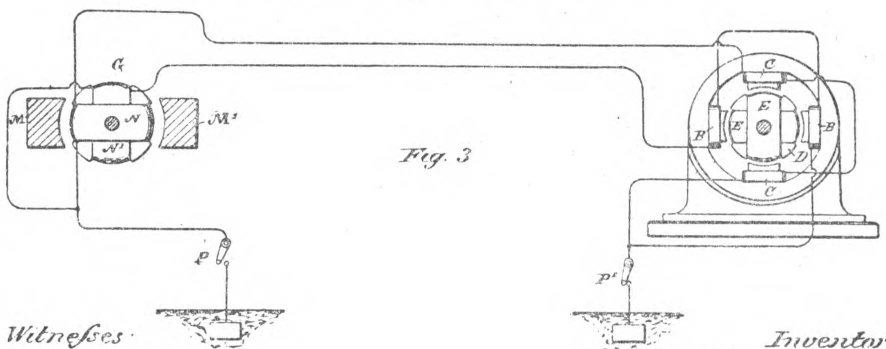


Fig. 3



Witnesses:

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Attorneys.

UNITED STATES PATENT OFFICE.

NIKOLA TESLA, OF NEW YORK, N. Y., ASSIGNOR OF TWO-THIRDS TO CHARLES F. PECK, OF ENGLEWOOD, NEW JERSEY, AND ALFRED S. BROWN, OF NEW YORK, N. Y

DYNAMO-ELECTRIC MACHINE.

SPECIFICATION forming part of Letters Patent No. 406,968, dated July 16, 1889.

Application filed March 23, 1889. Serial No. 304,498. (No model.)

To all whom it may concern:

He it known that I, NIKOLA TESLA, from Smiljan, Lika, border country of Austria-Hungary, a subject of the Emperor of Austria, and a resident of New York, in the county and State of New York, have invented certain new and useful Improvements in Dynamo or Magneto Electric Machines, of which the following is a specification, reference being had to the accompanying drawings.

This invention relates to that class of electrical generators known as "unipolar", in which a disk or cylindrical conductor is mounted between magnetic poles adapted to produce an approximately-uniform field. In the first-named or disk armature machines the currents induced in the rotating conductor flow from the center to periphery, or conversely, according to the direction of rotation or the lines of force as determined by the signs of the magnetic poles, and these currents are taken off usually by connections or brushes applied to the disk at points on its periphery and near its center. In the case of the cylindrical armature-machine the currents developed in the cylinder are taken off by brushes applied to the sides of the cylinder at its ends.

In order to develop economically an electro-motive force available for practicable purposes, it is necessary either to rotate the conductor at a very high rate of speed or to use a disk of large diameter or cylinder of great length; but in either case it becomes difficult to secure and maintain a good electrical connection between the collecting-brushes and the conductor, owing to the high peripheral speed.

It has been proposed to couple two or more disks together in series with the object of obtaining a higher electro-motive force; but with the connections heretofore used and using other conditions of speed and dimension of disk necessary to securing good practicable results this difficulty is still felt to be a serious obstacle to the use of this kind of generator. These objections I have sought to avoid; and for this purpose I construct a machine with two fields, each having a rotary conductor mounted between its poles, but the same principle is involved in the case of both forms of machine above described, and as I prefer to use the disk form I shall confine the description herein to that machine. The disks are formed with flanges, after the manner of pulleys, and are connected together by flexible conducting bands or belts.

I prefer to construct the machine in such manner that the direction of magnetism or order of the poles in one field of force is opposite to that in the other, so that rotation of the disks in the same direction develops a current in one from center to circumference and in the other from circumference to center. Contacts applied therefore to the shafts upon which the disks are mounted form the terminals of a circuit the electro-motive force in which is the sum of the electro-motive forces of the two disks.

I would call attention to the obvious fact that if the direction of magnetism in both fields be the same the same result as above will be obtained by driving the disks in opposite directions and crossing the connecting-belts. In this way the difficulty of securing and maintaining good contact with the peripheries of the disks is avoided and a cheap and durable machine made which is useful for many purposes—such as for an exciter for alternating-current generators, for a motor, and for any other purpose for which dynamo-machines are used.

The specific construction of the machine which I have just generally described I have illustrated in the accompanying drawings, in which—

Figure 1 is a side view, partly in section, of my improved machine. Fig. 2 is a vertical section of the same at right angles to the shafts.

In order to form a frame with two fields of force, I cast a support A with two pole-pieces B B' integral with it. To this I join by bolts E a easting D, with two similar and corresponding pole-pieces C C'. The pole-pieces B B' are wound or connected to produce a field of force of given polarity, and the pole-pieces C C' are wound or connected to produce a field of opposite polarity. The driving-shafts F G pass through the poles and are journaled in insulating-bearings in the casting A D, as shown.

H K are the disks or generating-conductors. They are composed of copper, brass, or iron and are keyed or secured to their respective shafts. They are provided with broad peripheral flanges J. It is of course obvious that the disks may be insulated from their shafts, if so desired. A flexible metallic belt L is passed over the flanges of the two disks, and, if desired, may be used to drive one of the disks. I prefer, however, to use this belt merely as a conductor, and for this purpose may use sheet steel, copper, or other suitable metal. Each shaft is provided with a driving-pulley M, by which power is imparted from a counter-shaft.

N N are the terminals. For sake of clearness they are shown as provided with springs P, that bear upon the ends of the shafts. This machine, if self-exciting, would have copper bands around its poles, or conductors of any kind—such as the wires shown in the drawings—may be used.

I do not limit my invention to the special construction herein shown. For example, it is not necessary that the parts be constructed in one machine or that the materials and proportions herein given be strictly followed. Furthermore, it is evident that the conducting belt or band may be composed of several smaller bands and that the principle of connection herein described may be applied to more than two machines.

What I claim is—

1. An electrical generator consisting of the combination, with two rotary conductors mounted in unipolar fields, of a flexible conductor or belt passing around the peripheries of said conductors, as herein set forth.

2. The combination, with two rotary conducting-disks having peripheral flanges and mounted in unipolar fields, of a flexible conducting belt or band passing around the flanges of both disks, as set forth.

3. The combination of independent sets of field-magnets adapted to maintain unipolar fields, conducting-disks mounted to rotate in said fields, independent driving mechanism for each disk, and a flexible conducting belt or band passing around the peripheries of the disks, as set forth.

NIKOLA TESLA.

Witnesses:

PARKER W. PAGE,

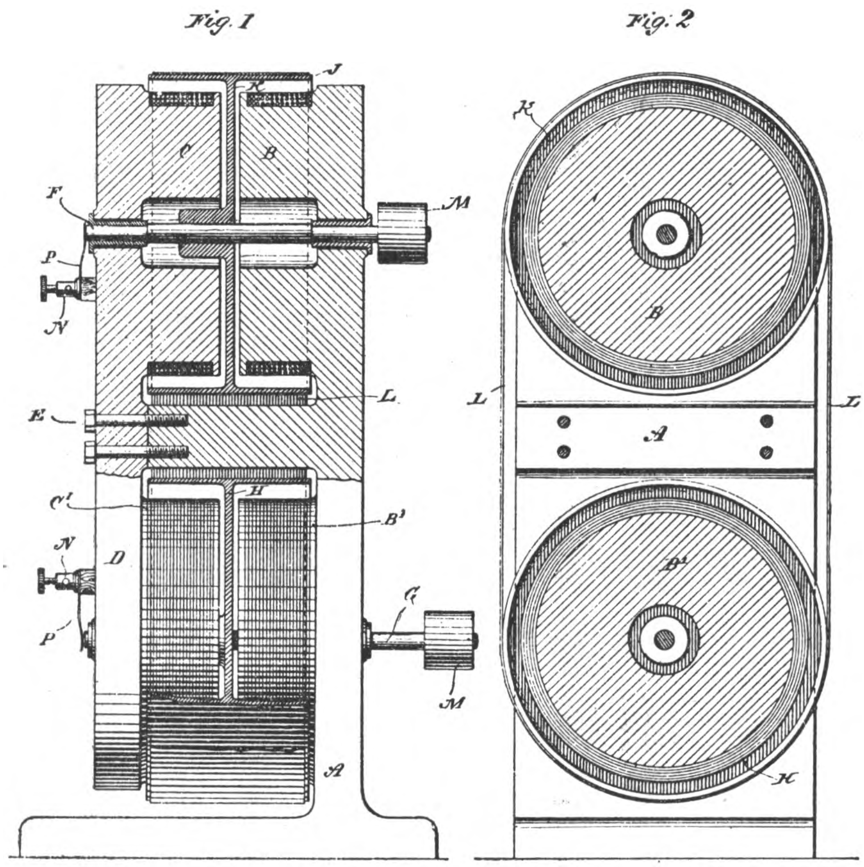
ROBT. F. GAYLORD.

(No Model.)

N. TESLA.

DYNAMO ELECTRIC MACHINE.

No. 406,968. Patented July 16, 1889.



Witnesses:
Robt. F. Gaylord
Ernest Hopkinson

Inventor
Nikola Tesla
by
Duncan, Curtis & Page.
Attorneys.

UNITED STATES PATENT OFFICE.

NIKOLA TESLA, OF NEW YORK, N. Y., ASSIGNOR TO THE TESLA ELECTRIC COMPANY, OF SAME PLACE.

ELECTRO-MAGNETIC MOTOR.

SPECIFICATION forming part of Letters Patent No. 459,772, dated September 22, 1891.

Application filed April 6, 1889. Serial No. 306,165. (No model.)

To all whom it may concern:

Be it known that I, NIKOLA TESLA, a subject of the Emperor of Austria, from Smiljan, Lika, border country of Austria-Hungary, residing at New York, in the county and State of New York, have invented certain new and useful Improvements in Electro-Magnetic Motors, of which the following is a specification, reference being had to the drawings accompanying and forming a part of the same.

As is well known, certain forms of alternating-current machines have the property, when connected in circuit with an alternating-current generator, of running as a motor in synchronism therewith; but while the alternating current will run the motor after it has attained a rate of speed synchronous with that of the generator it will not start it. Hence in all instances heretofore when these "synchronizing motors", as they are termed, have been run, some means have been adopted to bring the motors up to synchronism with the generator, or approximately so, before the alternating current of the generator is applied to drive them.

In an application filed February 13, 1889, Serial No. 300,220, I have shown and described an improved system of operating this class of motors, which consists, broadly, in winding or arranging the motor in such manner that by means of suitable switches it could be started as a multiple-circuit motor, or one operating by a progression of its magnetic poles, and then, when up to speed, or nearly so, converted into an ordinary synchronizing motor, one in which the magnetic poles were simply alternated. In some cases, as when a large motor is used and when the number of alternations is very high, there is more or less difficulty in bringing the motor to speed as a double or multiple-circuit motor, for the plan of construction which renders the motor best adapted to run as a synchronizing motor impairs its efficiency as a torque or double-circuit motor under the assumed conditions on the start. This will be readily understood, for in a large synchronizing motor the length of the magnetic circuit of the polar projections and their mass are so great that apparently considerable time is required for magnetization and demagnetization. Hence with a current of a very high number of alternations the motor may not respond properly. To avoid this objection and to start up a synchronizing motor in which these conditions pertains is the object of my present invention. I have therefore combined two motors, one a synchronizing motor, the other a multiple circuit or torque motor, and by the latter I bring the first named up to speed, and then either throw the whole current into the synchronizing motor or operate jointly both of the motors.

This invention involves several novel and useful features. It will be observed, in the first place, that both motors are run without, commutators of any kind, and, secondly, that the speed of the torque motor may be higher than that of the synchronizing motor, as will be the case when it contains a fewer number of poles or sets of poles, so that the motor will be more readily and easily brought up to speed. Thirdly, the synchronizing motor may be constructed so as to have a much more pronounced tendency to synchronism without lessening the facility with which it is started.

In the drawings I have illustrated the invention.

Figure 1 is a part sectional view of the two motors; Fig. 2, an end view of the synchronizing motor; Fig. 3, an end view and part section of the torque or double-circuit motor; Fig. 4, a diagram of the circuit connections employed; and Figs. 5, 6, 7, 8, and 9 are diagrams of modified dispositions of the two motors.

Inasmuch as neither motor is doing any work while the current is acting upon the other, I prefer to rigidly connect the two armatures. I therefore mount both upon the same shaft A, the field-magnets B of the synchronizing and C of the torque motor being secured to the same base D. The preferably larger synchronizing motor has polar projections on its armature, which rotate in very close proximity to the poles of the field, and in other respects it conforms to the conditions, now well understood, that are necessary to secure synchronous action. I prefer, however, to wind the. pole-pieces of the armature with closed coils K, as this obviates the employment of sliding contacts. The smaller or torque motor, on the other hand, has, preferably, a cylindrical armature F, without polar projections and wound with closed coils G, as I have described in my previous patents, notably No. 382,279, dated May. 1, 1888. The field-coils of the torque motor are connected up in two series H and I, and the alternating current from the generator is directed through or divided between these two circuits in any manner to produce a progression of the poles or points of maximum magnetic effect I secure this result, in a convenient way by connecting the two motor-circuits in derivation with the circuit from the generator, inserting in one motor-circuit a dead, resistance and in the other a self-induction coil, by which means a difference in phase between the two divisions of the current is secured. If both motors have the same number of field-poles, the torque motor for a given number of alternations will tend to run at double the speed of the other, for, assuming the connections to be such as to give the best results, its poles are divided into two series and the number of poles is virtually reduced one-half, which being acted upon by the same number of alternations tend to rotate the armature at twice the speed. By this means the main armature is more easily brought to or above the required speed. When the speed necessary for synchronism is imparted to the main motor, the current is shifted from the torque motor into the other.

A convenient arrangement for carrying out this invention is shown in Fig. 4. In said figure J J are the field-coils of the synchronizing, and H I the field-coils of the torque, motor. L L' are the conductors of the main line. One end of, say, coils H is connected to wire L through a self-induction coil M. One end of the other set of coils I is connected to the same wire through a dead resistance N. The opposite ends of these two circuits are connected to the contact *m* of a switch the handle or lever of which is in connection with the line-wire L'. One end of the field-circuit of the synchronizing motor is connected to the wire L. The other terminates in the switch-contact *n*. From the diagram it will be readily seen that if the lever P be turned onto contact *m* the torque motor will start by reason of the difference of phase between the currents in its two energizing-circuits. Then when the desired speed is attained if the lever P be shifted onto contact *n* the entire current will pass through the field-coils of the synchronizing motor and the other will be doing no work.

The torque motor may be constructed and operated in various ways, many of which I have described in other applications; but I do not deem it necessary in illustration of the principle of construction and mode of operation of my present invention to describe these further herein. It is not necessary that one motor be cut out of circuit while the other is in, for both may be acted upon by the current at the same time and I have devised various dispositions or arrangements of the two motors for accomplishing this. Some of these arrangements are illustrated in Figs. 5 to 9.

Referring to Fig. 5, let T designate the torque or multiple-circuit motor and S the synchronizing motor, L L' being the line-wires from a source of alternating current. The two circuits of the torque motor of different degrees of self-induction, and designated by N M, are connected in derivation to the wire L. They are then joined and connected to the energizing-circuit of the synchronizing motor, the opposite terminal of which is connected to wire L'. The two motors are thus in series. To start them I short-circuit the synchronizing motor by a switch P', throwing the whole current through the torque motor. Then when the desired speed is reached the switch P' is opened, so that the current passes through both motors. In such an arrangement as this it is obviously desirable for economical and other reasons that a proper relation between the speeds of the two motors should be observed.

In Fig. 6 another disposition is illustrated. S is the synchronizing motor and T the torque motor, the circuits of both being in parallel. W is a circuit also in derivation to the motor-circuits and containing a switch P''. S' is a switch in the synchronizing-motor circuit. On the start the switch S' is opened, cutting out the motor S. Then P'' is opened, throwing the entire current through the motor T, giving it a very strong torque. When the desired speed is reached, switch S' is closed and the current divides between both motors. By means of switch P'' both motors may be cut out.

In Fig. 7 the arrangement is substantially the same, except that a switch T' is placed in the circuit which includes the two circuits of the torque motor.

Fig. 8 shows the two motors in series, with a shunt around both containing a switch S T. There is also a shunt around the synchronizing motor S, with a switch P'.

In Fig. 9 the same disposition is shown; but each motor is provided with a shunt, in which are switches P' and T'', as shown.

The manner of operating the systems will be understood from the foregoing descriptions.

I do not claim herein the torque motor nor any part thereof, except in so far as they enter into the combination which forms the subject of this application, for I have made the distinguishing features of said motor the subject of other applications.

What I now claim is—

1. An alternating-current non-synchronizing electric motor coupled with a synchronizing alternating-current motor, substantially as set forth, whereby the former starts the latter, and throws it into synchronism with

its actuating-current, and switch mechanism for directing the current through either or both of the motors, as set forth.

2. The combination of two motors the armatures of which are mounted upon the same shaft, one of said motors being an alternating-current torque motor, or one in which the magnetic points or poles are progressively shifted by the action of the energizing-current, the other motor being an alternating-current synchronizing motor, and switch mechanism for directing the current through either or both of said motors, as set forth.

3. The combination, with an alternating-current synchronizing motor having one energizing-field, of an alternating-current torque motor having a plurality of energizing-circuits and adapted to be operated by currents differing in phase, and a switch for directing the alternating current or currents through the several circuits of one motor or the single circuit of the other, as and for the purpose set forth.

4. The combination, with an alternating-current motor having field-cores wound with coils adapted to be connected to a source of alternating currents and an armature wound with induced coils closed upon themselves, of a starting device for bringing said motor into synchronism with the generator with which it is connected.

5. The combination, with an alternating-current motor composed of a multipolar alternating field-magnet, and an armature having poles wound with coils closed upon themselves, of a starting device, as set forth.

6. In an alternating-current motor, the combination of a field-magnet having poles wound with coils adapted when connected with a source of alternating current to produce simultaneously opposite magnetic polarities and an armature provided with poles or projections and wound with coils connected in a continuously-closed unconnected circuit, as set forth.

7. The herein-described method of operating alternating-current motors, which consists in actuating a motor by an alternating current to bring a second alternating-current motor up to synchronizing speed relative to the actuating-current and then switching the synchronizing motor into circuit.

NIKOLA TESLA.

Witnesses:

GEORGE N. MONRO,

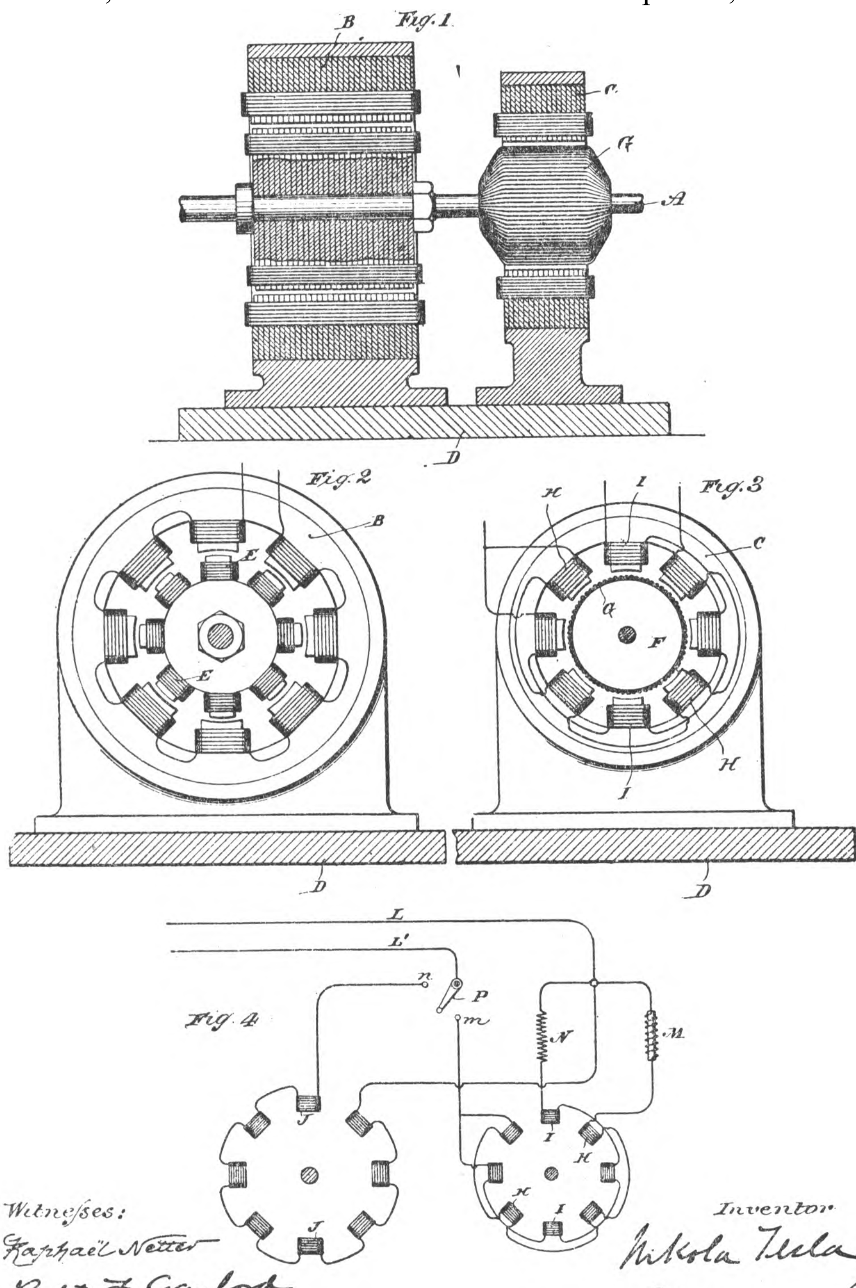
EDWARD T. EVANS.

(No Model.) 2 Sheets—Sheet 1

N. TESLA.

ELECTRO MAGNETIC MOTOR.

No. 459,772. Patented Sept. 22, 1891.



Witnesses:
Raphaël Netter
Robt F. Gaylord

Inventor
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By
Duncan, Curtis & Page
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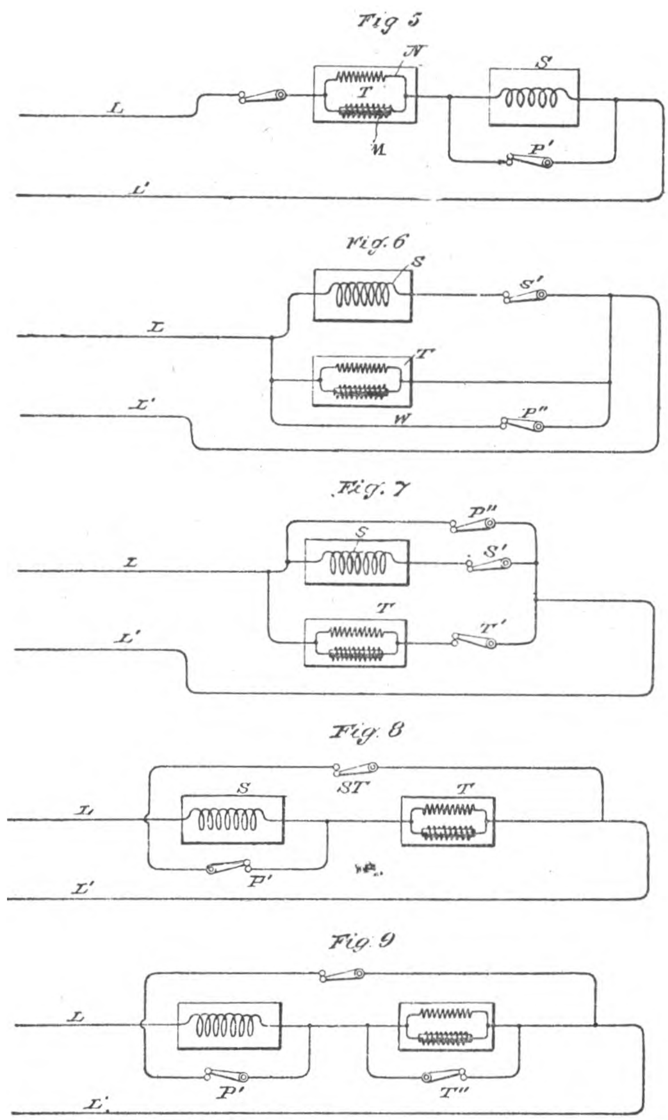
P-82

(No Model.)

2 Sheets—Sheet 2.

N. TESLA.
ELECTRO MAGNETIC MOTOR.

No. 459.772. Patented Sept. 22, 1891,



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UNITED STATES PATENT OFFICE.

NIKOLA TESLA, OF NEW YORK, N Y, ASSIGNOR TO THE TESLA ELECTRIC COMPANY, OF SAME PLACE

ELECTRO-MAGNETIC MOTOR

SPECIFICATION forming part of Letters Patent No. 416,191, dated December 3, 1889

Application filed May 20, 1889. Serial No. 311,413 (No model.)

To all whom it may concern:

Be it known that I, NIKOLA TESLA, a subject of the Emperor of Austria, from Smiljan, Lika, border country of Austria-Hungary, residing at New York, in the county and State of New York, have invented certain new and useful Improvements in Electro - Magnetic Motors, of which the following is a specification, reference being had to the drawings accompanying and forming a part of the same.

This invention pertains to that class of electro-magnetic motors invented by me in which two or more independent energizing-circuits are employed, and through which alternating currents differing in phase are passed to produce the operation or rotation of the motor.

One of the general ways which I have followed in carrying out this invention is to produce practically independent currents differing primarily in phase and pass these through the motor-circuits. Another way is to produce a single alternating current, to divide it between the motor-circuits, and to effect artificially a lag in one of the said circuits or branches, as by giving to the circuits different self-inductive capacity, and in other ways. In the former case, in which the necessary difference of phase is primarily effected in the generation of currents, I have, in some instances, passed the currents through the energizing-coils of both elements of the motor—the field and armature; but I have made the discovery that a new and useful result is or may be obtained by doing this under the conditions hereinafter specified in the case of motors in which the lag, as above stated, is artificially secured In this my present invention resides.

In illustration of the nature of this invention I shall refer to the accompanying drawings, in which—

Figures 1 to 6, inclusive, are diagrams of different ways in which the invention is or may be carried out; and Fig. 7, a side view of a form of motor which I have used for this purpose.

The diagrams in detail will be described separately.

A B in Fig. 1 indicate the two energizing-circuits of a motor, and C D two circuits on the armature circuit or coil A is connected in series with circuit or coil C, and the two circuits B D are similarly connected Between coils A and C is a contact-ring *e*, forming one terminal of the latter, and a brush *a*, forming one terminal of the form r. A ring *d* and brush *c* similarly connect coils B and D. The opposite terminals of the field-coils connect to one binding-post *h* of the motor, and those of the armature-coils are similarly connected to the opposite binding-post *i* through a contact-ring *f* and brush *g*. Thus each motor-circuit while in derivation to the other includes one armature and one field coil. These circuits are of different self-induction, and may be made so in various ways For the sake of clearness I have shown in one of these circuits an artificial resistance R and in the other a self-induction coil S When an alternating current is passed through this motor it divides between its two energizing-circuits. The higher self-induction of one circuit produces a greater retardation or lag in the current therein than in the other The difference of phase between the two currents effects the rotation or shifting of the points of maximum magnetic effect that secures the rotation of the armature. In certain respects this plan of including both armature and field coils in circuit is a marked improvement. Such a motor has a good torque at starting; yet it has also considerable tendency to synchronism, owing to the fact that when properly constructed the maximum magnetic effects in both armature and field coincide—a condition which in the usual construction of these motors with closed armature-coils is not readily attained The motor thus constructed exhibits, too, a better regulation of current from no load to load, and there is less difference between the apparent and real energy expended in running it The true synchronous speed of this form of motor is that of the generator when both are alike—that is to say, if the number of the coils on the armature and on the field is *x,* the motor will run normally at the same speed as a generator driving it if the number of field-magnets or poles of the same be also *x*.

Fig. 2 shows a somewhat modified arrangement of circuits. There is in this case but one armature-coil E, the winding of which maintains effects corresponding to the resultant poles produced by the two field-circuits.

Fig. 3 represents a disposition in which both armature and field are wound with two sets of coils, all in multiple arc to the line or main circuit. The armature-coils are wound to correspond with the field-coils with respect to their self-induction. A modification of this plan is shown in Fig. 4—that is to say, the two field-coils and two armature-coils are in derivation to themselves and in series with one another. The armature-coils in this case, as in the previous figure, are wound for different self-induction to correspond with the field coils.

Another modification is shown in Fig. 5. In this case only one armature-coil, as D, is included in the line-circuit, while the other, as C, is short-circuited.

In such a disposition as that shown in Fig. 2, or where only one armature-coil is employed, the torque on the start is somewhat reduced, while the tendency to synchronism is somewhat increased. In such a disposition, as shown in Fig. 5, the opposite conditions would exist. In both instances, however, there is the advantage of dispensing with one contact-ring.

In Fig. 5 the two field-coils and the armature-coil D are in multiple arc. In Fig. 6 this disposition is modified, coil D being shown in series with the two field-coils.

Fig. 7 is an outline of the general form of motor in which I have embodied this improvement. The circuit-connections between the armature and field coils are made, as indicated in the previous figures, through brushes and rings, which are not shown.

In the above description I have made use of the terms “armature” and “field”; but it will be understood that these are in this case convertible terms, for what is true of the field is equally so of the armature, except that one is stationary, the other capable of rotation.

I do not claim in this application the method or means of operating a double-circuit motor by making its circuits of different self-induction or in any way retarding the phases of current in one circuit more than in another, having made these features subject of other applications; but

What I claim is—

1. In an alternating-current motor, the combination, with field-circuits of different self-inductive capacity, of corresponding armature-circuits electrically connected therewith, as set forth.

2. In an alternating-current motor, the combination, with independent field-coils of different self-induction, of independent armature-coils, one or more in circuit with the field-coils and the others short-circuited, as set forth.

NIKOLA TESLA.

Witnesses:
ROBT. F. GAYLORD,
FRANK E. HARTLEY.

(No Model.) 2 Sheets—Sheet 1

N. TESLA.
ELECTRO MAGNETIC MOTOR.

No. 416,191. Patented Dec. 3, 1889

Fig. 1

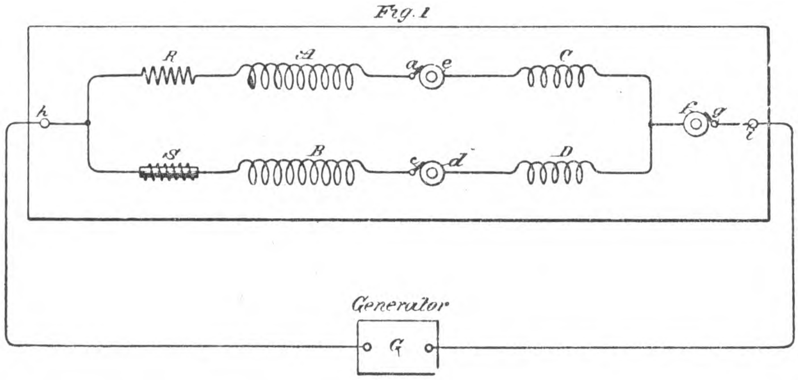


Fig. 2

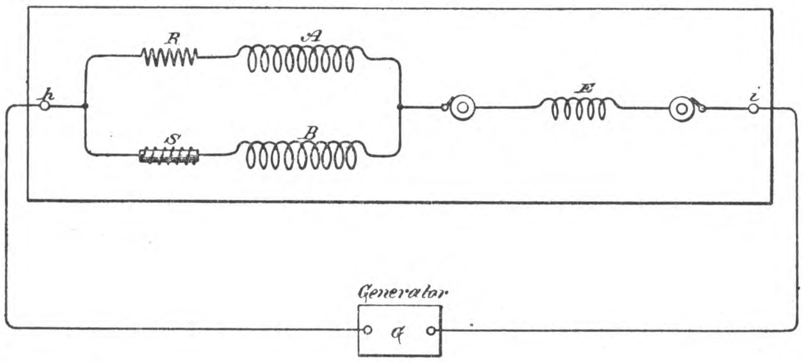
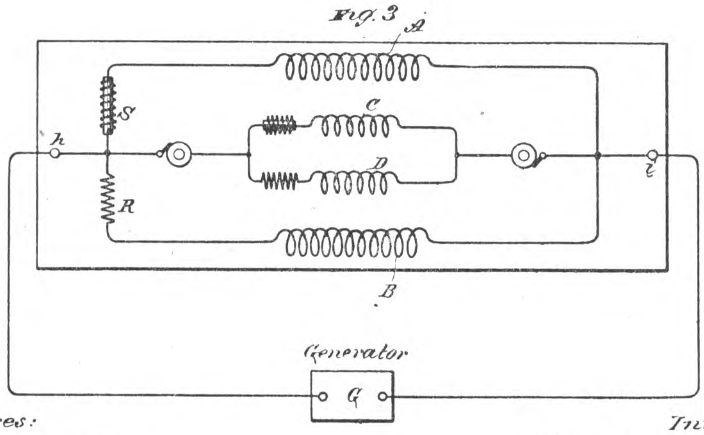


Fig. 3



Witnesses:
Raphael Netter
Robt. F. Gaylord

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By
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Attorneys.

P-86

(No Model.) 2 Sheets—Sheet 2.

N. TESLA.
ELECTRO MAGNETIC MOTOR.

No. 416,191. Patented Dec. 3, 1889.

Fig. 4.

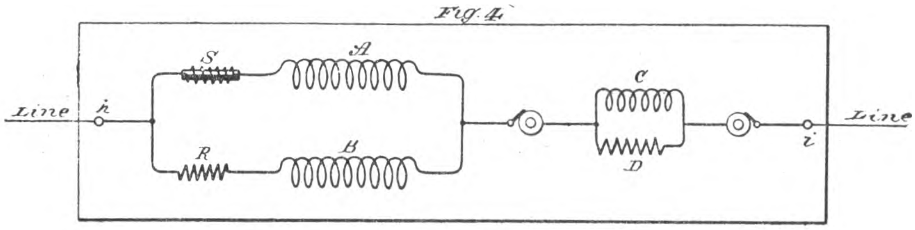


Fig. 5

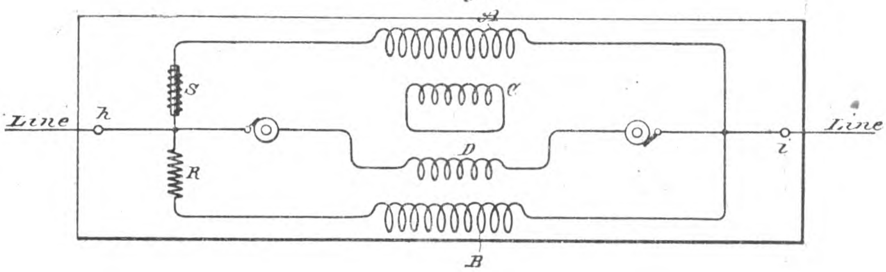


Fig. 6

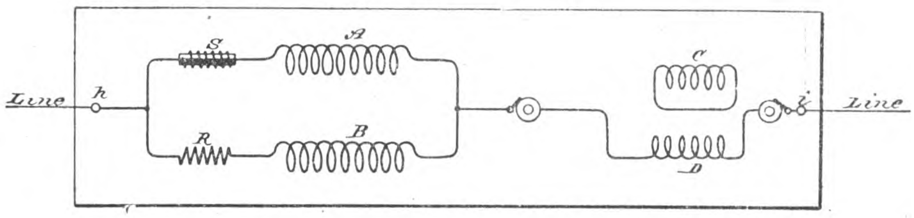
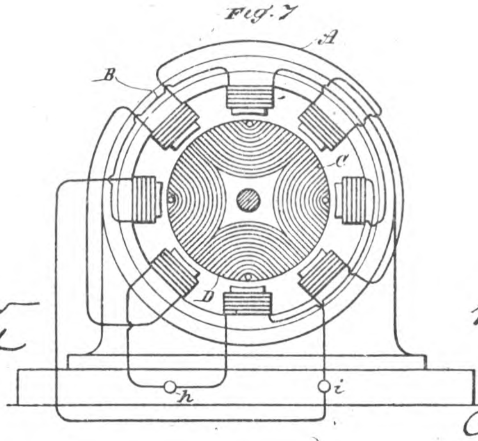


Fig. 7



Witnesses:
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Robt. F. Gaylord

Inventor
Nikola Tesla
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Attorneys.

UNITED STATES PATENT OFFICE.

NIKOLA TESLA, OF NEW YORK, N.Y., ASSIGNOR TO THE TESLA ELECTRIC COMPANY, OF SAME PLACE.

METHOD OF OPERATING ELECTRO-MAGNETIC MOTORS.

SPECIFICATION forming part of Letters Patent No. 416,192, dated December 3, 1889.

Application filed May 20, 1889. Serial No. 311,414. (No model.)

To all whom it may concern:

Be it known that I, NIKOLA TESLA, a subject of the Emperor of Austria, from Smiljan, Lika, border country of Austria-Hungary, and a resident of New York, in the county and State of New York, have invented certain new and useful Improvements in Methods of Operating Electro-Magnetic Motors, of which the following is a specification, reference being had to the drawings accompanying and forming a part of the same.

In a patent granted to me April 16, 1889, No. 401,520, I have shown and described a method of starting and operating synchronizing motors which involved the transformation of the motor from a torque to a synchronizing motor. This I have heretofore done by a change of the circuit-connections, whereby on the start the poles or resultant attraction of the field-magnets of the motor were shifted or rotated by the action of the current until the motor reached synchronous speed, after which the poles were merely alternated. The present application is based upon another way of accomplishing this result, the main features being as follows: If an alternating current be passed through the field-coils only of a motor having two energizing-circuits of different self-induction and the armature-coils be short-circuited, the motor will have a strong torque, but little or no tendency to synchronism with the generator; but if the same current which energizes the field be passed also through the armature-coils the tendency to remain in synchronism is very considerably increased. This is due to the fact that the maximum magnetic effects produced in the field and armature more nearly coincide. This principle discovered by me I have utilized in the operation of motors. In other words, I construct a motor having independent field-circuits of different self-induction, which are joined in derivation to a source of alternating currents. The armature I wind with one or more coils, which are connected with the field-coils through contact rings and brushes, and around the armature-coils I arrange a shunt with means for opening or closing the same. In starting this motor I close the shunt around the armature-coils, which will therefore be in closed circuit. When the current is directed through the motor, it divides between the two circuits, (it is not necessary to consider any case where there are more than two circuits used,) which, by reason of their different self-induction, secure a difference of phase between the two currents in the two brandies that produces a shifting or rotation of the poles. By the alternations of current other currents are induced in the closed—or short-circuited—armature-coils and the motor has a strong torque. When the desired speed is reached, the shunt around the armature-coils is opened and the current directed through both armature and field coils. Under these conditions the motor has a strong tendency to synchronism.

In the drawings hereto annexed I have illustrated several modifications of the plan above set forth for operating motors. The figures are diagrams, and will be explained in their order.

Figure 1: A and B designate the field-coils of the motor. As the circuits including these coils are of different self-induction, I have represented this by a resistance-coil R in circuit with A, and a self-induction coil S in circuit with B. The same result may of course be secured by the winding of the coils. C is the armature-circuit, the terminals of which are rings *a b*. Brushes *c d* bear on these rings and connect with the line and field circuits. D is the shunt or short circuit around the armature. E is the switch therein. The operation of these devices I have stated above.

It will be observed that in such a disposition as is illustrated in Fig. 1, the field-circuits A and B being of different self-induction, there will always be a greater lag of the current in one than the other, and that generally, the armature phases will not correspond with either, but with the resultant of both. It is therefore important to observe the proper rule in winding the armature. For instance, if the motor have eight poles—four in each circuit—there will be four resultant poles, and hence the armature-winding should be such as to produce four poles, in order to constitute a true synchronizing motor.

Fig 2: This diagram differs from the previous one only in respect to the order of connections. In the present case the armature-coil, instead of being in series with the field-coils, is in multiple arc therewith. The armature-winding may be similar to that of the field—that is to say, the armature may have two or more coils wound or adapted for different self-induction and adapted, preferably, to produce the same difference of phase as the field-coils. On starting the motor the shunt is closed around both coils. This is shown in Fig. 3, in which the armature-coils are F G. To indicate their different electrical character, I have shown in circuit with them, respectively, the resistance R' and the self-induction coil S'. The two armature coils are in series with the field-coils and the same disposition of the shunt or short circuit D is used. It is of advantage in the operation of motors of this kind to construct or wind the armature in such manner that when short-circuited on the start it will have a tendency to reach a higher speed than that which synchronizes with the generator. For example, a given motor having, say, eight poles should run, with the armature-coil short-circuited, at two thousand revolutions per minute to bring it up to synchronism. It will generally happen, however, that this speed is not reached, owing to the fact that the armature and field currents do not properly correspond, so that when the current is passed through the armature (the motor not being quite up to synchronism) there is a liability that it would not "hold on," as it is termed. I therefore prefer to so wind or construct the motor that on the start, when the armature-coils are short-circuited, the motor will tend to reach a speed higher than the synchronous—as, for instance, double the latter. In such case the difficulty above alluded to is not felt, for the motor will always hold up to synchronism if the synchronous speed—in the case supposed of two thousand revolutions—is reached or passed. This may be accomplished in various ways; but for all practical purposes the following will suffice: I wind on the armature two sets of coils. On the start I short-circuit one only, thereby producing a number of poles on the armature, which will tend to run the speed up above the synchronous limit. When such limit is readied or passed, the current is directed through the other coil, which, by increasing the number of armature-poles, tends to maintain synchronism. In Fig. 4 such a disposition is shown. The motor having, say, eight poles contains two field-circuits A and B, of different self-induction. The armature has two coils F and G. The former is closed upon itself, the latter connected with the field and line through contact-rings *a b*, brushes *c d*, and a switch E. On the start the coil F alone is active and the motor tends to run at a speed above the synchronous; but when the coil G is connected to the circuit the number of armature-poles is increased, while the motor is made a true synchronous motor. This disposition has the advantage that the closed armature-circuit imparts to the motor torque when the speed falls off, but at the same time the conditions are such that the motor comes out of synchronism more readily. To increase the tendency to synchronism, two circuits may be used on the armature, one of which is short-circuited on the start and both connected with the external circuit after the synchronous speed is reached or passed. This disposition is shown in Fig. 5. There are three contact-rings *a b e* and three brushes *c d f,* which connect the armature-circuits with the external circuit. On starting, the switch H is turned to complete the connection between one binding-post P and the field-coils. This short-circuits one of the armature-coils, as G. The other coil F is out of circuit and open. When the motor is up to speed, the switch H is turned back, so that the connection from binding-post P to the field-coils is through the coil G, and switch K is closed, thereby including coil F in multiple arc with the field-coils. Both armature-coils are thus active.

From the above-described instances it is evident that many other dispositions for carrying out the invention are possible.

I do not claim herein the method and means described and shown for operating a motor by producing artificially a difference of current phase in its independent energizing-circuits; nor do I claim, broadly, a motor having independent energizing-circuits of different self-induction and armature-circuits connected therewith, as these features are made subjects of other applications which I have filed.

What I claim is—

1. The method herein described of operating alternating-current motors having independent energizing-circuits, which consists in short-circuiting the armature circuit or circuits until the motor has reached or passed a synchronizing speed and then connecting said armature-circuits with the external circuit, as set forth.

2. The method of operating alternating, current motors having field-coils of different self-induction, which consists in directing alternating-currents from an external source through the field-circuits only until the motor has reached a given speed and then directing said currents through both the field circuits and one or more of the armature-circuits, as set forth.

3. The method of operating alternating-current motors having field-coils of different self-induction, which consists in directing alternating currents from an external source through the field-circuits and short-circuiting a part of the armature-circuits, and then when the motor has attained a given speed directing the alternating currents through both the field and one or more of the armature-circuits, as set forth.

NIKOLA TESLA

Witnesses:

ROBT. F. GAYLORD,

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(No Model.) (2 Sheets—Sheet 1.

N. TESLA

METHOD OF OPERATING ELECTRO MAGNETIC MOTORS,

No. 416,192. Patented Dec. 3, 1889

Fig. 1.

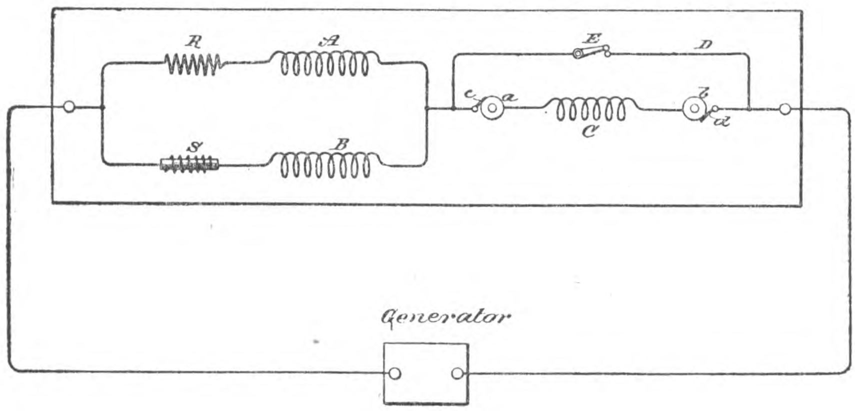


Fig. 2

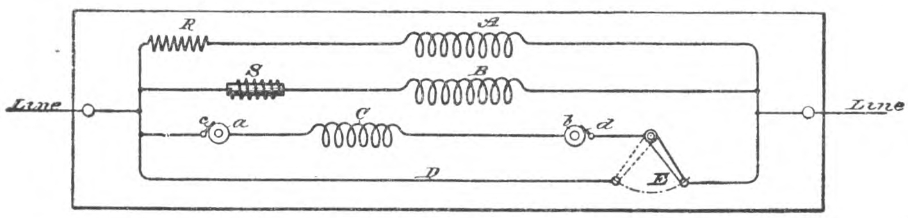
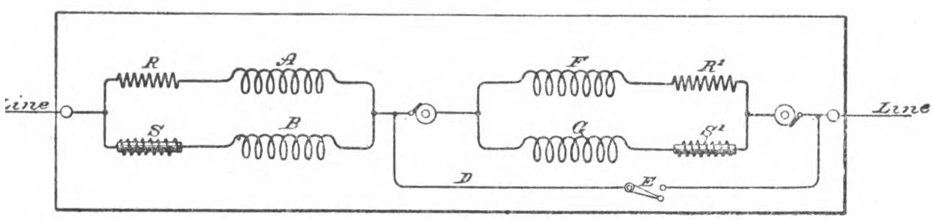


Fig. 3



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P-90

(No Model.) 2 Sheets—Sheet 2.

N. TESLA.

METHOD OF OPERATING ELECTRO MAGNETIC MOTORS.

No. 416,192. Patented Dec. 3, 1889.

Fig. 4

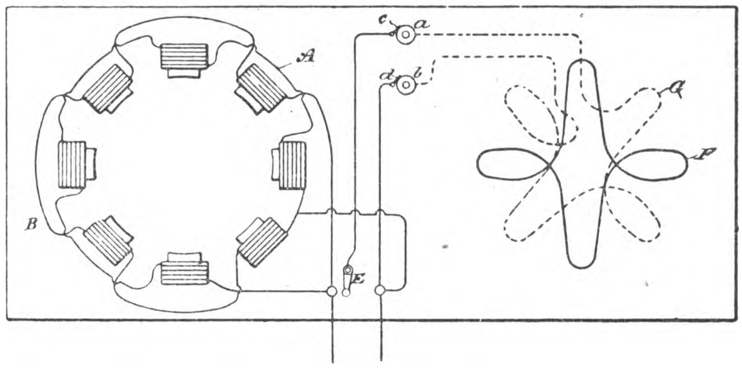
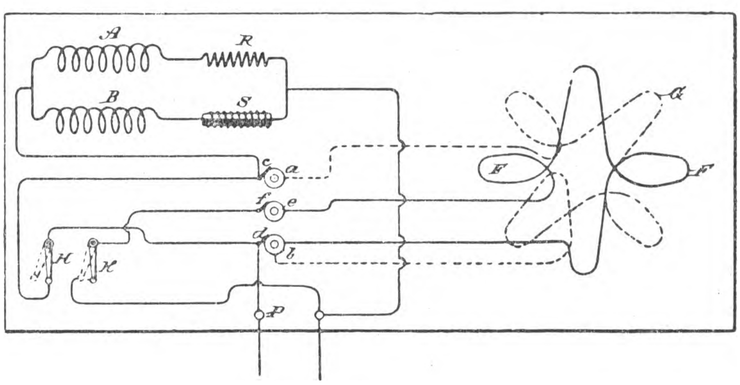


Fig 5



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UNITED STATES PATENT OFFICE.

NIKOLA TESLA, OF NEW YORK, N. Y., ASSIGNOR TO THE TESLA ELECTRIC COMPANY, OF SAME PLACE.

ELECTRO-MAGNETIC MOTOR.

SPECIFICATION forming part of Letters Patent No. 416,193, dated December 3, 1889.

Application filed May 20, 1889. Serial No. 311,415. (No model.)

To all whom it may concern:

Be it known that I, NIKOLA TESLA, a subject, of the Emperor of Austria, from Smiljan, Lika, border country of Austria-Hungary, residing at New York, in the county and State of New York, have invented certain new and useful Improvements in Electro-Magnetic Motors, of which the following is a specification, reference being had to the accompanying drawings.

This invention relates to alternating-current motors of the general description invented by me, and in which two or more energizing-circuits are employed, through which alternating currents differing in phase are passed, with the result of producing a progressive shifting or rotation of the poles or points of maximum attractive effect.

In prior patents and applications I have shown and described various forms of motors of this kind. Among them are motors in which both energizing-circuits are electrically alike—that is to say, both have the same or approximately the same electrical resistance and self-induction—in the operation of which the alternating currents used are primarily of different phase. In others the difference of phase is artificially produced—as, for instance, in cases where the motor-circuits are of different resistance and self-induction, so that the same current divided between them will be retarded in one to a greater extent than in the other, and the requisite phase difference secured in this way. To this latter class generally my present invention relates.

The lag or rotation of the phases of an alternating current is directly proportional to the self-induction and inversely proportional to the resistance of the circuit through which the current flows. Hence, in order to secure the proper difference of phase between the two motor-circuits, it is desirable to make the self-induction in one much higher and the resistance much lower than the self-induction and resistance, respectively, in the other. At the same time the magnetic quantities of the two poles or sets of poles which the two circuits produce should be approximately equal. These requirements, which I have found to exist in motors of this kind, have led me to the invention of a motor having the following general characteristics: The coils which are included in that energizing-circuit which is to have the higher self-induction I make of coarse wire, or a conductor of relatively low resistance, and I use the greatest possible length or number of turns. In the other set of coils I use a comparatively few turns of finer wire or a wire of higher resistance. Furthermore, in order to approximate the magnetic quantities of the poles excited by these coils, I use in the self-induction circuit cores much longer than those in the other or resistance circuit. I have shown in the drawings a motor embodying these features.

Figure 1 is a part-sectional view of the motor at right angles to the shaft. Fig. 2 is a diagram of the field-circuits.

In Fig, 2, let A represent the coils in one motor-circuit, and B those in the other. The circuit A is to have the higher self-induction. I therefore use a long length or a large number of turns of coarse wire in forming the coils of this circuit. For the circuit B, I use a smaller conductor, or a conductor of a higher resistance than copper, such as German silver or iron, and wind the coils with fewer turns. In applying these coils to a motor I build up a field-magnet of plates of iron or steel, secured together in the usual manner by bolts D. Each plate is formed with four (more or less) long cores E, around which is a space to receive the coil and an equal number of short project ions F to receive the coils of the resistance-circuit. The plates are generally annular in shape, having an open space in the center for receiving the armature G, which I prefer to wind with closed coils. An alternating current divided between the two circuits is retarded as to its phases in the circuit A to a much greater extent than in the circuit B. By reason of the relative sizes and disposition of the cores and coils the magnetic effect of the poles E and F upon the armature closely approximate. Those conditions are well understood and readily secured by one skilled in the art.

An important result secured by the construction herein shown of the motor is, that these coils which are designed to have the higher self-induction are almost completely surrounded by iron, by which the retardation is considerably increased.

I do not claim herein, broadly, the method and means of securing rotation by artificially producing a greater lag of the current in one motor-circuit than in the other, nor the use of poles or cores of different magnetic susceptibility, as these are features which I have specially claimed in other applications filed by me.

What I claim is—

1. An alternating-current motor having two or more energizing-circuits, the coils of one circuit being composed of conductors of large size dr low resistance and those of the other of fewer turns of wire of smaller size or higher resistance, as set forth.

2. In an alternating-current motor, the combination, with long and short field-cores, of energizing-coils included in independent circuits, the coils on the longer cores containing an excess of copper or conductor over that in the others, as set forth.

3. The combination, with a field-magnet composed of magnetic plates having an open center and pole-pieces or cores of different length, of coils surrounding said cores and included in independent circuits, the coils on the longer cores containing an excess of copper over that in the others, as set forth.

4. The combination, with a field-magnet composed of magnetic plates having an open center and pole-pieces or cores of different length, of coils surrounding said cores and included in independent circuits, the coils on the longer cores containing an excess of copper over that in the others and being set in recesses in the iron core formed by the plates, as set forth.

NIKOLA TESLA.

Witnesses:
ROBT. F. GAYLORD,
FRANK E. HARTLEY.

(No Model,)

N. TESLA.
ELECTRO MAGNETIC MOTOR.

No. 416,193. Patented Dec. 3, 1889.

Fig. 1

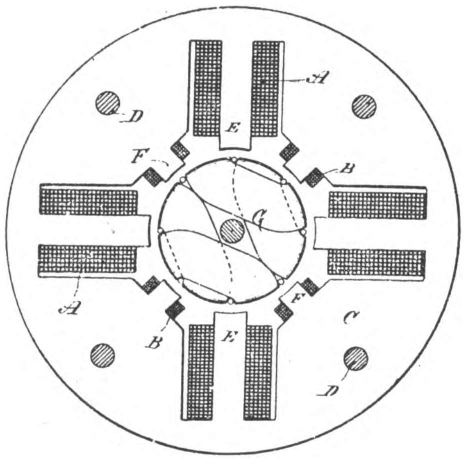
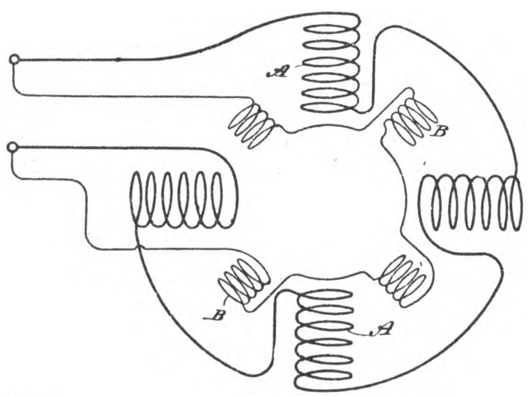


Fig. 2



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UNITED STATES PATENT OFFICE.

NIKOLA TESLA, OF NEW YORK, N. Y., ASSIGNOR TO THE TESLA ELECTRIC COMPANY, OF SAME PLACE.

ELECTRIC MOTOR.

SPECIFICATION forming part of Letters Patent No. 416,194, dated December 3, 1889.

Application filed May 20, 1889. Serial No. 311,418. (No model)

To all whom it may concern:

Be it known that I, NIKOLA TESLA, a subject of the Emperor of Austria, from Smiljan, Lika, border country of Austria-Hungary, residing at New York, in the county and State of New York, have invented certain new and useful Improvements in Electro-Magnetic Motors, of which the following is a specification.

This invention relates to the alternating-current electro-magnetic motors invented by me, in which a progressive shifting or rotation of the poles or points of maximum magnetic effect is produced by the action of the alternating currents. These motors I have constructed in a great variety of ways. As instances, I have built motors with two or more energizing-circuits, which I connected up with corresponding circuits of a generator so that the motor will be energized by alternating currents differing primarily in phase. I have also built motors with independent energizing-circuits of different electrical character or self-induction, through which I have passed an alternating current the phases of which were artificially distorted by the greater retarding effect of one circuit over another. I have also constructed other forms of motor operating by magnetic or electric lag, which it is not necessary to describe herein in detail, although my present invention is applicable thereto. In such motors I use an armature wound with a coil or coils, which is sometimes connected with the external circuit and sometimes closed upon itself, and to both forms the present invention applies. In these motors the total energy supplied to effect their operation is equal to the sum of the energies expended in the armature and the field. The power developed, however, is proportionate to the product of these quantities. This product will be greatest when these quantities are equal; hence in constructing a motor I determine the mass of the armature and field cores and the windings of both and adapt the two so as to equalize as nearly as possible the magnetic quantities of both. In motors which have closed armature-coils this is only approximately possible, as the energy manifested in the armature is the result of inductive action from the other element; but in motors in which the coils of both armature and field are connected with the external circuit the result can be much more perfectly obtained.

In further explanation of my object let it be assumed that the energy as represented in the magnetism in the field of a given motor is ninety and that of the armature ten. The sum of these quantities, which represents the total energy expended in driving the motor, is one hundred; but, assuming that the motor be so constructed that the energy in the field is represented by fifty and. that in the armature by fifty, the sum is still one hundred; but while in the first instance the product is nine hundred, in the second it is two thousand five hundred, and as the energy developed is in proportion to these products it is clear that those motors are the most efficient—other things being equal—in which the magnetic energies developed in the armature and field are equal. These results I obtain by using the same amount of copper or ampere turns in both elements when the cores of both are equal, or approximately so, and the same current energizes both; or in cases where the currents in one element are induced to those of the other I use in the induced coils an excess of copper over that in the primary element or conductor.

While I know of no way of illustrating this invention by a drawing such as will meet the formal requirements of an application for patent, I have appended for convenience a conventional figure of a motor such as I employ. I would state, however, that I believe that with the problem before him which I have herein stated, and the solution which I have proposed, any one skilled in the art will be able to carry out and apply this invention without difficulty.

Generally speaking, if the mass of the cores of armature and field be equal, the amount of copper or ampere turns of the energizing-coils on both should also be equal; but these conditions will be modified in well-understood ways in different forms of machine. It will be understood that these results are most advantageous when existing under the conditions presented when the motor is running with its normal load, and in carrying out the invention this fact should be taken into consideration.

Referring to the drawing, A is the field-magnet, B the armature, C the field-coils, and D the armature-coils, of the motor.

The motors described in this application, except as to the features specifically pointed out in the claims, are described and claimed in prior patents granted to and applications filed by me, and are not herein claimed

What I claim is—

1. An electro-magnetic motor having field and armature magnets of equal strength or magnetic quantity when energized by a given current, as set forth.

2. In an alternating-current motor, the combination, with field and armature cores of equal mass, of energizing-coils containing equal amounts of copper, as herein set forth.

NIKOLA TESLA.

Witnesses:

ROBT. F. GAYLORD,

FRANK E. HARTLEY.

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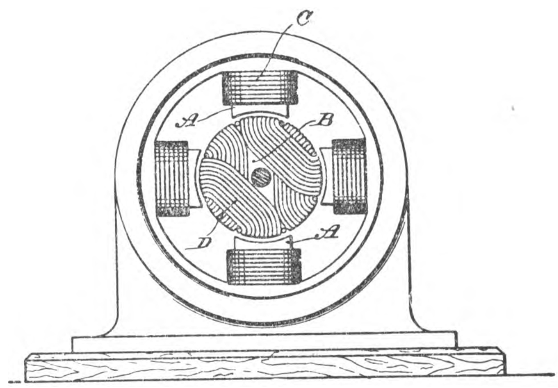
P-96

(No Model.)

N. TESLA.

ELECTRIC MOTOR.

No. 416,194. Patented Dec. 3, 1889.



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Robt. F. Gaylord

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UNITED STATES PATENT OFFICE.

NIKOLA TESLA, OK NEW YORK, N. Y., ASSIGNOR TO THE TESLA ELECTRIC COMPANY, OF SAME PLACE.

ELECTRO-MAGNETIC MOTOR.

SPECIFICATION forming part of Letters Patent No. 416,198, dated December 3, 1889.

Application filed May 20, 1889. Serial No. 311,419. (No model.)

To all whom it may concern:

Be it known that I, NIKOLA TESLA, a subject of the Emperor of Austria, from Smiljan, Lika, border country of Austria-Hungary, residing at New York, in the county and State of New York, have invented certain new and useful Improvements in Electro-Magnetic Motors, of which the following is a specification, reference being had to the drawings accompanying and forming a part of the same.

This invention relates to that form of alternating-current motor invented by me, in which there are two or more energizing-circuits through which alternating currents differing in phase are caused to pass. I have in prior patents and applications shown various forms or types of this motor—first, motors having two or more energizing-circuits of the same electrical character, and in the operation of which the currents used differ primarily in phase; second, motors with a plurality of energizing-circuits of different electrical character, in or by means of which the difference of phase is produced artificially, and, third, motors with a plurality of energizing-circuits, the currents in one being induced from currents in another. I shall hereinafter show the application of my present invention to these several types. Considering the structural and operative conditions of any-one of them—as, for example, that first-named—the armature which is mounted to rotate in obedience to the co-operative influence or action of the energizing-circuits has coils wound upon it which are closed upon themselves and in which currents are induced by the energizing-currents with the object and result of energizing the armature-core; but under any such conditions as must exist in these motors it is obvious that a certain time must elapse between the manifestations of an energizing-current impulse in the field-coils, and the corresponding magnetic state or phase in the armature established by the current induced thereby; consequently a given magnetic influence or effect in the field which is the direct result of a primary-current impulse will have become more or less weakened or lost before the corresponding effect in the armature indirectly produced has reached its maximum. This is a condition unfavorable to efficient working in certain cases—as, for instance, when the progress of the resultant poles or points of maximum attraction is very great, or when a very high number of alternations is employed—for it is apparent that a stronger tendency to rotation will be maintained if the maximum magnetic attractions or conditions in both armature and field coincide, the energy developed by a motor being measured by the product of the magnetic quantities of the armature and field.

The object, therefore; in this invention is to so construct or organize these motors that the maxima of the magnetic effects of the two elements—the armature and field—shall more nearly coincide. This I accomplish in various ways, which I may best explain by reference to the drawings, in which various plans for accomplishing the desired results are illustrated.

Figure 1; This is a diagrammatic illustration of a motor system such as I have described in my prior patents, and in which the alternating currents proceed from independent sources and differ primarily in phase.

A designates the field-magnet or magnetic frame of the motor; B B, oppositely-located pole-pieces adapted to receive the coils of one energizing-circuit; and C C, similar pole-pieces for the coils of the other energizing-circuit. These circuits are designated, respectively, by D E, the conductor D" forming a common return to the generator G. Between these poles is mounted an armature—for example, a ring or annular armature, wound with a series of coils F, forming a closed circuit or circuits. The action or operation of a motor thus constructed is now well understood. It will be observed, however, that the magnetism of poles B, for example, established by a current-impulse in the coils t hereon, precedes the magnetic effect set up in the armature by the induced current in coils F. Consequently the, mutual attraction between the armature and field-poles is considerably reduced. The same conditions will be found to exist if, instead of assuming the poles B or C as acting independently, we regard the ideal resultant of both acting together, which is the real condition. To remedy this, I construct the motor-field with secondary poles B' C', which are situated between the others. These pole-pieces I wind with coils D' E', the former in derivation to the coils D, the latter to coils E. The main or primary coils D and E are wound for a different self-induction from that of the coils B' and E', the relations being so fixed that if the currents in D and E differ, for example, by a quarter-phase, the currents in each secondary coil, as D' E', will differ from those in its appropriate primary D or E by, say, forty-five degrees, or one-eighth of a period.

I explain the action of this motor as follows: Assuming that an impulse or alternation in circuit or branch E is just beginning while in the branch B it is just falling from maximum, the conditions of a quarter-phase difference. The ideal resultant of the attractive forces of the two sets of poles B C therefore may be considered as progressing from poles B to poles C while the impulse in E is rising to maximum and that in D is falling to zero or minimum. The polarity set up in the armature, however, lags behind the manifestations of field magnetism, and hence the maximum points of attraction in armature and field, instead of coinciding, are angularly displaced. This effect is counteracted by the supplemental poles B' C'. The magnetic phases of these poles succeed those of poles B C by the same, or nearly the same, period of time as elapses between the effect of the poles B C and the corresponding induced effect in the armature; hence the magnetic conditions of poles B', C' and of the armature more nearly coincide and a better result is obtained. As poles B' C' act in conjunction with the poles in the armature established by poles B C, so in turn poles C B act similarly with the poles set up by B' C', respectively. Under such conditions the retardation of the magnetic effect of the armature and that of the secondary poles will bring the maximum of the two more nearly into coincidence and a correspondingly-stronger torque or magnetic attraction secured.

In such a disposition as is shown in Fig. 1 it will be observed that as the adjacent pole-pieces of either circuit are of like polarity they will have a certain weakening effect upon one another. I therefore prefer to remove the secondary poles from the direct influence of the others. This I may do by constructing a motor with two independent sets of fields, and with either one or two armatures electrically connected, or by using two armatures and one field. These modifications will be illustrated hereinafter.

Fig. 2 is a diagrammatic illustration of a motor and system in which the difference of phase is artificially produced. There are two coils D D in one branch and two coils E E in the other branch of the main circuit from the generator G. These two circuits or branches are of different self-induction, one, as D, being higher than the other. For convenience I have indicated this by making coils D much larger than coils E. By reason of this difference in the electrical character of the two circuits the phases of current in one are retarded to a greater extent than the other. Let this difference be thirty degrees. A motor thus constructed will rotate under the action of an alternating current; but as happens in the case previously described the corresponding magnetic effects of the armature and field do not coincide owing to the time that elapses between a given magnetic effect in the armature and the condition of the field that produces it. I therefore employ the secondary or supplemental poles B' C'. There being thirty degrees difference of phase between the currents in coils D E, the magnetic effects of poles B' C' should correspond to that produced by a current differing from the current in coils D or E by fifteen degrees. This I may accomplish by winding each supplemental pole B' C' with two coils H H'. The coils H are included in a derived circuit having the same self induction as circuit D, and coils H' in a circuit having the same self-induction as circuit E, so that if these circuits differ by thirty degrees the magnetism of poles B' C' will correspond to that produced by a current differing from that in either D or E by fifteen degrees. This is true in all other cases. For example, if in Fig. 1 the coils D' E' be replaced by the coils H H' included in derived circuits, the magnetism of the poles B' C' will correspond in effect or phase, if it may be so termed, to that produced by a current differing from that in either circuit B or E by forty-five degrees, or one-eighth of a period.

This invention as applied to a derived-circuit motor is illustrated in Figs. 3 and 4. The former is an end view of the motor with the armature in section and a diagram of connections, and Fig. 4 a vertical section through the field. These figures are also drawn to show one of the dispositions of two fields that may be adopted in carrying out the invention. The poles B B C C are in one field, the remaining poles in the other. The former are wound with primary coils I J and secondary coils I' J', the latter with coils K L. The primary coils I J are in derived circuits, between which, by reason of their different self-induction, there is a difference of phase, say, of thirty degrees. The coils I' K are in circuit with one another; as also are coils J' L, and there should be a difference of phase between the currents in coils K and L and their corresponding primaries of, say, fifteen degrees. If the poles B C are at right angles; the armature-coils should be connected directly across, or a single armature-core wound from end to end may be used; but if the poles B C be in line there should be an angular displacement of the armature-coils, as will be well understood.

The operation will be understood from the foregoing. The maximum magnetic condition of a pair of poles, as B' B', coincides closely with the maximum effect in the armature, which lags behind the corresponding condition in poles B B.

There are many other ways of carrying out this invention, but they all involve the same broad principle of construction and operation.

In using expressions herein to indicate a coincidence of the magnetic phases or effects in one set of field-magnets with those set up in the armature by the other I refer only to approximate results; but this of course will be understood.

What I claim is—

1. In an alternating-current motor, the combination, with an armature wound with closed coils, of main and supplemental field magnets or poles, one set of which is adapted to exhibit their maximum magnetic effect simultaneously with that set up in the armature by the action of the other, as set forth.

2. In an electro-magnetic motor, the combination, with an armature, of a plurality of field or energizing coils included, respectively, in main circuits adapted to produce a given difference of phase and supplemental or secondary circuits adapted to produce an intermediate difference of phase, as set forth.

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Witnesses:

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JOHN GILLESPIE.

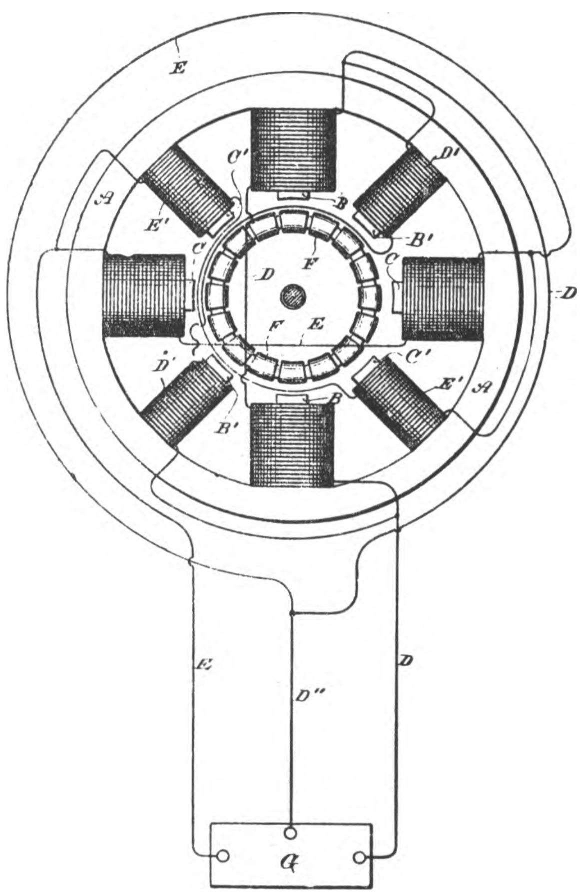
P-100

(No Model) 3 Sheets—Sheet 1

N. TESLA.
ELECTRO MAGNETIC MOTOR.

No. 416,195. Patented Dec. 3, 1889.

Fig 1



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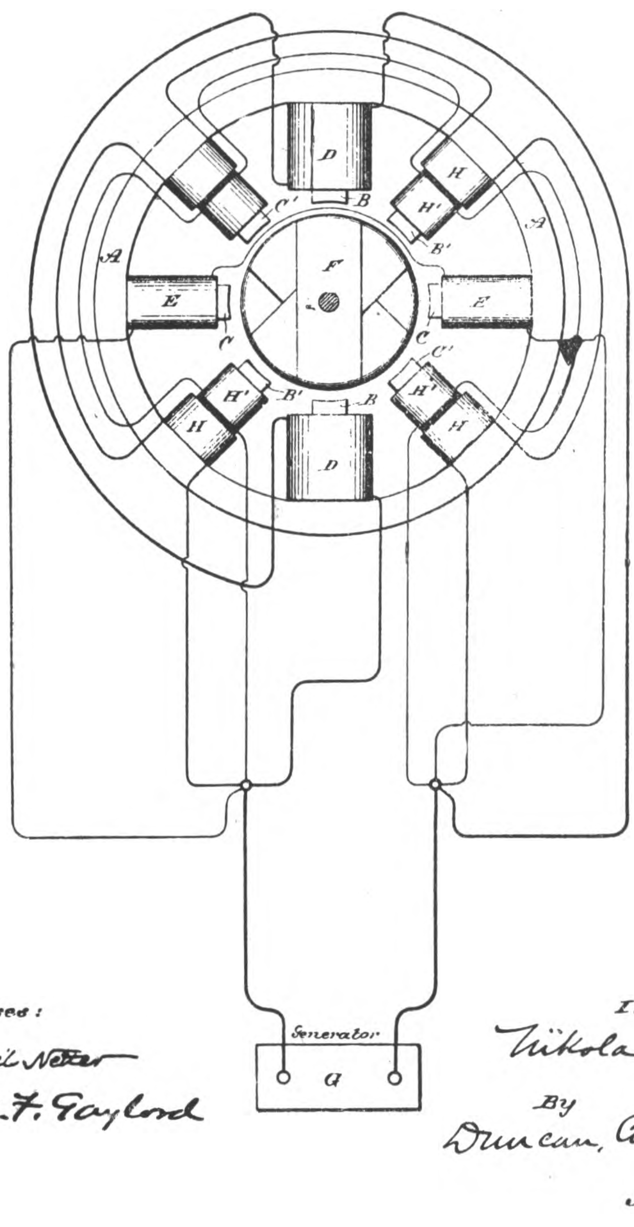
(No Model) 3 Sheets—Sheet 2.

N. TESLA.
ELECTRO MAGNETIC MOTOR.

No. 416,195. Patented Dec. 3, 1889.

Fig. 2



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(No Model.) 3 Sheets —Sheet 3

N. TESLA.

ELECTRO MAGNETIC MOTOR.

No. 416,195 Patented Dec. 3, 1889.

Fig. 3

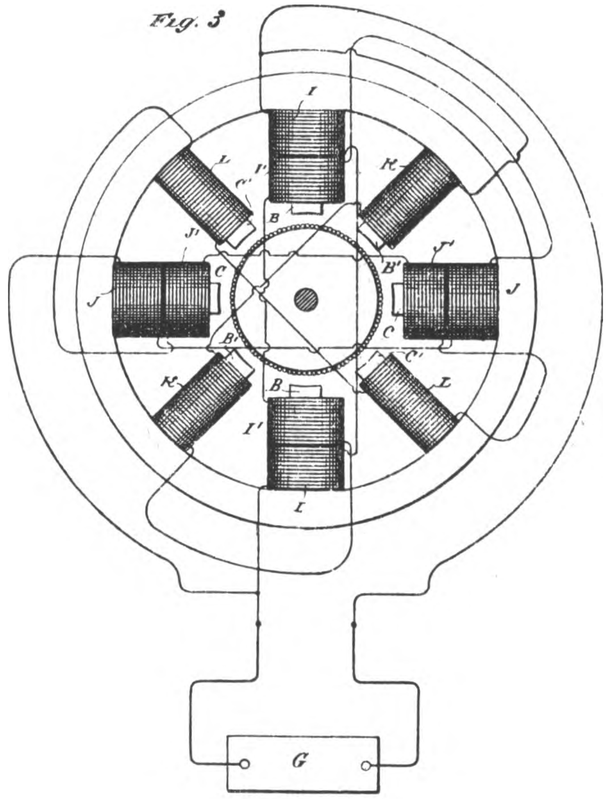
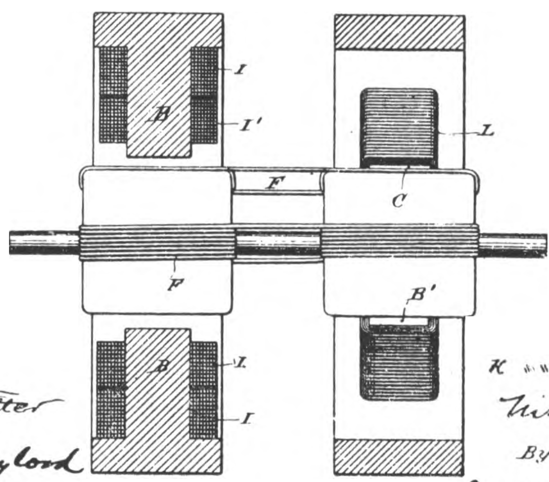


Fig. 4



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UNITED STATES PATENT OFFICE.

NICOLA TESLA, OF NEW YORK, N. Y., ASSIGNOR TO THE TESLA ELECTRIC COMPANY, OF SAME PLACE.

ELECTRO-MAGNETIC MOTOR.

SPECIFICATION forming part of Letters Patent No. 418,248, dated December 31, 1889.

Application filed May 20. 1889. Serial No. 311,420. (No model.)

To all whom it may concern:

Be it, known that I, NIKOLA TESLA, a subject of the Emperor of Austria-Hungary, formerly of Smiljan, Lika, border country of Austria-Hungary, but now residing at New York, in the county and State of New York, have invented certain new and useful Improvements in Methods of Operating Electro-Magnetic Motors, of which the following is a specification, reference being had to the drawing accompanying and forming a part of the same.

In a patent granted to me April 16, 1889, No. 401,520, I have shown and described a method of operating alternating-current motors by first shifting or rotating their magnetic poles until they had reached or passed a synchronous speed and then alternating the poles, or, in other words, by transforming the motor by a change of circuit-connections from one operated by the action of two or more independent energizing-currents to a motor operated by a single current or several acting as one.

The present invention is a specific way of carrying out the same invention; and it consists in the following method: On the start I progressively shift the magnetic poles of one element or field of the motor by alternating currents differing in phase and passed through independent energizing-circuits and short-circuit the coils of the other element. When the motor thus started reaches or passes the limit of speed synchronous with the generator, I connect up the coils previously short-circuited with a source of direct current and by a change of the circuit-connections produce a simple alternation of the poles. The motor then continues to run in synchronism with the generator. There are many specifically-different ways in which this may be carried out, but I have selected one for illustrating the principle. This is illustrated in the annexed drawing, which is a side view of a motor with a diagram of the circuits and devices used in the system.

The motor shown is one of the ordinary forms, with field-cores either laminated or solid and with a cylindrical laminated armature wound, for example, with the coils A B at right angles. The shaft, of the armature carries three collecting or contact rings C D E. (Shown, for better illustration, as of different diameters.)

One end of coil A connects to one ring, as C, and one end of coil B connects with ring D. The remaining ends are connected to ring E. Collecting springs or brushes F G H bear upon the rings and lead to the contacts of a switch, to be hereinafter described. The field-coils have their terminals in binding-posts K K, and may be either closed upon themselves or connected with a source of direct current L by means of a switch M. The main or controlling switch has five contacts *a b c d e* and two levers *f g,* pivoted and connected by an insulating cross-bar *h,* so as to move in parallelism. These levers are connected to the line-wires from a source of alternating currents N. Contact *a* is connected to brush G and coil B through a dead-resistance R and wire P. Contact *b* is connected with brush F and coil A through a self-induction coil S and wire O. Contacts *c* and *e* are connected to brushes G F, respectively, through the wires P O, and contact *d* is directly connected with brush H. The lever *f* has a widened end, which may span the contacts *a b.* When in such position and with lever *g* on contact *d,* the alternating currents divide between the two motor-coils, and by reason of their different self-induction a difference of current-phase is obtained that starts the motor in rotation. In starting, as I have above stated, the field-coils are short-circuited.

When the motor has attained the desired speed, the switch is shifted to the position shown in dotted lines—that is to say, with the levers *f g* resting on points *c e.* This connects up the two armature-coils in series, and the motor will then run as a synchronous motor. The field-coils are thrown into circuit with the direct-current source when the main switch is shifted.

What I claim herein as my invention is—

1. The method of operating electro-magnetic motors, which consists in first progressively shifting or rotating the magnetic poles of one element until it has reached a synchronous speed and then alternating said poles and passing a direct current through the coils of the other element, as herein set forth.

2. The method of operating electro-mag-

netic motors, which consists in short-circuiting the coils of one element, as the field-magnet, and passing through the energizing-coils of the other element, as the armature, alternating currents differing in phase, and then when the motor has attained a given speed, passing through the field-coils a direct current and through the armature-coils alternating currents coinciding in phase.

NIKOLA TESLA.

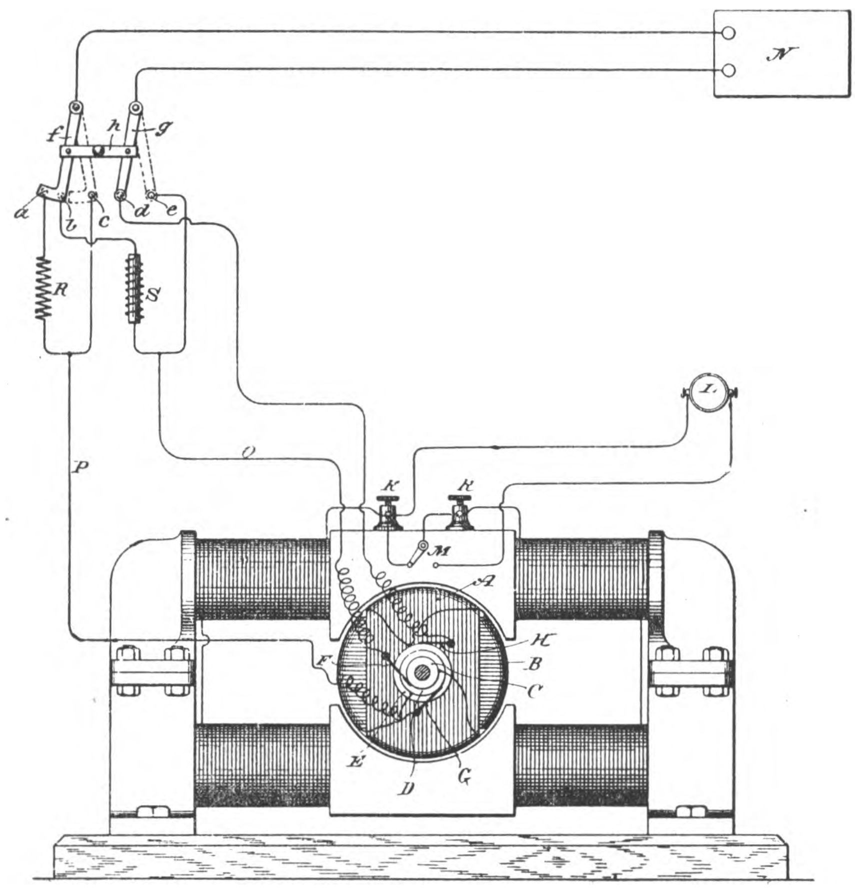
Witnesses
R. J. STONEY, Jr.,
E. P. COFFIN.

(No Model.)

N. TESLA.

ELECTRO MAGNETIC MOTOR

No 418,248. Patented Dec. 31, 1889.



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UNITED STATES PATENT OFFICE.

NIKOLA TESLA, OF NEW YORK, N. Y., ASSIGNOR TO THE TESLA ELECTRIC COMPANY, OF SAME PLACE.

ELECTRO-MAGNETIC MOTOR.

SPECIFICATION forming part of Letters Patent No. 424,036, dated March 25, 1890.

Application filed May 20, 1889. Serial No. 311,416. (No model.)

To all whom it may concern:

Be it known that I, NIKOLA TESLA, a subject of the Emperor of Austria-Hungary, from Smiljan, Lika, border country of Austria-Hungary, residing at New York, in the county and State of New York, have invented certain new and useful Improvements in Electro-Magnetic Motors, of which the following is a specification, reference being had to the drawings accompanying and forming a part of the same.

I have invented and elsewhere described an electro-magnetic motor operated or adapted to be operated by an alternating electric current, and which is now commonly designated, whether correctly or not, a "magnetic-lag" motor. The main distinguishing features of this motor are the following: An armature is mounted within the magnetizing influence of a certain number of field magnets or poles of different magnetic susceptibility—that is to say, poles of unequal length, mass, or composition—and wound with coils adapted in the operation of the motor to be connected to a source of alternating currents. When an alternating current is passed through the coils of such a motor, the field magnets or poles do not appear to manifest their attractive effect upon the armature simultaneously, the magnetic attraction of some appearing to lag behind that of others, with the result of producing a torque and rotation of the motor. Generally I have made such motors with closed armature-coils.

I have invented another form of motor, which, for similar reasons, may be called a "magnetic-lag" motor; but in operation it differs from that which I have above described in that the attractive effects or phases of the poles, while lagging behind the phases of current which produce them, are manifested simultaneously and not successively.

To carry out this invention I employ a motor embodying the principle of construction of a motor described and claimed in an application filed by me January 8, 1889, No. 295,745, to the extent that both the armature and field receive their magnetism from a single energizing-coil or a plurality of coils acting as one.

A motor which embodies my invention, with certain modifications thereof, is illustrated in the accompanying drawings.

Figure 1 is a side view of the motor in elevation. Fig. 2 is a part-sectional view at right angles to Fig. 1. Fig. 3 is an end view in elevation and part section of a modification, and Fig. 4 is a similar view of another modification.

In Figs. 1 and 2, A designates a base or stand, and B B the supporting-frame of the motor. Bolted to the said supporting-frame are two magnetic cores or pole-pieces C C', of iron or soft steel. These may be subdivided or laminated, in which case hard iron or steel plates or bars should be used, or they should be wound with closed coils. D is a circular disk-armature built up of sections or plates of iron and mounted in the frame between the pole-pieces C C', which latter are preferably curved to conform to the circular shape thereof. I may wind this disk with a number of closed coils E. F F are the main energizing-coils, supported in any convenient manner by the supporting-frame, or otherwise, but so as to include within their magnetizing influence both the pole-pieces C C' and the armature D. The pole-pieces C C' project out beyond the coils F F on opposite sides, as indicated in the drawings. If an alternating current be passed through the coils F F, rotation of the armature will be produced, and this rotation I explain by the following apparent action or mode of operation: An impulse of current in the coils F F establishes two polarities in the motor. The protruding end of pole-piece C, for instance, will be of one sign, and the corresponding end of pole-piece C' will be of the opposite sign. The armature also exhibits two poles at right angles to the coils F F, like poles to those in the pole-pieces being on the same side of the coils. While the current is flowing there is no appreciable tendency to rotation developed; but after each current impulse ceases or begins to fall the magnetism in the armature and in the ends of the pole-pieces C C' lags or continues to manifest itself, which produces a rotation of the armature by the repellent force between the more closely approximating points of maximum magnetic effect. This effect is continued by the reversal of current, the polarities of field and armature being simply reversed. One or both of the elements—the armature or field—may be wound with closed induced coils to intensify this effect, although in the drawings I have shown but one of the fields, each element of the motor really constitutes a field, wound with the closed coils, the currents being induced mainly in those convolutions or coils which are parallel to the coils F F. A modified form of this motor is shown in Fig. 3. In this form G is one of two standards that support the bearings for the armature-shaft. H H are uprights or sides of a frame, preferably magnetic, the ends C C' of which are bent, substantially as shown, to conform to the shape of the armature D and form field-magnet poles. The construction of the armature may be the same as in the previous figure, or it may be simply a magnetic disk or cylinder, as shown, and a coil or coils F F are secured in position to surround both the armature and the poles C C'. The armature is detachable from its shaft, the latter being passed through the armature after it has been inserted in position. The operation of this form of motor is the same in principle as that previously described and needs no further explanation.

One of the most important features in alternating-current motors is that they should be adapted to and capable of running efficiently in the alternating systems in present use, in which almost without exception the generators yield a very high number of alternations. Such a motor I have designed by a development of the principle of the motor shown in Fig. 3, making a multipolar motor, which is illustrated in Fig. 4. In the construction of this motor I employ an annular magnetic frame J, with inwardly-extending ribs or projections K, the ends of which all bend or turn in one direction and are generally shaped to conform to the curved surface of the armature. Coils F F are wound from one part K to the one next adjacent, the ends or loops of each coil or group of wires being carried over toward the shaft, so as to form U-shaped groups of convolutions at each end of the armature. The pole-pieces C C', being substantially concentric with the armature, form ledges, along which the coils are laid and should project to some extent beyond the coils, as shown. The cylindrical or drum armature D is of the same construction as in the other motors described, and is mounted to rotate within the annular frame J and between the U-shaped ends or bends of the coils F. The coils F are connected in multiple or in series with a source of alternating currents, and are so wound that with a current or current impulse of given direction they will make the alternate pole-pieces C of one polarity and the other pole-pieces C' of the opposite polarity. The principle of the operation of this motor is the same as the other herein described, for, considering any two pole-pieces C C', a current impulse passing in the coil which bridges them or is wound over both tends to establish polarities in their ends of opposite sign and to set up in the armature-core between them a polarity of the same sign as that of the nearest pole-piece C. Upon the fall or cessation of the current impulse that established these polarities the magnetism which lags behind the current phase, and which continues to manifest itself in the polar projections C C' and the armature, produces by repulsion a rotation of the armature. The effect is continued by each reversal of the current. What occurs in the case of one pair of pole-pieces occurs simultaneously in all, so that the tendency to rotation of the armature is measured by the sum of all the forces exerted by the pole-pieces, as above described. In this motor also the magnetic lag or effect is intensified by winding one or both cores with closed induced coils. The armature-core is shown as thus wound. When closed coils are used, the cores should be laminated.

It is evident that a pulsatory as well as an alternating current might be used to drive or operate the motors herein described; but I prefer to use alternating currents.

It will be understood that the degree of subdivision, the mass of the iron in the cores, their size, and the number of alternations in the current employed to run the motor must be taken into consideration in order to properly construct this motor. In other words, in all such motors the proper relations between the number of alternations and the mass, size, or quality of the iron must be preserved in order to secure the best results. These are matters, however, that are well understood by those skilled in the art.

What I claim is—

1. In an alternating-current motor, the combination, with the armature and field-cores, of stationary energizing-coils enveloping the said cores and adapted to produce polarities or poles in both, the field-cores extending out. from the coils and constructed so as to exhibit the magnetic effect imparted to them after the fall or cessation of current impulse producing such effect, as set forth.

2. In an alternating-current motor, the combination, with an armature-core circular in configuration, of a supporting-frame, field-cores extending therefrom over portions of the periphery of the armature, and energizing-coils surrounding said armature and parts of the field-cores, as set forth.

3. The combination, with the rotatably-mounted armature, of the circular frame J, the ribs K, with polar extensions extending over portions of the armature, and the energizing-coils F, wound over portions of the pole-pieces and carried in loops over the ends of the armature, as herein set forth.

NIKOLA TESLA.

Witnesses:
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P-108

(No Model) 2 Sheets—Sheet 1

N. TESLA
ELECTRO MAGNETIC MOTOR.

No 424,036 Patented Mar. 25, 1890.

Fig 1

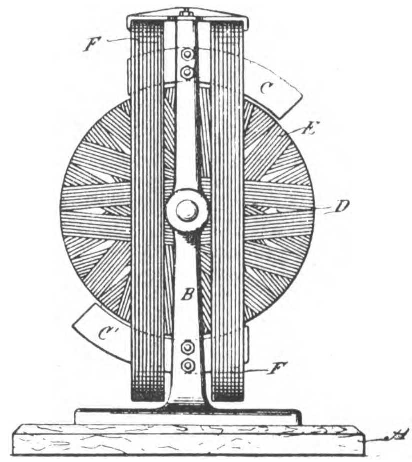
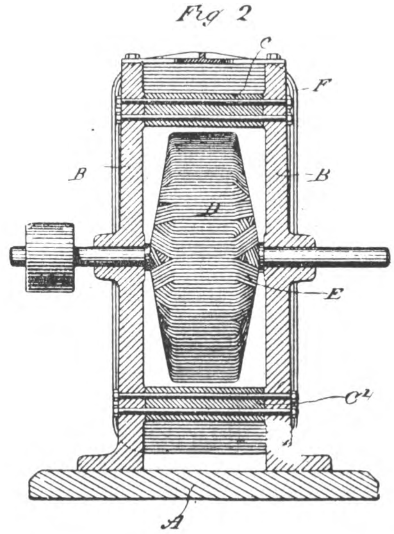


Fig 2



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P-109

(No Model.) 2 Sheets—Sheet 2

N. TESLA.

ELECTRO MAGNETIC MOTOR.

No. 424,036. Patented Mar. 25, 1890.

Fig. 3

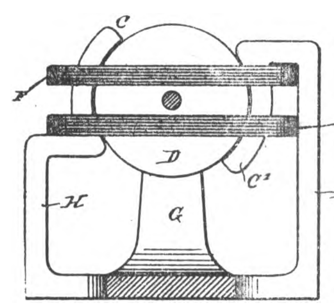
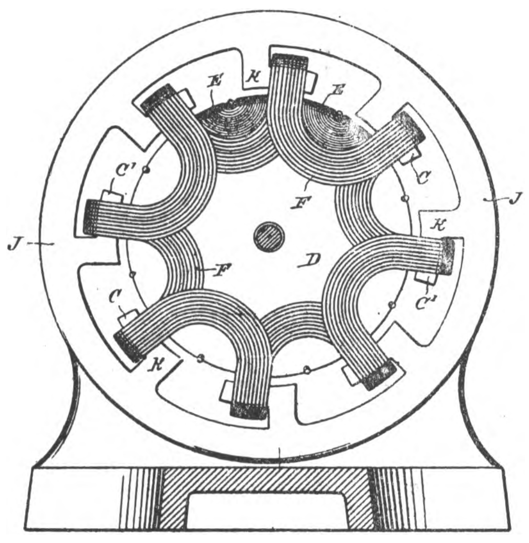


Fig. 4



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NIKOLA TESLA, OF NEW YORK, N. Y., ASSIGNOR TO THE TESLA ELECTRIC COMPANY, OF SAME PLACE.

ELECTRO-MAGNETIC MOTOR.

SPECIFICATION forming part of Letters Patent No. 445,207, dated February 27, 1891.

Application filed May 20, 1889. Serial No. 311,417. (No model)

To all whom it may concern:

Be it known that I, NIKOLA TESLA, a subject of the Emperor of Austria-Hungary, from Smiljan, Lika, border country of Austria-Hungary, residing at New York, in the county and State of New York, have invented certain now and useful Improvements in Electro-Magnetic Motors, of which the following is a specification, reference being had to the drawings accompanying and forming a part of the same.

Among the various forms of alternating-current motors invented by me is one which I have described in other applications, and which is constructed as follows: I build a field-core with, say, four poles, between which is mounted an armature that is generally wound with closed coils. On two of the opposite poles of the field I wind primary coils, which are connected up in the main circuit. On the same cores I also wind secondary coils, which are closed through coils on the other pair or set of poles. In this motor when an alternating current is caused to passthrough the primary coils it energizes directly one set of poles and induces currents in the secondary coils, which act to energize the other poles; but the phases of the current in the secondary coils may differ in time from those of the primary current, and hence a rotation or shifting of the poles is effected that imparts rotation to the motor.

These motors may be constructed in many other ways; but for purposes of this case it is only necessary to consider the specific form which I have thus generally described, as my improvements relate mainly to such form.

The object of my present invention is to render this form of motor more efficient and to improve its action or mode of operation.

In the motors constructed in accordance with this principle I bring two energizing-circuits into inductive relation in the motor itself—that is to say, the secondary currents which energize one set of the field-cores are induced in the motor itself, and the employment of an external induction device is thus avoided. The operation of these motors, however, is dependent upon the existence of a certain difference of phase between the currents in the primary and secondary cells. To obtain a difference of phase or lag that is suited to working conditions is the specific object of my present invention.

The following explanations will serve to illustrate the principle upon which said invention is based. Let it be assumed that an ordinary alternating-current generator is connected up in a circuit of practically no self-induction, such, for example, as a circuit containing incandescent lamps only. On the operation of the machine alternating currents will be developed in the circuit, and the phases of these currents will theoretically coincide with the phases of the impressed electro-motive force. Such currents may be regarded and designated as the "unretarded currents."

It will be understood, of course, that in practice there is always more or less self-induction in the circuit, which modifies to a corresponding extent these conditions; but for convenience this may be disregarded in the consideration of the principle of operation, since the same laws apply. Assume next that a path of currents be formed across any two points of the above circuit, consisting, for example, of the primary of an induction device. The phases of the currents passing through the primary, owing to the self-induction of the same, will not coincide with the phases of the impressed electro-motive force, but will lag behind the same, such lag being directly proportional to the self-induction and inversely proportional to the resistance of the said coil. The insertion of this coil will also cause a lagging or retardation of the currents traversing and delivered by the generator behind the impressed electro-motive force, such lag being the mean or resultant of the lag of the current through the primary alone and that of what I have designated the "unretarded current" in the entire working-circuit. Next consider the conditions imposed by the association in inductive relation with the primary coil of a secondary coil. The current generated in the secondary coil will react upon the primary current, modifying the retardation of the same, according to the amount of self-induction and resistance in the secondary circuit If the secondary circuit have but little self-induction—as, for instance, when it contains incandescent lamps only—it will increase the actual difference of phase between its own and the primary current, first, by diminishing the lag between the primary current and the impressed electro-motive force, and, second, by its own lag or retardation behind the impressed electro-motive force. On the other hand, if the secondary circuit have a high self-induction its lag behind the current in the primary is directly increased, while it will be still further increased if the primary have a very low self-induction. The better results are obtained when the primary has a low self-induction. I apply these principles to the construction of a motor which I shall now describe.

The details of the improvements are illustrated in the drawings, in which—

Figure 1 is a diagram of a motor exhibiting my invention. Fig. 2 is a similar diagram of a modification of the same.

In Fig. 1 let A designate the field-magnet of a motor which, as in all these motors, is built up of sections or plates. B C are polar projections upon which the coils are wound. Upon one pair of these poles, as C, I wind primary coils D, which are directly connected to the circuit of an alternating-current generator G. On the same poles I also wind secondary coils F, either side by side or over or under the primary coils, and these I connect with other coils K, which surround the poles B B. The currents in both primary and secondary coils in such a motor will be retarded or will lag behind the impressed electro-motive force; but to secure a proper difference in phase between the primary and secondary currents themselves I increase the resistance of the circuit of the secondary and reduce as much as practicable its self-induction. I do this by using for the secondary circuit, particularly in the coils E, wire of comparatively small diameter and having but few turns around the cores; or I use some conductor of higher specific resistance, such as German silver; or I may introduce at some point, in the secondary circuit an artificial resistance R. Thus the self-induction of the secondary is kept down and its resistance increased with the result of decreasing the lag between the impressed electro-motive force and the current in the primary coils and increasing the difference of phase between the primary and secondary currents.

In the disposition shown in Fig. 2 the lag in the secondary is increased by increasing the self-induction of that circuit, while the increased tendency of the primary to lag is counteracted by inserting therein a dead resistance. The primary coils D in this case have a low self-induction and high resistance, while the coils E F, included in the secondary circuit, have a high self-induction and low resistance. This may be done by the proper winding of the coils, or in the circuit including the secondary coils E F, I may introduce a self-induction coil S, while in the primary circuit from the generator G and including coils D, I may insert a dead resistance R. By this means the difference of phase between the primary and secondary is increased. It is evident that both means of increasing the difference of phase—namely, by the special winding as well as by the supplemental or external inductive and dead resistance—may be employed conjointly.

In the operation of this motor the current impulses in the primary coils induce currents in the secondary coils, and by the conjoint action of the two the points of greatest magnetic attraction are shifted or rotated.

In practice I have found it desirable to wind the armature with closed coils in which currents are induced by the action thereon of the primaries.

I do not claim, broadly, herein the method of operating motors by inducing in one circuit currents by means of those in another, nor the other features herein not specifically pointed out in the claims, having personally filed applications for such features.

What I claim is—

1. The combination, in a motor, of a primary energizing-circuit adapted to be connected with the circuit of a generator and a secondary energizing-circuit in inductive relation thereto, the two circuits being of different electrical character or resistance, as set forth.

2. The combination, in a motor, of a primary energizing-circuit adapted to be connected with the circuit of a generator and a secondary energizing-circuit in inductive relation thereto, the two circuits being of different self-induction, as herein set forth.

3. The combination, in a motor, of primary energizing-coils adapted to be connected to a source of current and secondary energizing-coils in a circuit in inductive relation thereto, one set of said coils being formed by conductors of small size and few turns, the other by conductors of larger size, as set forth.

NIKOLA TESLA.

Witnesses:

R. J. STONEY, Jr.,

E. P. COFFIN.

P-112

N. TESLA.

ELECTROMAGNETIC MOTOR.

No. 445,207. Patented Jan. 27, 1891

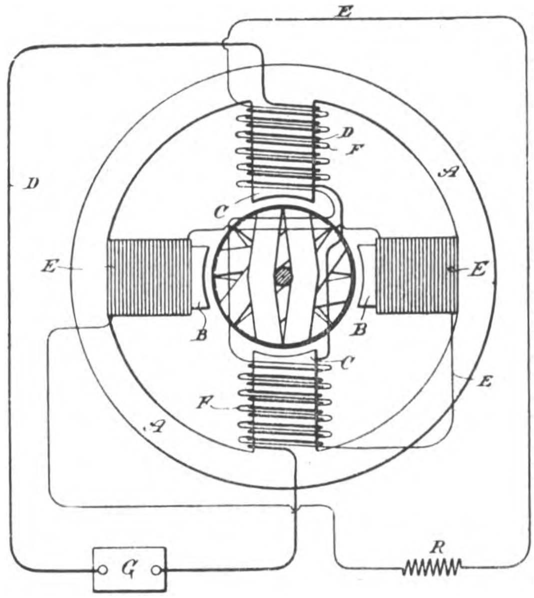
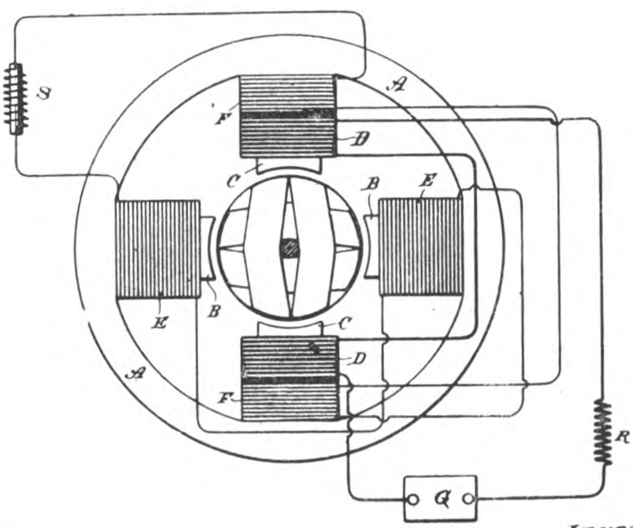


Fig. 2



Witnesses:
Raphael Netter
Frank E. Hartley

Inventor
Nikola Tesla
By
Duncan, Curtis & Page,
Attorneys.

UNITED STATES PATENT OFFICE.

ALBERT SCHMID, OF ALLEGHENY, AND NIKOLA TESLA, OF PITTSBURG, ASSIGNORS TO THE WESTINGHOUSE ELECTRIC COMPANY, OF PITTSBURG, PENNSYLVANIA.

ARMATURE FOR ELECTRIC MACHINES.

SPECIFICATION forming part of Letters Patent No. 417,794, dated December 24, 1889.

Application filed June 28, 1889. Serial No. 315,937. (No model.)

To all whom, it may concern:

Be it known that we, ALBERT SCHMID and NIKOLA TESLA, citizens, respectively, of the Republic of Switzerland and Smiljan, Lika, border country of Austria-Hungary, now residing in Allegheny and Pittsburg, both in the county of Allegheny and State of Pennsylvania, have in vented a certain new and useful Improvement in Armatures for Electric Machines, (Case No. 310.) of which the following is a specification.

The invention relates to the const ruction of armatures for electric generators and motors, and the object is to provide an electrically-efficient armature, the construction of which is simple and economical, and in which the coils of insulated conducting wire or ribbon may be conveniently wound or formed into bobbins so located with reference to the body of the armature as to afford as good results as possible.

For certain purposes it is desirable to construct the armatures of electric generators and motors with their cores of magnetizable material projecting through the coils into close proximity to the field-magnet poles. When armatures are constructed in this manner, some means are necessary for holding the coils in position and preventing them from being thrown out by centrifugal force.

This invention aims to provide such means in an armature having polar projections, and also to form an armature in such manner as to expose a large area of core-surface to the field-magnet poles.

The invention consists, in general terms, in forming an armature-core which is preferably built up of laminæ of magnetizable material insulated from each other, with diverging slots or openings for receiving the armature wire or ribbon, which slots are connected with the exterior of the armature by Openings through which the wire may be laid in the slots, and in placing the wire in such slots in the proper manner.

We are aware of the United States Patents No. 327,797, granted to Immisch, and No. 292,077, granted to Wenstrom, and the British patent of Coerper, No. 9,013 of 1887, and do not claim the constructions shown and described therein.

The invention will be described more particularly in connection with the accompanying drawings, in which—

Figure 1 is an end view, partly in section, of an armature embodying the features of the invention, and Fig. 2 is a plan of the armature.

Referring to the figures, F F indicate field-magnet poles, and A represents the body or core of an armature composed, in this instance, of laminæ of magnetizable material built up in any suitable manner, the laminæ being preferably separated by intervening strata of insulating material. The individual plates or laminæ are constructed with radial openings c, extending a short distance from the surface, and with slots or openings *b,* which extend in different directions from the openings c. The slots diverge from each other at such angles as to cause the two slots upon the opposite sides of each web *e* thus formed to lie in the same chord of the circle of the armature. The plates may also be stamped or formed with openings G to remove the unnecessary metal. After the plates are formed they are laid up in the proper manner to form the entire armatur-core, the slots *b* being placed opposite each other to form continuous openings through the entire length of the armature. These openings may be lined by pockets *h* of insulating material—such, for instance, as vulcanized fiber—and the wires are then wound into the slots from the openings *c* and around the respective webs *e.* Winding-clips *k* may be placed at the respective ends of the armature opposite each web *e* to hold the wires in the proper positions as they are wound in the slots and down upon the armature ends.

The wires having been wound into their proper positions, they may be held more securely in position by means of blocks K of non-magnetic material, placed at intervals or extending through the entire slots or openings c and projecting into the slots *b.*

An armature constructed in the manner

described is found to be very efficient in its operations and at the same time simple in its construction.

The connections between the armature coils and the conductors or collecting-plates may be made in any usual well-known manner, according to the purposes desired to be served.

We claim as our invention—

1. A core for electrical machines, composed of plates of magnetizable material separated by insulation, said plates having diverging slots for receiving the armature-conductors and an opening to the exterior of the plate at the origin of the diverging slots.

2. A core-plate for electrical machines, stamped with diverging slots at intervals near its periphery and an opening to the periphery at the angle formed by each two diverging slots.

3. A core for electrical machines, composed of plates of magnetizable material separated by insulation, said plates having diverging slots for receiving the armature-conductors and an opening to the exterior of the plate at the origin of the diverging slots, the width of such openings being approximately equal to the width of the slot.

4. An armature-core for electric machines, consisting of plates of magnetizable material separated by insulation, having radial openings at intervals, slots diverging from said openings for receiving armature-coils, and winding blocks or clips at the ends of the core.

5. An armature-core for electrical apparatus, composed of plates of magnetizable material separated by initiation and having radial openings at intervals, slots extending in opposite directions from said openings for receiving wires, and insulating-linings for said slots.

6. An armature for electric machines, consisting of a laminated core formed with diverging slots for receiving the wires, said slots leaving intervening webs, and coils of wire wound in said slots.

7. An armature for electric machines, consisting of a laminated core formed with diverging slots for receiving the wires, said slots leaving intervening webs, coils of wire wound in said slots, and non-magnetizable material closing the openings of the adjacent slots outside the wires, substantially as described.

8. An armature for electric machines, consisting of a core having its outer surface continuous except for narrow longitudinal openings at intervals and having slots diverging from said openings armature-coils wound in said slots, and blocks or strips of non-magnetizable material closing the openings and forming with the metal of the armature a practically continuous surface.

In testimony whereof we have hereunto subscribed our names this 25th day of June, A. D. 1889.

ALBERT SCHMID
NIKOLA TESLA.

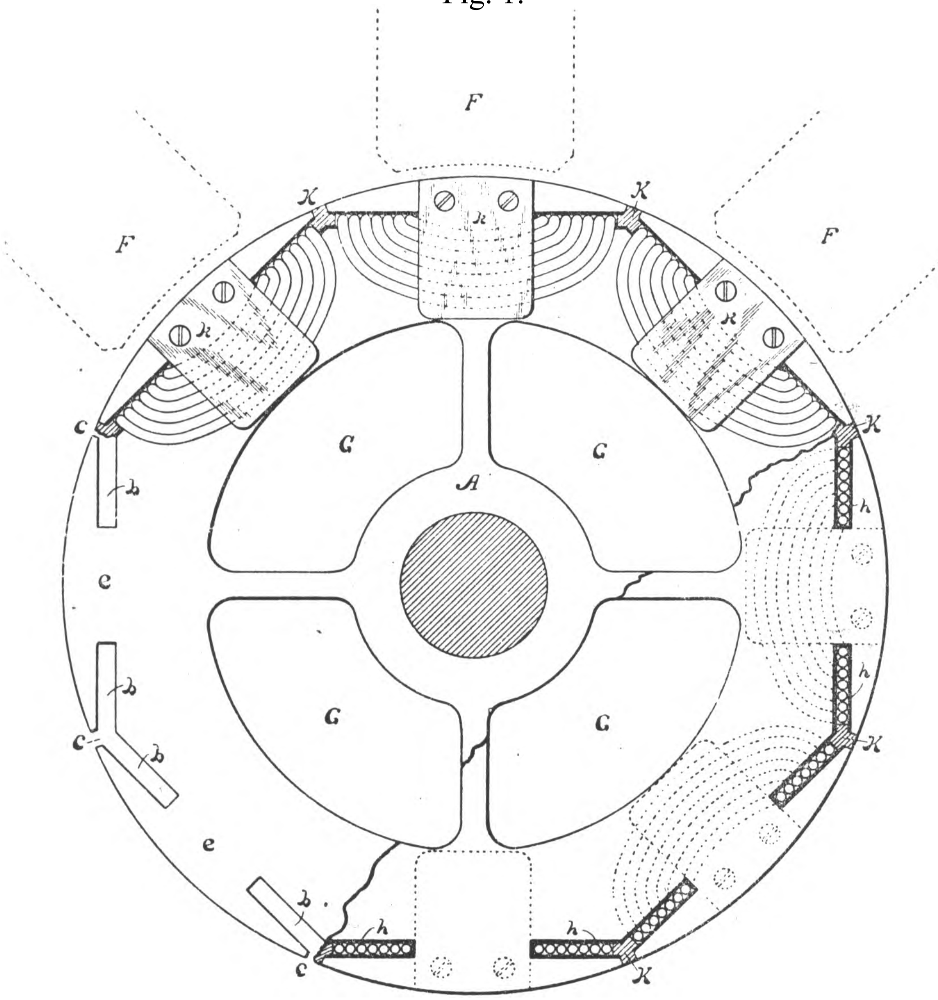
Witnesses:
W. D. UPTEGRAFF,
CHARLES A. TERRY.

(No Model) 2 Sheets—Sheet I

A. SCHMID & N. TESLA.
ARMATURE FOR ELECTRIC MACHINES.

No. 417,794. Patented Dec. 24, 1889.

Fig. 1.



WITNESSES

George Brown Jr.
Wm Smith

INVENTOR

Albert Schmid.
Nikola Tesla.

Charles A. Terry
Att'y.

P-116

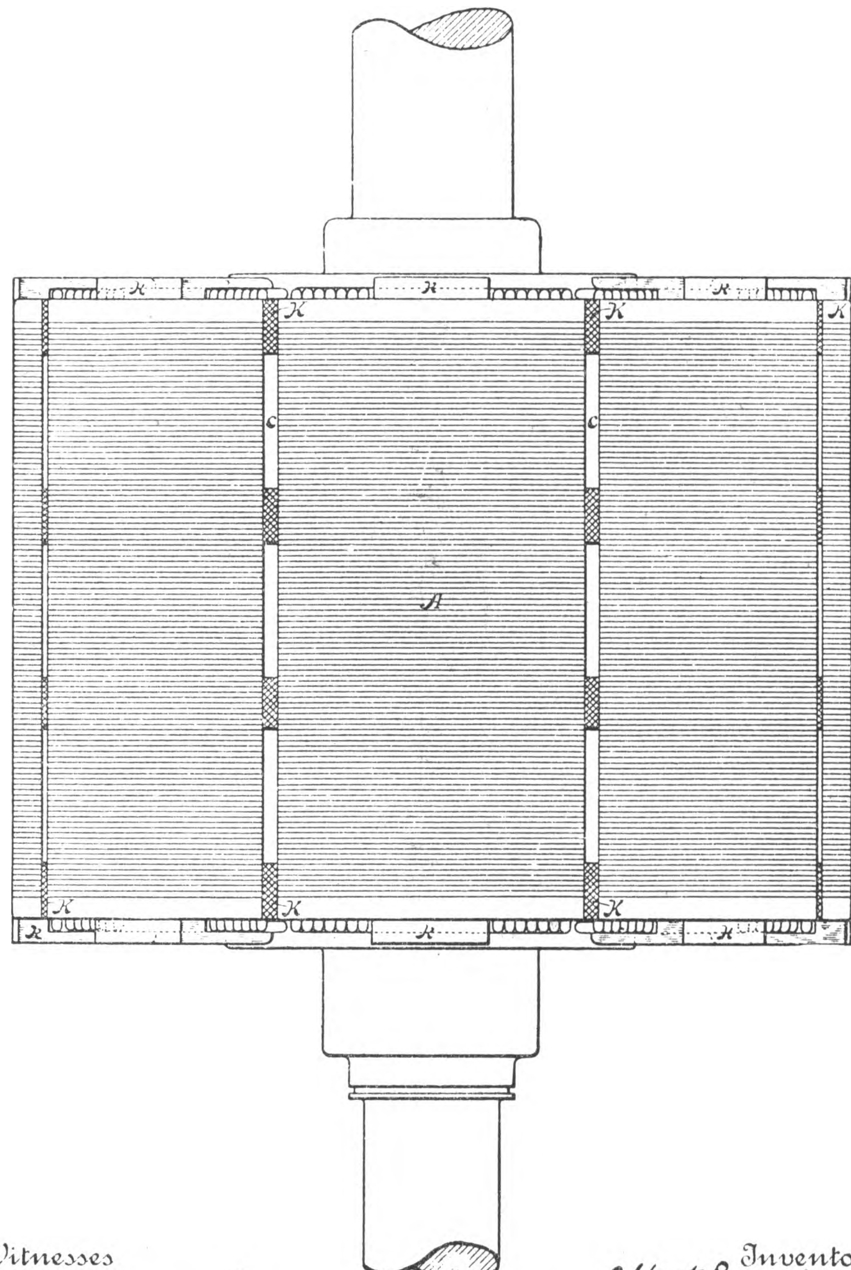
(No Model) 2 Sheets—Sheet 2

A. SCHMID & N. TESLA

ARMATURE FOR ELECTRIC MACHINES.

No. 417,794. Patented Dec. 24, 1889.

Fig. 2.



Witnesses
George Brown Jr.
J. Wm. Smith

Inventor
Albert Schmid
Nikola Tesla
By their Attorney
Charles A. Terry

UNITED STATES PATENT OFFICE

NIKOLA TESLA, OF NEW YORK, N. Y., ASSIGNOR TO THE TESLA ELECTRIC COMPANY, OF SAME PLACE.

ALTERNATING-CURRENT ELECTRO-MAGNETIC MOTOR.

SPECIFICATION forming part of Letters Patent No. 483,700, dated August 5, 1890.

Application filed March 26, 1890. Serial Ho. 345,388. (No model.)

To all whom it may concern:

Be it known that I, NIKOLA TESLA, a subject of the Emperor of Austria-Hungary, from Smiljan, Lika, border country of Austria-Hungary, residing at New York, in the county and State of New York, have invented certain new and useful Improvements in Alternating-Current Electro-Magnetic Motors, of which the following is a specification, reference being had to the drawings accompanying and forming a part of the same.

This invention is an improvement in that class of electro-magnetic motors in which the rotation is produced by the progressive movement or effect of the maximum magnetic, points or poles produced by the conjoint action or effect of two energizing-circuits through which are passed alternating currents, or currents of rapidly-varying strength of a kindred nature.

The improvements subject of this application are more particularly applicable to that class of motors in which two or more sets of energizing-magnets are employed, and in which by artificial means a certain interval of time is made to elapse between the respective maximum or minimum periods or phases of their magnetic attraction or effect. This interval or difference in phase between the two sets of magnets, when artificially produced, is limited in extent. It is desirable, however, for the economical working of such motors that the strength or attraction of one set of magnets should be maximum at the time when that of the other set is minimum and conversely; but these conditions have not heretofore been realized except in cases where the two currents have been obtained from independent sources in the same or different machines.

The object of the present invention is to establish conditions more nearly approaching the theoretical requirements of perfect working, or, in other words, to produce artificially a difference of magnetic phase by means of a current from a single primary source sufficient in extent to meet the requirements of practical and economical working.

In carrying out my invention I employed motor with two sets of energizing or field magnets, each wound with coils connected with a source of alternating or rapidly-varying currents, but forming two separate paths or circuits. The magnets of one set I protect to a certain extent from the energizing action of the current by means of a magnetic shield or screen interposed between the magnet and its energizing-coil. This shield is properly adapted to the conditions of particular cases, so its to shield or protect the main core from magnetization until it has become itself saturated and no longer capable of containing all the lines of force produced by the current. By this means it will be seen that the energizing action begins in the protected set of magnets a certain arbitrarily-determined period of time later than in the other, and that by this means alone or in conjunction with other means or devices heretofore employed a practically-economical difference of magnetic phase may readily be secured.

The nature and operation of the invention will be more fully explained by reference to the accompanying drawings.

Figure 1 is a view of a motor, partly in section, with a diagram illustrating this invention. Fig. 2 is a similar view of a modification of the same.

In Fig. 1, which exhibits the simplest form of the invention, A A is the field-magnet of a motor, having, say, eight poles or inwardly-projecting cores B and C. The cores B form ones set of magnets and are energized by coils D. The cores C, forming the other set, are energized by coils E, and the coils are connected, preferably, in series with one another, in two derived or branched circuits F G, respectively, from a suitable source of current. Each coil E is surrounded by a magnetic shield H, which is preferably composed of an annealed, insulated, or oxidized iron wire wrapped or wound on the coils in the manner indicated, so as to form a closed magnetic circuit around the coils and between the same and the magnetic cores C. Between the pole pieces or cores B C is mounted the armature K, which, as is usual in this type of machines, is wound with coils L closed upon themselves. The operation resulting from this disposition is as follows: If a current impulse be directed through the two circuits of the motor, it will quickly energize the cores B, but not so the cores C, for the reason that in passing through the coils E there is encountered the influence of the closed magnetic circuits formed by the shields H. The first effect is to effectively retard the current impulse in circuit G, while at the same time the proportion of current which does pass does not magnetize the cores C, which are shielded or screened by the shields H. As the increasing electro-motive force then urges more current through the coils E, the iron wire H becomes magnetically saturated and incapable of carrying all the lines of force, and hence ceases to protect the cores C, which become magnetized, developing their maximum effect after an interval of time subsequent to the similar manifestation of strength in the other set of magnets, the extent of which is arbitrarily determined by the thickness of the shield H, and other well-understood conditions.

From the above it will be seen that the apparatus or device acts in two ways. First, by retarding the current, and, second, by retarding the magnetization of one set of the cores, from which its effectiveness will readily appear.

Many modifications of the principle of this invention are possible. One useful and efficient application of the invention is shown in Fig. 2. In said figure a motor is shown similar in all respects to that above described, except that the iron wire H, which is wrapped around the coils E, is in this case connected in series with the coils D. The iron-wire coils H, are connected and wound, so as to have little or no self-induction, and being added to the resistance of the circuit F the action of the current in that circuit will be accelerated, while in the other circuit G it will be retarded. The shield H may be made in many forms, as will be understood, and used in different ways, as appears from the foregoing description. I do not, however, limit myself to any specific form or arrangement; but

What I claim is—

1. In an alternating-current, motor having two energizing-circuits, the combination, with the magnetic cores and coils of one of the circuits, of interposed magnetic shields or screens for retarding the magnetization of said cores, as set forth.

2. In an alternating-current motor having two energizing-circuits, the combination, with the magnetic cores and the coils of one of the circuits wound thereon, of magnetic shields or coils wound around said coils at right angles to their convolutions, as set forth.

3. In an alternating-current motor having two energizing-circuits, the combination, with the magnetic cores and the coils of one of the circuits which energize the said cores, of magnetic shields forming closed magnetic circuits around the coils and interposed between the coils and cores, as set forth.

4. In an alternating-current motor having two energizing-circuits derived from the same source, the combination, with the cores and the coils of one of the circuits that energizes the same, of insulated iron-wire coils wound on the said energizing-coils at right angles to their convolutions and connected up in series with the coils of the other energizing-circuit, as set forth.

NIKOLA TESLA.

Witnesses:
ROBT. F. GAYLORD,
PARKER W. PAGE

(No Model.)

N. TESLA.

ALTERNATING CURRENT ELECTRO MAGNETIC MOTOR.

No. 433,700. Patented Aug. 5, 1890.

Fig. 1

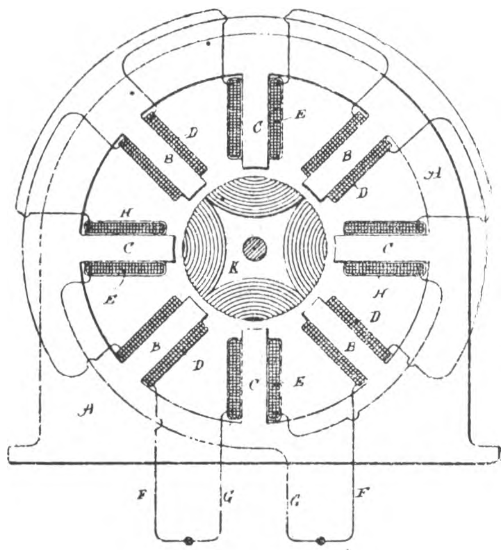
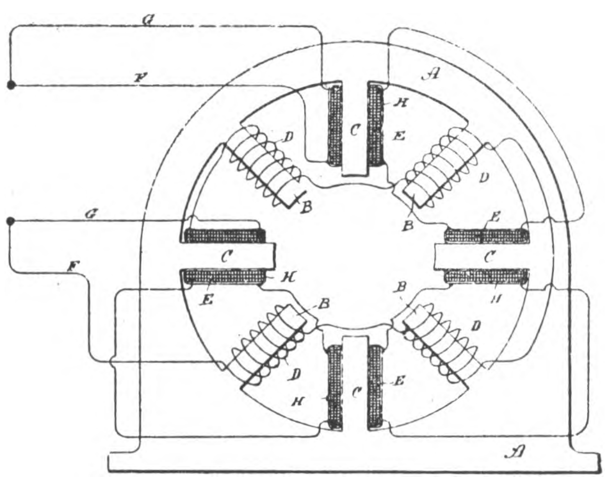


Fig. 2



Witnesses:
Raphael Netter
Ernest Hopkinson

Inventor
Nikola Tesla
by
Duncan. Curtis & Page
Attorneys.

UNITED STATES PATENT OFFICE.

NIKOLA TESLA, OF NEW YORK, N. Y., ASSIGNOR TO THE TESLA ELECTRIC COMPANY, OF SAME PLACE.

ALTERNATING-CURRENT MOTOR.

SPECIFICATION forming part of Letters Patent No. 433,701, dated August 5, 1890.

Application filed March 28, 1890. Serial No. 345,339. (No model.)

To all whom it may concern:

Be it known that I, NIKOLA TESLA, a subject of the Emperor of Austria-Hungary, from Smiljan, Lika, border country of Austria-Hungary, residing at New York, in the county and State of Now York, have invented certain new and useful Improvements in Alternating-Current Motors, of which the following is a specification, reference being had to the drawings accompanying and forming a part of the same.

This invention relates to that class of alternating-current motors in which the field-magnets are energized by coils connected up in two circuits derived from the same source and having different degrees of self-induction, whereby the currents in one circuit or branch are retarded more than in the other, with the result of producing a progressive advance or rotation of the points of maximum magnetic effect in the field that maintains the armature in rotation. In motors of this kind I have employed, among other means, a self-induction coil in one circuit and a dead-resistance in the other, or I have secured the same result by the special character of the winding of the two circuits, and in still another instance I have so constructed the motor that the retarded-current coils were nearly inclosed by icon, whereby the self-induction of such coils was very greatly increased.

The invention subject of this application is an improvement on this last-named plan.

In carrying out the invention I construct a field magnet having two sets of poles or inwardly-projecting cores and placed side by side, so as practically to form two fields of force and alternately disposed—that is to say, with the poles of one set or field opposite the spaces between the other. I then connect the free ends of one set of poles by means of laminated iron bands or bridge-pieces of considerably smaller cross-section than the cores themselves, whereby the cores will all form parts of complete magnetic circuits. When the coils on each set of magnets are connected in multiple circuits or branches from a source of alternating currents, electromotive forces are set up in or impressed upon each circuit simultaneously; but the coils on the magnetically bridged or shunted cores will have, by reason of the closed magnetic circuits, a high self-induction, which retards the current, permitting at the beginning of each impulse but little current to pass. On the other hand, no such opposition being encountered in the other set of coils, the current passes freely through them, magnetizing the poles on which they are wound. As soon, however, as the laminated bridges become saturated and incapable of carrying all the lines of force, which the rising electro-motive force, and consequently increased current, produce, free poles are developed at the ends of the cores, which, acting in conjunction with the others, produce rotation of the armature.

The construction in detail by which this invention is illustrated is shown in the accompanying drawings.

Figure 1 is a view in side elevation of a motor embodying the invention. Fig. 2 is a vertical cross-section of the same.

A is the frame of the motor, which is preferably built up of sheets of iron punched out to the desired shape and bolted together with insulation of a proper character between the sheets. When complete, the frame makes a field-magnet with inwardly-projecting pole-pieces B and C. To adapt them to the requirements of this particular case these pole-pieces are out of line with one another, those marked B surrounding one end of the armature and the others, as C, the opposite end, and they are disposed alternately—that is to say, the pole-pieces of one set occur in line with the spaces between those of the other sets.

The armature D is of cylindrical form, and is also laminated in the usual way and is wound longitudinally with coils closed upon themselves. The pole-pieces C are connected or shunted by bridge-pieces E. These may be made independently and attached to the pole-pieces, or they may be parts of the forms or blanks stamped or punched out of sheet-iron. Their size or mass is determined by various conditions, such as the strength of the current to be employed, the mass or size of the cores to which they are applied, and other well-understood conditions.

Coils F surround the pole-pieces B, and other coils G are wound on the pole-pieces C.

These coils are connected in series in two circuits, which are branches of a circuit from a generator of alternating currents, and they may be so wound, or the respective circuits in which they are included may be so arranged, that the circuit of coils G will have independently of the particular construction herein described a higher self-induction than the of her circuit or branch.

The function of the shunts or bridges E is that they shall form with the cores C a closed magnetic circuit for a current up to a predetermined strength, so that when saturated by such current and unable to carry more lines of force than such a current produces they will to no further appreciable extent interfere with the development by a stronger current of free magnetic poles at the ends of the cores C.

In such a motor the current is so retarded in the coils G and the manifestation of the free magnetism in the poles C is delayed beyond the period of maximum magnetic effect in poles B that a strong torque is produced and the motor operates with approximately the power developed in a motor of this kind energized by independently-generated currents differing by a full-quarter phase.

What I claim in this application is:

1. In an alternating-current motor having two sets or series of pole-pieces, the combination, with one of such sets or series, of magnetic shunts or bridges connecting their free ends, as herein set forth.

2. In an alternating-current motor having two sets or series of pole-pieces energized by coils in independent circuits from, the same source, the combination, with one of the sets or series of pole-pieces, of magnetic shunts or bridges connecting their free ends, as described.

3. In an alternating-current motor having a laminated or subdivided field-magnet provided with two sets or series of cores or pole-pieces, the combination, with such pole-pieces, of energizing-coils connected, respectively, in two circuits derived from the same source of alternating currents and laminated or subdivided iron shunts or bridges of smaller cross-section than the pole-pieces and joining the free ends of all the cores or pole-pieces of one set to form closed magnetic circuits, as set forth.

4. In an alternating-current motor, the combination, with a set or series of field-poles and energizing-coils wound thereon, of an intermediate set of pole-pieces forming portions of closed magnetic circuits and coils thereon in a circuit derived from the same source of alternating currents as the other, as set forth.

NIKOLA TESLA.

Witnesses:
ROBT. F. GAYLORD.
PARKER W. PAGE.

P-122

(No Model.)

N. TESLA

ALTERNATING CURRENT MOTOR.

No. 433,701 Patented Aug. 5, 1890.

Fig. 1

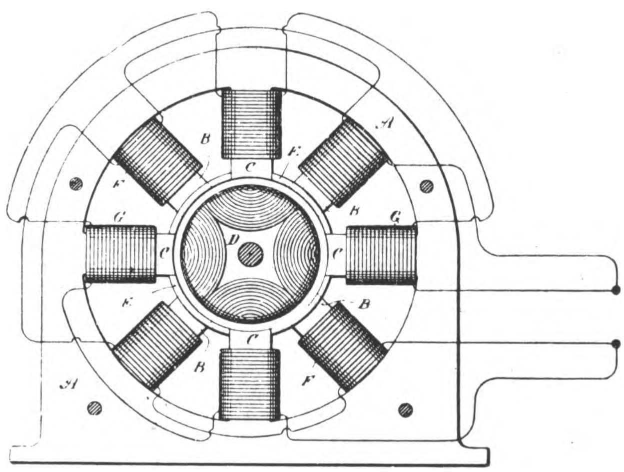
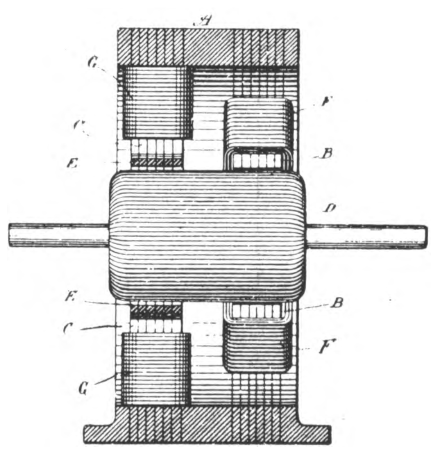


Fig. 2



Witnesses:
Raphael Netter
Ernest Hopkinson

Inventor
Nikola Tesla
by
Duncan Curtis & Page
Attorneys.

UNITED STATES PATENT OFFICE.

NIKOLA TESLA, OF NEW YORK, N. Y., ASSIGNOR TO THE TESLA ELECTRIC COMPANY, OF SAME PLACE.

ELECTRICAL TRANSFORMER OR INDUCTION DEVICE.

SPECIFICATION forming part of Letters Patent No. 433,702, dated August 5, 1890.

Application filed March 26, 1890. Serial No. 345,390. (No model.)

To all whom it may concern:

Be it known that I, NIKOLA TESLA, a subject of the Emperor of Austria Hungary, from Smiljan, Lika, border country of Austria-Hungary, residing at New York, in the county and State of New York, have invented certain new and useful Improvements in Electrical Transformers or Induction Devices, of which the following is a specification, reference being had to the drawings accompanying and forming a part of the same.

This invention is an improvement in electrical transformers or converters, and has for its main objects the provision of means for securing, first, a phase difference between the primary and secondary currents adapted to the operation of my alternating-current motors and other like purposes, and, second, a constant current for all loads imposed upon the secondary.

In transformers as constructed now and heretofore it will be found that the electromotive force of the secondary very nearly coincides with that of the primary, being, however, of opposite sign. At the same time the currents, both primary and secondary, lag behind their respective electro-motive forces; but as this lag is practically or nearly the same in the case of each it follows that the maximum and minimum of the primary and secondary currents will nearly coincide, but differ in sign or direction, provided the secondary be not loaded or if it contain devices having the property of self-induction. On the other hand, the lag of the primary behind the impressed electro-motive force may be diminished by loading the secondary with a non-inductive or dead resistance—such as incandescent lamps—whereby the time interval between the maximum or the minimum periods of the primary and secondary currents is increased. This time interval, however, is limited, and the results obtained by phase difference in the operation of such devices as my alternating-current motors can only be approximately realized by such means of producing or securing this difference, as above indicated, for it is desirable in such cases that there should exist between the primary and secondary currents, or those which, however produced, pass through the two circuits of the motor, a difference of phase of ninety degrees; or, in other words, the current in one circuit should be maximum when that in the other circuit is minimum. To more perfectly attain to this condition I obtain or secure an increased retardation of the secondary current in the following manner: Instead of bringing the primary and secondary coils or circuits of a transformer into the closest possible relations, as has hitherto been done, I protect in a measure the secondary from the inductive action or effect of the primary by surrounding either the primary or the secondary with a comparatively-thin magnetic shield or screen. Under these conditions or circumstances, as long as the primary current has a small value, the shield protects the secondary; but as soon as the primary current has reached a certain strength, which is arbitrarily determined, the protecting magnetic shield becomes saturated and the inductive action upon the secondary begins. It results, therefore, that the secondary current begins to flow at a certain fraction of a period later than it would without the interposed shield, and since this retardation may be obtained without necessarily retarding the primary current also, an additional lag is secured, and the time interval between the maximum or minimum periods of the primary and secondary currents is increased. I have further discovered that such a transformer may, by properly proportioning its several elements and determining in a manner well understood the proper relations between the primary and secondary windings, the thickness of the magnetic shield, and other conditions, be constructed to yield a constant current at all loads. No precise rules can be given for the specific construction and proportions for securing the best results, as this is a matter determined by experiment and calculation in particular cases; but the general plan of construction which I have described will be found under all conditions to conduce to the attainment of this result.

In the accompanying drawings I have illustrated the construction above set forth.

Figure 1 is a cross-section of a transformer embodying my improvement. Fig. 2 is a similar view of a modified form of transformer, showing diagrammatically the manner of using the same.

A A is the main core of the transformer, composed of a ring of soft annealed and insulated or oxidized iron wire. Upon this core is wound the secondary circuit or coil B B. This latter is then covered with a layer or layers of annealed and insulated iron wires C C, wound in a direction at right angles to said secondary coil. Over the whole is then wound the primary coil or wire D D. From the nature of this construction it will soon be obvious that as long as the shield formed by the wires C is below magnetic saturation the secondary coil or circuit is effectually protected or shielded from the inductive influence of the primary, although I would state that on open circuit it may exhibit some electro-motive force. When the strength of the primary readies a certain value, the shield C, becoming saturated, ceases to protect the secondary from inductive action, and current is in consequence developed therein. For similar reasons, when the primary current weakens, the weakening of the secondary is retarded to the same or approximately the same extent.

The specific construction of the transformer is largely immaterial. In Fig. 2, for example, the core A is built up of thin insulated iron plates or disks. The primary circuit D is wound next, the core A. Over this is applied the shield C, which in this case is made up of thin strips or plates of iron properly insulated and surrounding the primary, forming a closed magnetic circuit. The secondary B is wound over the shield C. In Fig. 2, also, E is a source of alternating or rapidly changing currents. The primary of the transformer is connected with the circuit of the generator.

F is a two-circuit alternating-current motor, one of the circuits being connected with the main circuit from the source E, and the other being supplied with currents from the secondary of the transformer.

Having now described my invention, what I claim is—

1. In an electrical transformer or induction device, the combination, with the main magnetic core and the primary and secondary coils or circuits, of a magnetic shield or screen interposed between said coils, as herein, set forth.

2. In an electrical transformer or inductive device, the combination, with the magnetic core and the primary and secondary coils or circuits, of a magnetic shield or screen surrounding one of said coils only, as set forth.

3. In an electrical transformer or induction device, the combination, with the magnetic core and the primary and secondary coils wound thereon, of a magnetic shield or screen wound on or built up around one only of said coils, as described.

4. In an electrical transformer or induction device, the combination, with a main laminated magnetic core and primary and secondary coils thereon, of a subdivided or laminated magnetic shield or screen interposed between the coils, as set forth.

5. In an electrical transformer, the combination, with a magnetic core and primary and secondary coils wound thereon, of a magnetic shield or screen interposed between said coils and surrounding one of them and adapted to be or capable of being magnetically saturated by a predetermined current strength below the maximum in the primary, as set forth.

NIKOLA TESLA.

Witnesses:
ROBT. F GAYLORD.
PARKER W PAGE

(No Model.)

N. TESLA

ELECTRICAL TRANSFORMER OR INDUCTION DEVICE.

No. 433,702. Patented Aug. 5, 1890.

Fig. 1

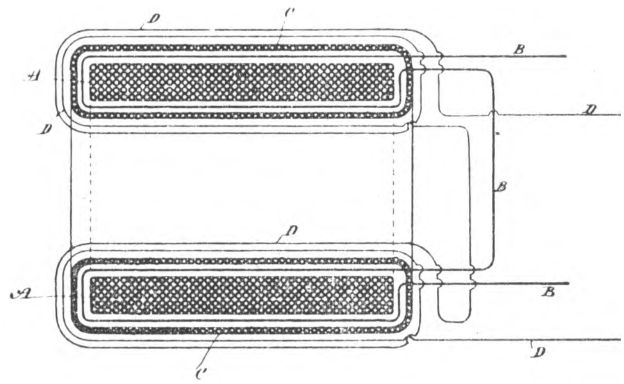
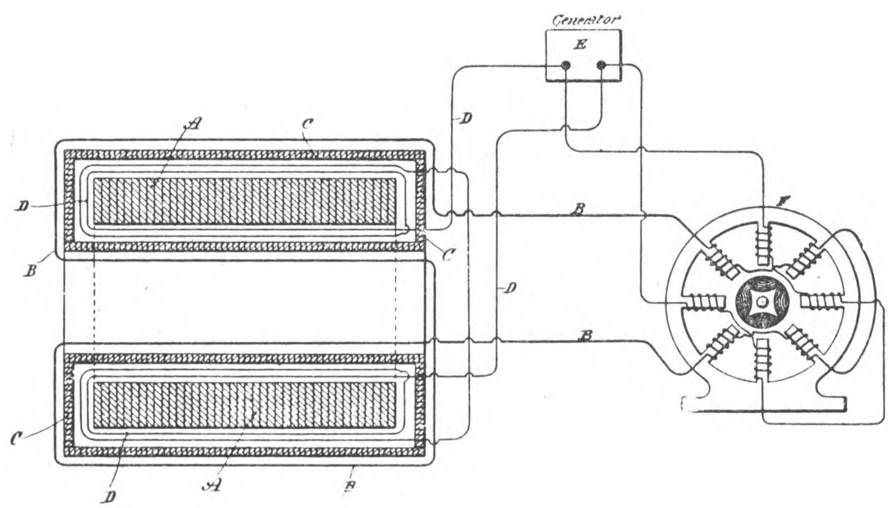


Fig. 2



Witnesses:
Raphael Netter
Ernest Hopkinson

Inventor
Nikola Tesla
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Duncan Curtis & Page
Attorneys.

UNITED STATES PATENT OFFICE.

NIKOLA TESLA. OF NEW YORK, N. Y., ASSIGNOR TO THE TESLA ELECTRIC COMPANY, OF SAME PLACE

ELECTRO-MAGNETIC MOTOR

SPECIFICATION forming part of Letters Patent No. 433,703, dated August 3, 1890.

Application filed April 4, 1890. Serial No. 346,603. (No model.)

To all whom it may concern:

Be it known that I, NIKOLA TESLA, a subject of the Emperor of Austria-Hungary, from Smiljan, Lika, border country of Austria-Hungary, residing at New York, in the county and State of New York, have invented certain new and useful Improvements in Electro-Magnetic Motors, of which the following is a specification, reference being had to the drawings accompanying and forming a part of the same.

This invention is an improvement in alternating-current motors, and has for its general object to produce a single-circuit alternating-current torque-motor of economical and simple construction.

The nature of the invention will be understood from the following statement:

It is well known that if a magnetic core, even if laminated or subdivided, be wound with an insulated coil and a current of electricity directed through the coil the magnetization of the entire core does not immediately ensue, the magnetizing effect not being exhibited in all parts simultaneously. This I attribute to the fact that the action of the current is to energize first those laminæ or parts of the core nearest the surface and adjacent to the exciting-coil, and from thence the action progresses toward the inferior. A certain interval of time therefore elapses between the manifestation of magnetism in the external and the internal sections or layers of the core. If the core be thin or of small mass, this effect may be inappreciable; but in the case of a thick core, or even of a comparatively thin one, if the number of alternation or rate of change of the current strength be very great the time interval occurring between the manifestations of magnetism in the interior of the core and in those parts adjacent to the coil is more marked, and in the construction of such apparatus as motors which are designed to be run by alternating or equivalent currents—such as pulsating or undulating currents generally—I have found it desirable and even necessary to give due consideration to this phenomenon and to make special provisions in order to obviate its consequences. The specific object of my present invention is to take advantage of this action or effect, and by rendering it more pronounced to utilize it in the operation of motors in general. This object I attain by constructing a field-magnet. in which the parts of the core or cores that exhibit at different intervals of time the magnetic effect imparted to them by alternating or equivalent currents in an energizing coil or coils are so placed with relation to a rotating armature as to exert thereon their attractive effect successively in the order of their magnetization. By this means I secure a similar result to that which I have heretofore attained in other forms or types of motor in which by means of one or more alternating currents I have produced a rotation or progression of the magnetic poles or points of maximum attraction of the field of force.

In the drawings I have shown a simple form of motor, which will serve to demonstrate the principle of the mode of operation, which I have above described in general terms

Figure 1 is a side elevation of such motor Fig. 2 is a side elevation of a more practicable and efficient embodiment of the invention. Fig. 3 is a central vertical section of the same in the plane of the axis of rotation.

Referring to Fig. 1, let X represent a large iron core, which may be composed of a number of sheets or laminæ of soft iron or steel. Surrounding this core is a coil Y, which is connected with a source E of rapidly-varying currents. Let us consider now the magnetic conditions existing in this core at any point, as *b,* at or near the center, and any other point, as *a,* nearer the surface. When a current-impulse is started in the magnetizing-coil Y, the section or part at *a*, being close to the coil, is immediately energized, while the section or part at *b*, which, to use a convenient expression, is "protected" by the intervening sections or layers between *a* and *b*, does not at once exhibit its magnetism. However, as the magnetization of *a* increases, *b* becomes also affected, reaching finally its maximum strength some time later than *a.* Upon the weakening of the current the magnetization of *a* first diminishes, while *b* still exhibits its maximum strength; but the continued weakening of *a* is attended by a subsequent weakening of *b*. Assuming the current to be an alternating one, *a* will now be reversed, while *b* still continues of the first imparted polarity. This action continues the magnetic condition of *b,* following that of *a* in the manner above described. If an armature—for instance, a simple disk F, mounted to rotate freely on an axis—be brought into proximity to the core, a movement of rotation will be imparted to the disk, the direction depending upon its position relatively to the core, the tendency being to turn the portion of the disk nearest to the core from *a* to *b*, as indicated in Fig. 1. This action or principle of operation I have embodied in a practicable form of motor, which is illustrated in Fig. 2. Let A in said figure represent a circular frame of iron, from diametrically-opposite points of the interior of which the cores project. Each core is composed of three main parts B, B, and C, and they are similarly formed with a straight portion or body *e*, around which the energizing-coil is wound, a curved arm or extension *e*, and an inwardly-projecting pole or end *d*. Each core is made up of two parts B B, with their polar extensions reaching in one direction and a part C between the other two and with its polar extension reaching in the opposite direction. In order to lessen in the cores the circulation of currents induced therein, the several sections are insulated from one another in the manner usually followed in such cases. These cores are wound with coils D, which are connected in the same circuit, either in parallel or series, and supplied with an alternating or a pulsating current, preferably the former, by a generator E, represented diagrammatically. Between the cores or their polar extensions is mounted a cylindrical or similar armature F, wound with magnetizing-coils G, that are closed upon themselves, as is usual in motors of this general class.

The operation of this motor is as follows: When a current impulse or alternation is directed through the coils D, the sections B B of the cores, being on the surface and in close proximity to the coils, are immediately energized. The sections C, on the other hand, are protected from the magnetizing influence of the coil by the interposed layers of iron B B. As the magnetism of B B increases, however, the sections C are also energized; but they do not attain their maximum strength until a certain lime subsequent to the exhibition by the sections B B of their maximum. Upon the weakening of the current the magnetic strength of B B first diminishes, while the sections C have still their maximum strength; but as B B continue to weaken the interior sections are similarly weakened. B B may then begin to exhibit an opposite polarity, which is followed later by a similar change on C, and this action continues. B B and C may therefore be considered as separate field-magnets, being extended so as to act on the armature in the most efficient positions, and the effect is similar to that in my other forms of motor—viz., a rotation or progression of the maximum points of the field of force. Any armature—such, for instance, as a disk—mounted in this field would rotate from the pole first to exhibit its magnetism to that which exhibits it later.

It is evident that the principle herein described may be carried out in conjunction with other means, such as I have elsewhere set forth, for securing a more favorable or efficient action of the motor. For example, the polar extensions of the sections C may be wound or surrounded by closed coils L, as indicated by dotted lines in Fig. 2. The effect of these coils will be to still more effectively retard the magnetization of the polar extensions of C.

I do not wish to be understood as limiting myself to any particular construction of this form of motor, as the same principle of action or operation may be carried out in a great variety of forms.

What I claim is—

1. In an alternating-current, motor the combination with an energizing-coil and a core composed of two parts, one protected from magnetization by the other interposed between it and the coil, of an armature mounted with the influence of the fields of force produced by said parts, as set forth.

2. The combination, in an alternating-current motor, of a rotating armature, a field-magnet composed of a coil and a core with two sections in proximity to the coil and an inner section between the same, the sections being formed or provided with polar projections extending in opposite directions over or around the armature, as set forth.

3. The combination, in an alternating-current motor, of a rotating armature, a frame and field-magnets thereon, each composed of an energizing-coil wound around a core made up of outer and inner or protected magnetic sections, each of which is formed or provided with independent laterally-extended pole pieces or projections, as herein described.

NIKOLA TESLA.

Witnesses:
ROBT. F. GAYLORD,
PARKER W. PAGE.

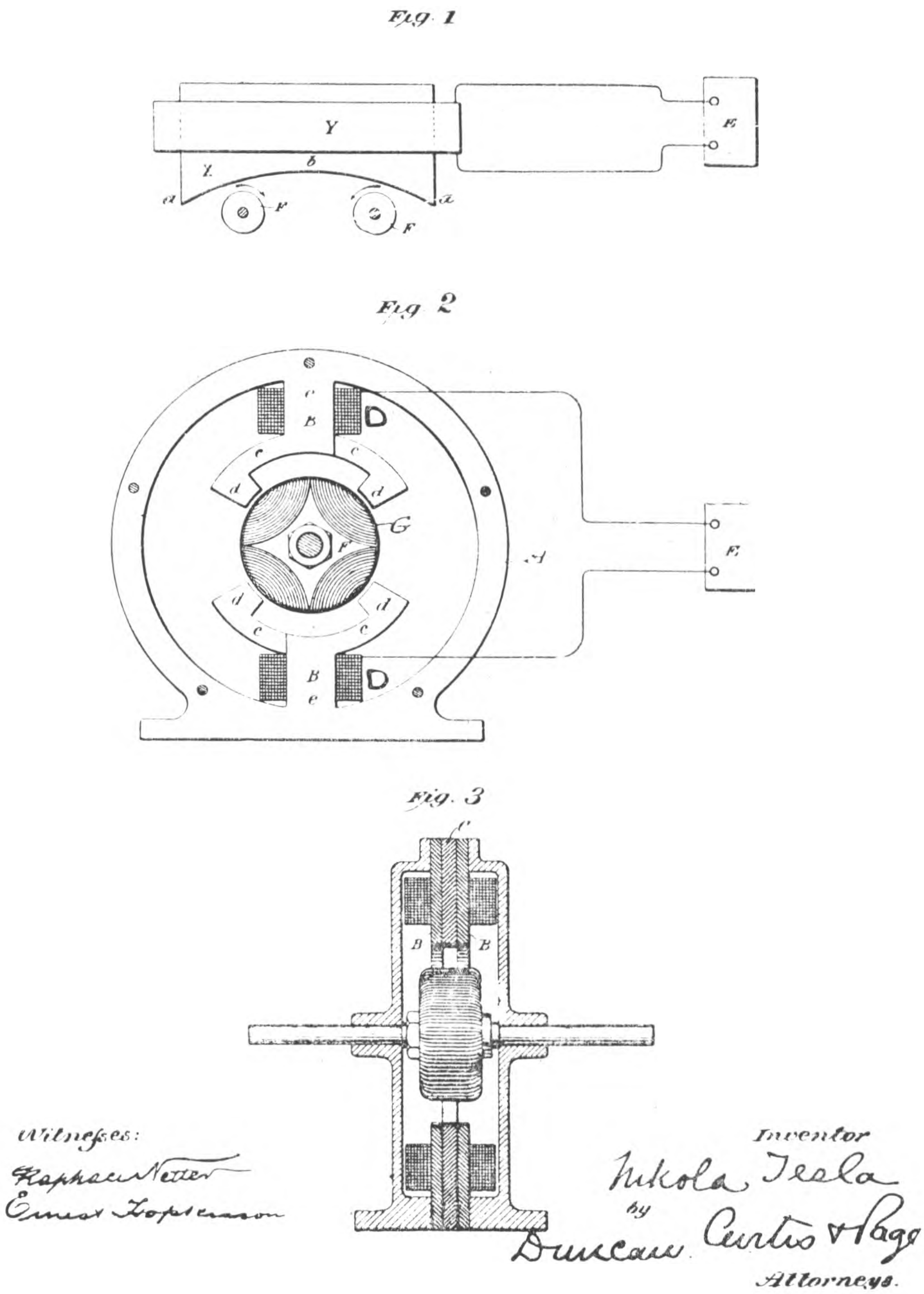
P-128

(No Model.)

N. TESLA

ELECTRO MAGNETIC MOTOR

No 433,703 Patented Aug. 5, 1890.



UNITED STATES PATENT OFFICE.

NIKOLA TESLA, OF NEW YORK, N. Y.

ALTERNATING-ELECTRIC-CURRENT GENERATOR.

SPECIFICATION forming part of Letters Patent No. 447,921, dated March 10, 1891.

Application filed November 16, 1890. Serial No. 371,664. (No model.)

To all whom it may concern:

Be it known that I, NIKOLA TESLA, a subject of the Emperor of Austria, from Smiljan, Lika, border country of Austria-Hungary, residing at New York, in the county and State of New York, have in vented certain new and useful Improvements in Alternating-Current Machines, of which the following is a specification, reference being had to the accompanying drawings.

In the systems of distribution of electrical energy from alternating-current generators in present use the generators give ordinarily from one to three hundred alternations of current per second. I have recognized and demonstrated in practice that it is of great advantage, on many accounts, to employ in such systems generators capable of producing a very much greater number of alternations per second—say fifteen thousand per second or many more. To produce such a high rate of alternation, it is necessary to construct a machine with a great number of poles or polar projections; but such construction, on this account, in order to be efficient, is rendered difficult. If an armature without polar projections be used, it is not easy to obtain the necessary strength of field, mainly in consequence of the comparatively great leakage of the lines of force from pole to pole. If, on the contrary, an armature-core formed or provided with polar projections be employed, it is evident that a limit is soon reached at which the iron is not economically utilized, being incapable of following without considerable loss the rapid reversals of polarity. To obviate these and other difficulties, I have devised a form of machine embodying the following general features of construction:

I provide a field-magnet core made up of two independent parts formed with grooves for the reception of one or more energizing-coils. The energizing coil, or coils, is completely surrounded by the iron core, except on one side, where occurs the opening between the polar faces of the core, which opening is made as narrow as the conditions of the machine will permit. The polar faces of the core of the field are not smooth, but formed with a great many projections or serrations, the points of which in one side or polar face are preferably exactly opposite those in the other. Between the faces so formed I mount or support the armature coil or coils and provide either for rotating the field-magnet or the armature, or both, and I arrange the said armature-coil or conductor so that it will be symmetrically disposed with respect to the field—that is to say, so that when one portion of the conductor is passing through the strongest portion of the field the other portion, which forms the return for the former, is passing through the weakest points or parts of the field. The strongest points of the field, it will be understood, are those between the projections or points on the polar faces, while the weakest points lie midway between them.

A field-magnet, when constructed as above described, produces, when the energizing-coil is traversed by a continuous current, a field of great strength, and one which may be made to vary greatly in intensity at points not farther distant from one another than the eighth of an inch. In a machine thus constructed there is comparatively little of that effect which is known as "magnetic leakage," and there is also but a slight armature reaction. Either the armature-conductor or the field-magnet may be stationary while the other rotates, and as it is often desirable to maintain the conductors stationary and to rotate the field-magnet I have made a special modification of the construction of the machine for this purpose, and with a view in such case of still further simplifying the machine and rendering it more easy to maintain in operation I arrange the armature-conductors and the frame or supports therefore so as to support also a fixed coil or coils for energizing the rotating field magnet thus obviating the employment of all sliding contacts.

In the accompanying drawings I have illustrated the two typical forms of my machine above referred to.

Figure 1 is a vertical central section of the machine, taken on lines *x x* of Fig. 2; and Fig. 2 is a horizontal section on lino *y y* of Fig. 1. The machine in these two figures is one in which the armature-conductor and the field-coil are stationary while the field-magnet core revolves. Fig. 3 is a vertical central section of a machine embodying the same plan of construction, but having a stationary field-magnet and rotating armature. Fig. 4 is a diagram illustrating the peculiar configuration of the polar faces and the relation of the armature conductor or conductors thereto.

In Figs. 1 and 2, A A designate two cylindrical castings provided with bracket-arms B B, in which latter are bushings C for the rotating shaft. The conductor in which the currents are induced may be constructed or arranged in various ways; but I prefer to form it in the following manner: I take an annular plate of copper D and by means of a saw or other cutting-tool cut in it radial slots from one edge nearly through to the other, beginning alternately from opposite edges. In this way a continuous zigzag conductor is formed. To the inner edge of this plate are secured two rings of noil-magnetic metal E, which are insulated from the copper conductor, but held firmly thereto, as by means of bolts F. Within the rings E is then placed an annular coil G, which is the energizing-coil for the field-magnet. The conductor D and the parts attached thereto are supported by means of the cylindrical shell or casting A A, the two parts of which are brought together and clamped by bolts F' to the outer edge of the conductor D. The conductor D is also insulated from the shell A.

The core for the field-magnet is built up of two circular parts H H, formed with annular grooves I, which, when the two parts are brought together, form a space for the reception of the energizing-coil G. The central parts or hubs of the cores H H are trued off, so as to fit closely against one another, while the outer portions or flanges which form the polar faces J J are reduced somewhat in thickness to make room for the conductor D, and are serrated on their faces or provided in any other convenient way with polar projections. The two parts of the core H H are mounted on and fixed to the shaft K, and are bound together by bolts L. The number of serrations in the polar faces is arbitrary; but there must exist between them and the radial portions of the conductor D a certain relation, which will be understood by reference to Fig. 4, in which N N represent the projections or points on one face of the core of the field, and S S the points of the other face. The conductor D is shown in this figure in section, *a a'* designating the radial portions of the conductor, and *b* the insulating-divisions between the same. The relative width of the parts *a a'* and the space between any two adjacent points N N or S S is such that when the radial portions *a* of the conductor are passing between the opposite points N S, where the field is strongest, the intermediate radial portions *a'* are passing through the widest spaces midway between such points and where the field is weakest. Since the core on one side is of opposite polarity to the part facing it, all the points or projections of one polar face will be of opposite polarity to those of the other face. Hence, although the space between any two adjacent points on the same face may be extremely small, there will be no leakage of the magnetic lines between any two points of the same name; but the lines of force will pass across from one set of points to the other. The construction followed obviates to a great degree the distortion of the magnetic lines by the action of the current in the conductor D, in which it will be observed the current is flowing at any given time from the center toward the periphery in one set of radial parts a and in the opposite direction in the adjacent parts *a'*.

In order to connect the energizing-coil G with a source of continuous current, I have found it convenient to utilize two adjacent radial portions of the conductor D for connecting the terminals of the coil G with two binding-posts M. For this purpose the plate D is cut entirely through, as shown, and the break thus made is bridged over by a short conductor *c*.

At any convenient point the plate D is cut through to form two terminals *d,* which are connected to binding-posts N.

The core H H, when rotated by the driving-pulley P, generates in the conductors D an alternating current, which is taken off from the binding-posts N. It will be observed that from the nature of the construction described this machine is capable of producing an alternating current of an enormously high rate of alternations.

When it is desired to rotate the conductor between the faces of a stationary field-magnet, I adopt the construction shown in Fig. 3. The conductor D in this case is or may be made in substantially the same manner as above described by slotting an annular conducting-plate and supporting it between two heads O, held together by bolts *o* and fixed to the driving-shaft K. The inner edge of the plate or conductor D is preferably flanged to secure a firmer union between it and the heads O. It is insulated from said head. The field-magnet in this case consists of two annular parts H H, provided with annular grooves I for the reception of the coils. The flanges or faces surrounding the annular groove are brought together, while the inner flanges are serrated, as in the previous case, and form the polar faces. The two parts H H are formed with a base R, upon which the machine rests.

S S are non-magnetic bushings secured or set in the central opening of the cores.

The conductor D is cut entirely through at one point to form terminals, from which insulated conductors T are led through the shaft to collecting-rings V.

What I claim is—

1. The combination, in an annular field of force formed by opposing polar faces with radial grooves or serrations and with said poles, of a connected series of radial conductors so disposed with relation to the serrations that while one portion of the radial conduct-

ors is passing between the strongest parts of the field, or the points where the two poles most nearly approach, the adjacent or intermediate conductors will pass through the weakest parts of the field, or the points where the two poles are most remote, as set forth.

2. The combination, with a connected series of radial conductors forming an annular coil, of a stationary two-part supporting-frame clamped to and insulated from the outer ends of said conductors, a ring formed in two parts clamped to the inner ends of the same, an energizing-coil contained in said ring, and a field-core made in two parts and inclosing said energizing-coil and presenting annular polar faces to the series of radial conductors, as described.

3. The combination, with the annular conducting-plate slotted to form a connected series of radial conductors, a sectional supporting-frame secured to and insulated from the outer edge of the slotted plate, a sectional ring secured to and insulated from the inner edge of said plate, a hollow energizing-coil contained in said ring, and a field-core composed of two parts bolted together and recessed to inclose the energizing-coil, said cores being mounted in a rotating shaft, as set forth.

4. The combination, with two annular polar faces of opposite magnetic polarity and formed with opposite points, projections, or serrations, of a conductor turned back upon itself in substantially radial convolutions and mounted in the annular field, whereby a rotation of the field or said conductor will develop therein an alternating current, as set forth.

5. The combination, with a polar face of given polarity formed with grooves or serrations, of a polar face of opposite polarity with corresponding grooves or serrations, the two polar faces being placed with their grooves opposite to each other, and a conductor or coil mounted between said faces with the capability of movement across the lines of force in a direction at right angles to that of the grooves or serrations, as set forth.

6. In a magneto-electric machine, the combination of a sectional frame, a field-magnet core composed of two connected parts, a rotating shaft on which said core is mounted, a conductor in which currents are to be induced, the convolutions of which are radially disposed between the polar faces of the field-core and secured to and supported by the frame, and an energizing-coil for the field-core supported by the induced-current coil and contained in an annular recess formed by grooves in the faces of the two sections of the field-core.

7. The combination, with opposing field-magnet poles formed with projections or serrations in their faces, the highest parts or prominences of one face being opposite to those of the other, of a conductor the convolutions of which are adapted to pass at right angles through the magnetic lines between the opposing prominences, as set forth.

8. The combination, with a rotating field-magnet core having two opposing and annular polar faces with radial grooves or serrations therein systematically disposed, so that the highest parts or prominences of one face lie opposite to those of the other, of a stationary conductor with radial convolutions and mounted between the polar faces, as set forth.

NIKOLA TESLA.

Witnesses:
ROBT. F. GAYLORD,
PARKER N. PAGE.

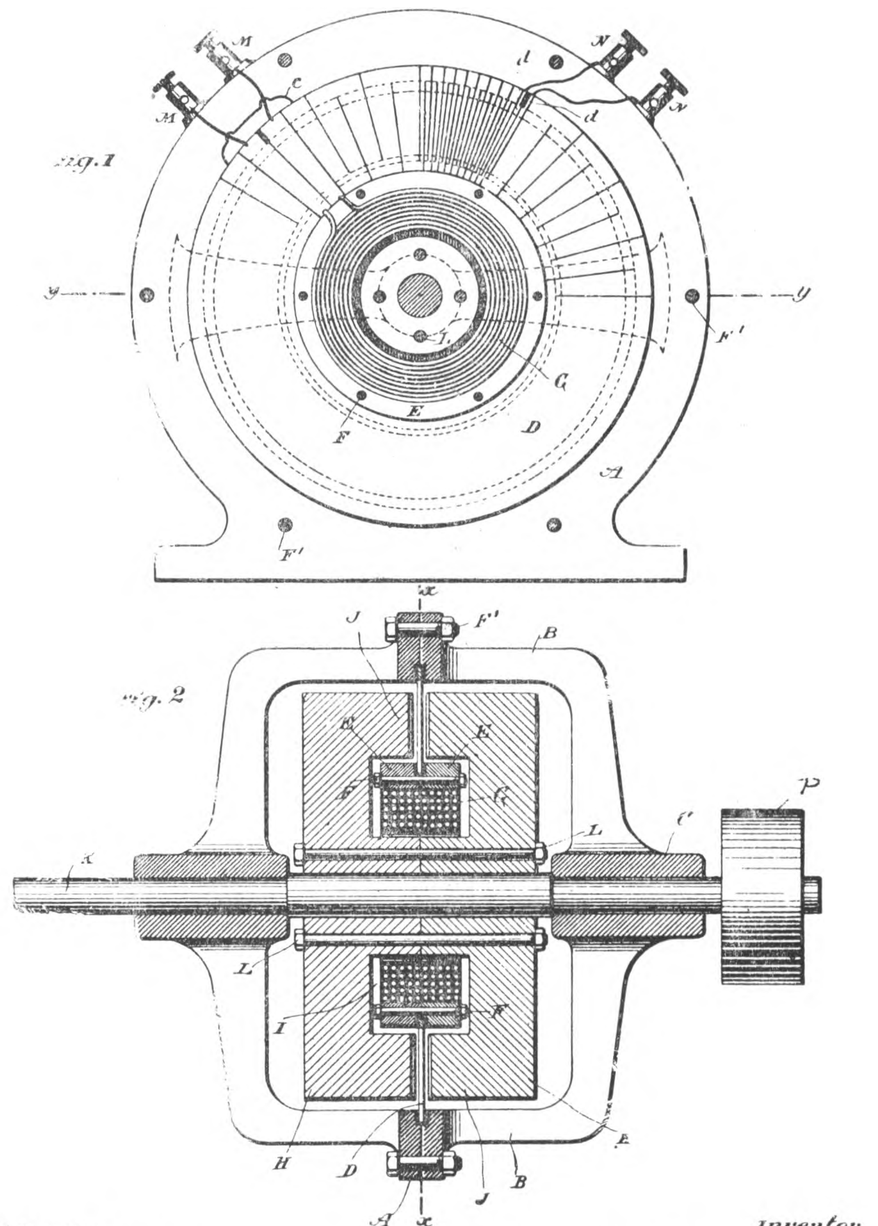
P-132

(No Model.) 2 Sheets—Sheet 1

N. TESLA.

ALTERNATING ELECTRIC CURRENT GENERATOR.

No. 447,921. Patented Mar. 10, 1891.



Witnesses:
Ernest Hopkinson
Frank B. Murphy.

Inventor
Nikola Tesla
by
Duncan & Page
Attorneys.

(No Model.) 2 Sheets—Sheet 2

N. TESLA.
ALTERNATING ELECTRIC CURRENT GENERATOR.

No. 447,921. Patented Mar. 10, 1891.

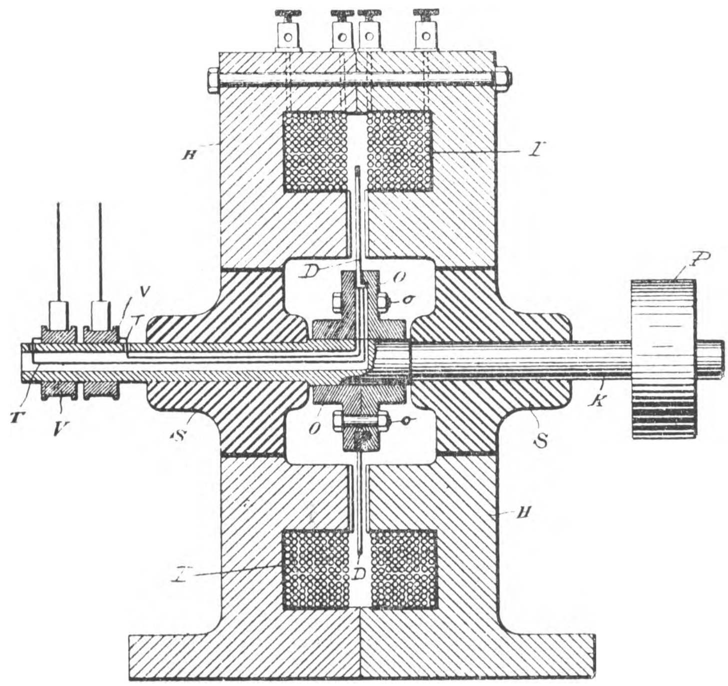
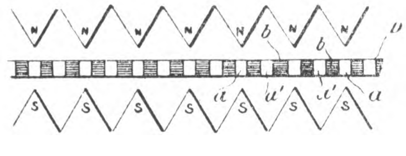


Fig. 4.



Witnesses.
Ernest Hopkinson
Frank B. Murphy.

Inventor
Nikola Tesla
by
Duncan & Page
Attorneys.

UNITED STATES PATENT OFFICE.

NIKOLA TESLA, OF NEW YORK, N. Y.

ELECTRO-MAGNETIC MOTOR.

SPECIFICATION forming part of Letters Patent No. 455,007, dated June 30, 1891.

Application filed January 27, 1891. Serial No. 379,251. (No model.)

To all whom it may concern:

Be it known that I, NIKOLA TESLA, a subject of the Emperor of Austria, from Smiljan, Lika, border country of Austria-Hungary, and residing at New York, in the county and State of New York, have invented certain new and useful Improvements in Electro-Magnetic Motors, of which the following is a specification, reference being had to the accompanying drawings.

The subject of my present invention is an improvement primarily designed for application to alternating-current motors of the special type invented by me, and of which the operation is due to the action of alternating currents differing in phase and directed through or developed in independent energizing-circuits in the motor, and causing a shifting or rotation of the magnetic poles or their resultant attractive forces upon the rotating element or armature.

My improvements are based upon certain laws governing the action or effects produced by a condenser when connected to an electric circuit through which an alternating or in general an undulating current is made to pass. Some of these effects, and those most important in connection with my invention, are as follows: First, if the terminals or plates of a condenser be connected with two points of a circuit, the potentials of which are made to rise and fall in rapid succession, the condenser allows the passage or, more strictly speaking, the transference of a current, although its plates or armatures may be so carefully insulated as to prevent almost completely the passage of a current of unvarying strength or direction and of moderate electro-motive force; second, if a circuit the terminals of which are connected with the plates of the condenser possess a certain self-induction, the condenser will overcome or counteract to a greater or less degree, dependent upon well-understood conditions, the effects of such self-induction; third, if two points of a closed or complete circuit through which a rapidly rising and falling current flows be shunted or bridged by a condenser, a variation in the strength of the currents in the branches and also a difference of phase of the currents therein is produced. These effects I have utilized and applied in a variety of ways in the construct ion and operation of my motors, as by producing a difference in phase in the two energizing-circuits of an alternating-current motor by connecting the two circuits in derivation and connecting up a condenser in series in one of the circuits; but such applications seem to be obvious to one familiar with my motors and the facts above enumerated.

My present improvements, however, possess certain novel features of practical value and involve a knowledge of facts less generally known. These improvements comprise the use of a condenser or condensers in connection with the induced or armature circuit of a motor and certain details of the construction of such motors. In an alternating-current motor of the type to which I have particularly referred above, or in any other which has an armature coil or circuit closed upon itself, the latter represents not only an inductive resistance, but one which is periodically varying in value, both of which facts complicate and render difficult the attainment of the conditions best suited to the most efficient working of the motors. The most efficient working conditions, in other words, require, first, that for a given inductive effect upon the armature there should be the greatest possible current through the armature or induced coils, and, second, that, there should always exist between the currents in the energizing and the induced circuits a given relation of phase. Hence whatever tends to decrease the self-induction and increase the current in the induced circuits will, other tilings being equal, increase the output and efficiency of the motor, and the same will be true of causes that operate to maintain the mutual attractive effect between the field-magnets and armature at its maximum. I secure these results by connecting with the induced circuit or circuits a condenser, in the manner hereinafter described, and I also, with this purpose in view, construct the motor in a special manner.

Referring to the drawings for a particular description of the invention, Figure 1 is a view, mainly diagrammatic, of an alternating-current motor to which my present invention is applied. Fig. 2 is a central section, in line with the shaft, of a special form of armature-core adapted to the invention. Fig. 3 is a similar section of a modification of the same. Fig. 4 is one of the sections of the core detached. Fig. 5 is a diagram showing a modified disposition of armature or induced circuits.

The general plan of the invention is illustrated in Fig. 1. A A in this figure represent the frame and field-magnets of an alternating-current motor, the poles or projections of which are wound with coils B and C, forming independent energizing-circuits connected either to the same or to independent sources of alternating currents, as is now well understood, so that the currents flowing through the circuits, respectively, will have a difference of phase. Within the influence of this field is an armature-core D, wound with coils E. In my motors of this description heretofore these coils have been closed upon themselves, or connected in a closed scries; but in the present case each coil or the connected series of coils terminates in the opposite plates of a condenser F. For this purpose the ends of the series of coils are brought out through the shaft to collecting-rings G, which are connected to the condenser by contact-brushes H and suitable conductors, the condenser being independent of the machine. The armature-coils are wound or connected in such manner that adjacent coils produce opposite poles.

The action of this motor and the effect of the plan followed in its construction are as follows: The motor being started in operation and the coils of the field-magnets being traversed by alternating currents, currents are induced in the armature-coils by one set of field-coils, as B, and the poles thus established are acted upon by the other set, as C. The armature-coils, however, have necessarily a high self-induction, which opposes the flow of the currents thus set up. The condenser F not only permits the passage or transference of these currents, but also counteracts the effects of self-induction, and by a proper adjustment of the capacity of the condenser, the self-induction of the coils, and the periods of the currents the condenser may be made to overcome entirely the effect of the self-induction.

It is preferable on account of the undesirability of using sliding contacts of all kinds to associate the condenser with the armature directly, or make it a part of the armature. In some cases I build up the armature of annular plates K K, held by bolts L between heads M, which are secured to the driving-shaft, and in the hollow space thus formed I place a condenser F, generally by winding the two insulated plates thereof spirally around the shaft. In other cases I utilize the plates of the core itself as the plates of the condenser. For example, in Figs. 3 and 4, N is the driving-shaft, M M are the heads of the armature-core, and K K' the iron plates of which the core is built up. These plates are insulated from the shaft and from one another, and are held together by rods or bolls L. The bolts pass through a large hole in one plate and a small hole in the one next adjacent, and so on, connecting electrically all of plates if, as one armature of a condenser, and all of plates K' as the other.

To either of the condensers above described the armaturc-coils may be connected, as explained by reference to Fig. 1.

In motors in which the armature-coils are closed upon themselves—as, for example, in any form of alternating-current motor in which one armature coil or set of coils is in the position of maximum induction with respect to the field coils or poles, while the other is in the position of minimum induction—the coils are preferably connected in one series, and two points of the circuit thus formed are bridged by a condenser. This is illustrated in Fig. 5, in which E represents one set of armature-coils and E' the other. Their points of union are joined through a condenser F. It will be observed that in this disposition the self-induction of the two branches E and E' varies with their position relatively to the field-magnet, and that each branch is alternately the predominating source of the induced current. Hence the effect of the condenser F is twofold. First, it increases the current in each of the branches alternately, and, secondly, it alters the phrase of the currents in the branches, this being the well-known effect which results from such a disposition of a condenser with a circuit, as above described. This effect is favorable to the proper working of the motor, because it increases the flow of current in the armature-circuits due to a given inductive effect, and also because it brings more nearly into coincidence the maximum magnetic effects of the coacting field and armature-poles.

It will be understood, of course, that the causes that contribute to the efficiency of condensers when applied to such uses as above must be given due consideration in determining the practicability and efficiency of the motors. Chief among these is, as is well known, the periodicity of the current, and hence the improvements which I have herein described are more particularly adapted to systems in which a very high rate of alternation or change is maintained.

Although this invention has been illustrated herein in connection with a special form of motor, it will be understood that it is equally applicable to any other alternating current motor in which there is a closed armature-coil wherein the currents are induced by the action of the field, and, furthermore, I would state that the feature of utilizing the plates or sections of a magnetic core for forming the condenser, I regard as applicable, generally, to other kinds of alternating-current apparatus.

Having now described my invention, what I claim is—

1. In an alternating-current motor, the com-

bination, with the field-magnets and energizing-circuit, of an armature-circuit and a core adapted to be. energized by currents induced in its circuit by the currents in the field-circuit, and a condenser connected with the armature-circuit only, as set forth.

2. In an alternating-current motor, the combination, with armature-coils in inductive relation to the field and connected in a closed circuit, of a condenser bridging said circuit, as set forth.

3. In an alternating-current motor, the combination, with an armature and two energizing-circuits formed by coils wound thereon in different inductive relations to the field and joined in a continuous or closed series, of a condenser the plates of which are connected, respectively, to the junctions of the circuits or coils as set forth.

4. In an alternating-current motor, the combination, with the induced energizing coil or coils of the armature, of a condenser connected therewith and made a part of the armature or rotating element of the motor.

5. In an alternating-current motor, the combination, with an armature-core composed of insulated conducting-plates alternately connected to form a condenser, of an induced energizing coil or coils wound thereon and connected to the plates or armatures of the said condenser.

6. A magnetic core for alternating-current apparatus, composed of plates or sections insulated from each other and alternately connected to form the two parts of armatures of a condenser.

NIKOLA TESLA.

Witnesses:

PARKER W. PAGE.

FRANK B. MURPHY.

(No Model.)

N. TESLA.

ELECTRO MAGNETIC MOTOR.

No. 455,067 Patented June 30, 1891.

Fig. 1

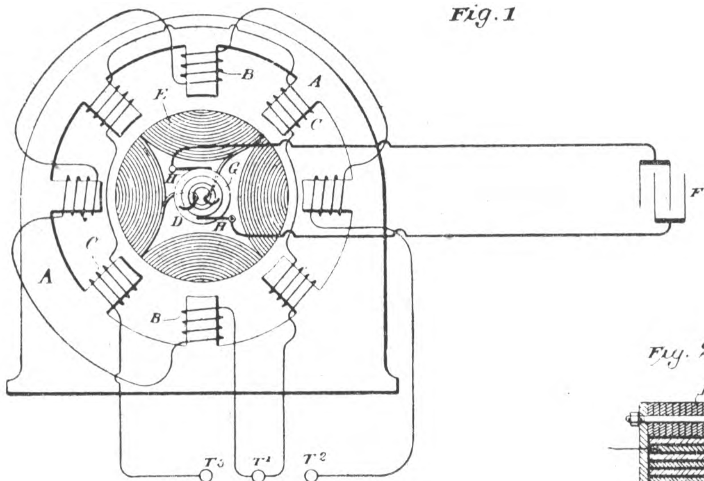


Fig. 2

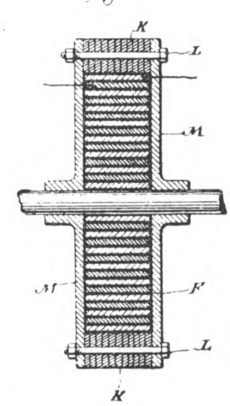


Fig. 4

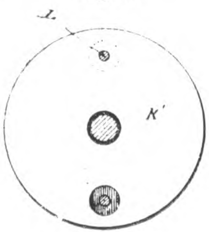


Fig. 3

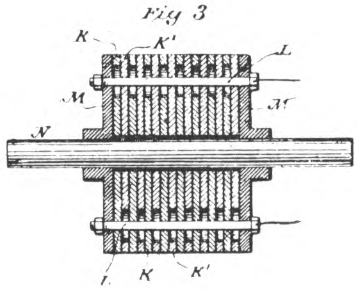
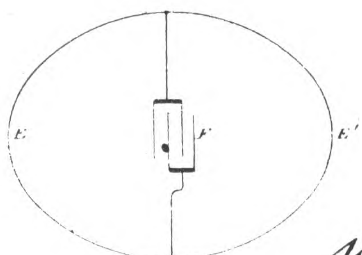


Fig. 5



Witnesses
Raphael Netter
Frank B. Murphy

Inventor
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Attorneys.

UNITED STATES PATENT OFFICE.

NIKOLA TESLA, OF NEW YORK, N. Y.

ELECTRO-MAGNETIC MOTOR.

SPECIFICATION forming part of Letters Patent No. 464,666, dated December 8, 1891.

Application filed July 13, 1801. Serial No. 399,312. (No model.)

To all whom it may concern:

Be it known that I, NIKOLA TESLA, a subject of the Emperor of Austria, from Smiljan, Lika, border country of Austria-Hungary, residing at New York, in the county and Slate of New York, have invented certain new and useful Improvements in Electro-Magnetic Motors, of which the following is a specification, reference being had to the drawing accompanying and forming a part of the same.

The general object of my present invention is to secure artificially a difference of a quarter of a phase between the currents in the two energizing-circuits of an alternating-current electro-magnetic motor of that general class invented by me, in which the action or operation is dependent upon the inductive influence upon a rotating armature of independent field magnets or coils exerted successively and not simultaneously.

It is a well-known fact that if the field or energizing circuits of such a motor be both derived from the same source of alternating currents and a condenser of proper capacity be included in one of the same, approximately the desired difference of phase may be obtained between the currents flowing directly from the source and those flowing through the condenser; but the great size and expense of condensers for this purpose that would meet the requirements of the ordinary systems of comparatively low potential are practically prohibitory to their employment.

Another now well-known method or plan of securing a difference of phase between the energizing-currents of motors of this kind is to induce by the currents in one circuit those in the other circuit or circuits; but no means have heretofore been proposed that would secure in this way between the phases of the primary or inducing and the secondary or induced currents that difference—theoretically ninety degrees—that is best adapted for practical and economical working.

I have devised a means which renders practicable both the above described plans or methods, and by which I am enabled to obtain an economical and efficient alternating-current motor, my invention consisting in placing a condenser in the secondary or induced circuit of the motor above described and raising the potential of the secondary currents to such a degree that the capacity of the condenser, which is in part dependent on the potential, need be quite small. The value of this condenser will be determined in a well-understood manner with reference to the self-induction and other conditions of the circuit, so as to cause the currents which pass through it to differ from the primary currents by a quarter-phase.

The drawing is a partly-diagrammatic illustration of a motor embodying my invention.

I have illustrated the invention as embodied in a motor in which the inductive relation of the primary and secondary circuits is secured by winding them inside the motor partly upon the same cores; but it will be understood that the invention applies, generally, to other forms of motor in which one of the energizing-currents is induced in any way from the other.

Let A B represent the poles of an alternating-current motor, of which C is the armature wound with coils D, closed upon themselves, as is now the general practice in motors of this kind. The poles A, which alternate with poles B, are wound with coils of ordinary or coarse wire E in such direction as to make them of alternate north and south polarity, as indicated in the diagram by the characters N S. Over these coils or in other inductive relation to the same are wound long fine-wire coils F F and in the same direction throughout as the coils E. These coils are secondaries, in which currents of very high potential are induced. I prefer to connect all the coils E in one series and all the secondaries F in another.

On the intermediate poles B are wound fine-wire energizing-coils G, which are connected in series with one another and also with the series of secondary coils F, the direction of winding being such that a current-impulse induced from the primary coils E imparts the same magnetism to the poles B as that produced in poles A by the primary impulse. This condition is indicated by the characters N' S'.

In the circuit formed by the two sets of coils F and G is introduced a condenser H; otherwise the said circuit is closed upon itself, while the free ends of the circuit of coils E are connected to a source of alternating currents. As the condenser capacity which is needed in any particular motor of this kind is dependent upon the rate of alternation or the potential, or both, its size or cost, as before explained, may be brought within economical limits for use with the ordinary circuits if the potential of the secondary circuit in the motor be sufficiently high. By giving to the condenser proper values any desired difference of phase between the primary and secondary energizing-circuits may be obtained.

What I claim is—

1. In an alternating-current motor provided with two or more energizing or field circuits, one of which is adapted for connection with a source of currents and the other or others in inductive relation thereto, the combination, with the secondary or induced circuit or circuits, of a condenser interposed in the same, as set forth.

2. In an alternating-current motor, the combination of two energizing-circuits, one connected or adapted for connection with a source of alternating currents, the other constituting a high-potential secondary circuit in inductive relation to the first, and a condenser interposed in said secondary circuit, as set forth.

NIKOLA TESLA.

Witnesses:
ROBT. F. GAYLORD,
ERNEST HOPKINSON.

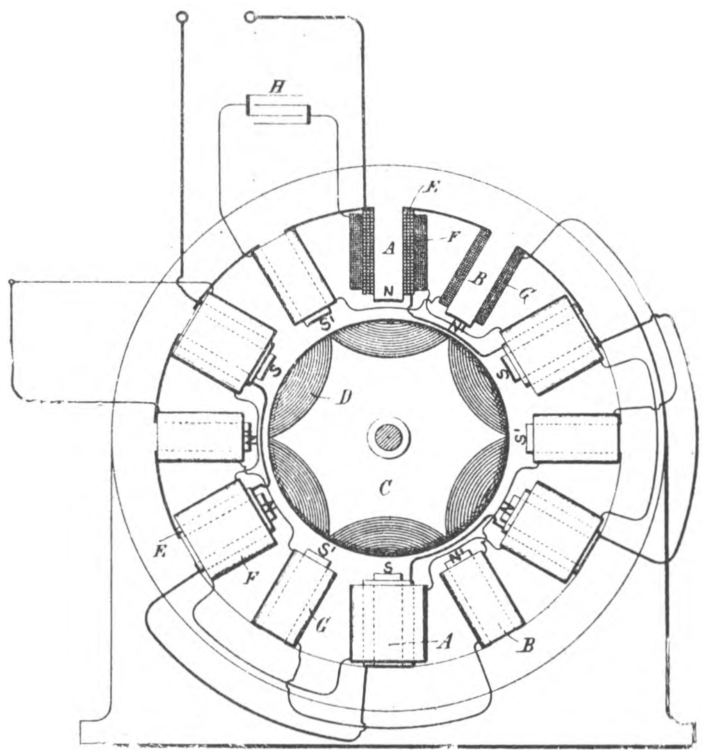
P-140

(No. Model.)

N. TESLA.

ELECTRO MAGNETIC MOTOR.

No. 464,666. Patented Dec. 8, 1891.



Witnesses:
Raphaël Netter
Frank B. Murphy

Inventor
Nikola Tesla
by
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UNITED STATES PATENT OFFICE.

NIKOLA TESLA, OF NEW YORK, N. Y.

ELECTRIC GENERATOR.

SPECIFICATION forming part of Letters Patent No. 511,916, dated January 2, 1894.

Application filed August 19, 1893. Serial Ho. 483,562. (No model.)

To all whom it may concern:

Be it known that I, NIKOLA TESLA, a citizen of the United States, residing at New York, in the county and State of New York, have invented certain new and useful Improvements in Electric Generators, of which the following is a specification, reference being had to the drawings accompanying and forming a part of the same.

In an application of even date herewith, Serial No. 483,503, I have shown and described a form of engine invented by me, which, under the influence of an applied force such as the elastic tension of steam or a gas under pressure, yields an oscillation of constant period.

In order that my present invention may be more readily understood I will explain the conditions which are to be observed in order to secure this result.

It is a well known mechanical principle that if a spring possessing a sensible inertia be brought under tension, as by being stretched, and then freed, it will perform vibrations which are isochronous, and as to period, in the main, dependent upon the rigidity of the spring, and its own inertia or that of the system of which it may form an immediate part. This is known to be true in all cases where the force which tends to bring the spring or movable system into a given position is proportionate to the displacement.

In the construction of my engine above referred to I have followed and applied this principle, that is to say, I employ a cylinder and a piston which in any suitable manner I maintain in reciprocation by steam or gas under pressure. To the moving piston or to the cylinder, in case the latter reciprocate and the piston remain stationary, a sprang is connected so as to be maintained in vibration thereby, and whatever may be the inertia of the piston or of the moving system and the rigidity of the spring relatively to each other, provided, the practical limits within which the law holds true that the forces which tend to bring the moving system to a given position are proportionate to the displacement, are not exceeded, the impulses of the power impelled piston and the natural vibrations of the spring will always correspond in direction and coincide in time. In the case of the engine referred to, the ports are so arranged that the movement of the piston within the cylinder in either direction ceases when the force tending to impel it and the momentum which it has acquired are counterbalanced by the increasing pressure of the steam or compressed air in that end of the cylinder toward which it is moving, and as in its movement the piston has shut off at a given point, the pressure that impelled it and established the pressure that tends to return it, it is then impelled in the opposite direction, and this action is continued as long as the requisite pressure is applied. The length of the stroke will vary with the pressure, but the rate or period of reciprocation is no more dependent upon the pressure applied to drive the piston, than would be the period of oscillation of a pendulum permanently maintained in vibration, upon the force which periodically impels it, the effect of variations in such force being merely to produce corresponding variations in the length of stroke or amplitude of vibration respectively.

In practice I have found that the best results are secured by the employment of an air spring, that is, a body of confined air or gas which is compressed and rarefied by the movements of the piston, and in order to secure a spring of constant rigidity I prefer to employ a separate chamber or cylinder containing air at the normal atmospheric pressure, although it might be at any other pressure, and in which works a plunger connected with or carried by the piston rod. The main reason why no engine heretofore has been capable of producing results of this nature is that it has been customary to connect with the reciprocating parts a heavy fly-wheel or some equivalent rotary system of relatively very great inertia, or in other cases where ho rotary system was employed, as in certain reciprocating engines or tools, no regard has been paid to the obtainment of the conditions essential to the end which I have in view, nor would the pressure of such conditions in said devices appear to result in any special advantage.

Such an engine as I have described affords a means for accomplishing a result heretofore unattained, the continued production of electric currents of constant period, by imparting the movements of the piston to a core or coil in a magnetic field. It should be stated however, that in applying the engine for this purpose certain conditions are encountered which should be taken into consideration in order to satisfactorily secure the desired result. When a conductor is moved in a magnetic field and a current caused to circulate therein, the electro-magnetic reaction between it and the field, might disturb the mechanical oscillation to such an extent as to throw it out of isochronism. This, for instance, might occur when the electro-magnetic reaction is very great incomparison to the power of the engine, and there is a retardation of the current so that the electro-magnetic reaction might have an effect similar to that which would result from a variation of the tension of the spring, but if the circuit of the generator be so adjusted that the phases of the electromotive force and current coincide in time, that is to say, when the current is not retarded, then the generator driven by the engine acts merely as a frictional resistance and will not, as a rule, alter the period of the mechanical vibration, although it may vary its amplitude. This condition may be readily secured by properly proportioning the self induction and capacity of the circuit including the generator. I have, however, observed the, further fact in connection with the use of such engines as a means for running a generator, that it is advantageous that the period of the engine and the natural period of electrical vibration of the generator should be the same, as in such case the best conditions for electrical resonance are established and the possibility of disturbing the period of mechanical vibrations is reduced to a. minimum. I have found that even if the theoretical conditions necessary for maintaining a constant period in the engine itself are not exactly maintained, still the engine and generator combined will vibrate at a constant period. For example, if instead of using in the engine an independent cylinder and plunger as an air spring of practically constant rigidity, I cause the piston to impinge upon air cushions at the ends of its own cylinder, although the rigidity of such cushions or springs might be considerably affected and varied by the variations of pressure within the cylinder, still by combining with such an engine a generator which has a period of its own approximately that of the engine constant vibration may be maintained even through a considerable range of varying pressure, owing to the controlling action of the electro-magnetic system. I have even found that under certain conditions the influence of the electro-magnetic system may be made so great as to entirely control the period of the mechanical vibration within wide limits of varying pressure. This is likely to occur in those instances where the power of the engine while fully capable of maintaining a vibration once started, is not sufficient to change its rate. So, for the sake of illustration, if a pendulum is started in vibration, and a small force applied periodically in the proper direction to maintain it in motion, this force would have no substantial control over the period of the oscillation, unless the inertia of the pendulum be small in comparison to the impelling force, and this would be true no matter through what fraction of the period the force may be applied. In the case under consideration the engine is merely an agent for maintaining the vibration once started, although it will be understood that this does not preclude the performance of useful work which would simply result in a shortening of the stroke. My invention, therefore, involves the combination of a piston free to reciprocate under the influence of steam or a gas under pressure and the movable element of an electric generator which is in direct mechanical connection with the piston, and it is more especially the object of my Invention to secure from such combination electric currents of a constant period. In the attainment of this object I have found it preferable to construct the engine so that it of itself controls the period, but as I have stated before, I may so modify the elements of the combination that the electro-magnetic system may exert a partial or even complete control of the period.

In illustration of the manner in which the invention is carried out I now refer to the accompanying drawings.

Figure 1 is a central sectional view of an engine and generator embodying the invention. Fig. 2 is a modification of the same.

Referring to Fig. 1 A is the main cylinder in which works a piston B. Inlet ports C C pass through the sides of the cylinder opening at the middle portion thereof and on opposite sides. Exhaust ports D D extend through the walls of the cylinder and are formed with branches that open into the interior of the cylinder on each side of the inlet ports and on opposite sides of the cylinder. The piston B is formed with two circumferential grooves E F which communicate through openings G in the piston with the cylinder on opposite sides of said piston respectively.

The particular construction of the cylinder, the piston and the ports controlling it may be very much varied, And is not in itself material, except that in the special case now under consideration it is desirable that all the ports, and more especially the exhaust ports should be made very much larger than is usually the case so that no force due to the action of the steam or compressed air will tend to retard or affect the return of the piston in either direction. The piston B is secured to a piston rod H which works in suitable stuffing boxes in the heads of the cylinder A. This rod is prolonged on one side and extends through bearings V in a cylinder I suitably mounted or supported in line with the first, and within which is a disk or plunger J carried by the rod H. The cylinder I is without ports of any kind and is air-tight except as a small leakage may occur through the bearings V, which experience has shown need not be fitted with any very considerable accuracy. The cylinder I is surrounded by a jacket K which leaves an open space or chamber around it. The bearings V in the cylinder I, extend through the jacket K to the outside air and the chamber between the cylinder and jacket is made steam or air-tight as by a suitable packing. The main supply pipe L for steam or compressed air leads into this chamber, and the two pipes that lead to the cylinder A run from the said chamber, oil cups M being conveniently arranged to deliver oil into the said pipes for lubricating the piston. In the particular form of engine shown, the jacket K which contains the cylinder I is provided with a flange N by which it is screwed to the end of the cylinder A. A small chamber O is thus formed which has air vents P in its sides and drip pipes Q leading out from it through which the oil which collects in it is carried off.

To explain now the operation of the engine described, in the position of the parts shown, or when the piston is at the middle point of its stroke, the plunger J is at the center of the cylinder I and the air on both sides of the same is at the normal pressure of the outside atmosphere. If a source of steam or compressed air be then connected to the inlet ports C C of the cylinder A and a movement be imparted to the piston as by a sudden blow, the latter is caused to reciprocate in a manner well understood. The movements of the piston compress and rarefy the air in the cylinder I at opposite ends of the same alternately. A forward stroke compresses the air ahead of the plunger J which acts as a spring to return it. Similarly on the back stroke the air is compressed on the opposite side of the plunger J and tends to drive it forward. The compressions of the air in the cylinder I and the consequent loss of energy due mainly to the imperfect elasticity of the air, give rise to a very considerable amount of heat. This heat I utilize by conducting the steam or compressed air to the engine cylinder through the chamber formed by the jacket surrounding the air-spring cylinder. The heat thus taken up and used to raise the temperature of the steam or air acting upon the piston is availed of to increase the efficiency of the engine. In any given engine of this kind the normal pressure will produce a stroke of determined length, and this will be increased or diminished according to the increase of pressure above or the reduction of pressure below the normal.

In constructing the apparatus proper allowance is made for a variation in the length of stroke by giving to the confining cylinder I of the air spring properly determined dimensions. The greater the pressure upon the piston, the higher the degree of compression of the air-spring, and the consequent counteracting force upon the plunger The rate or period of reciprocation of the piston, how ever, is mainly determined as described above by the rigidity of the air spring and the inertia of the moving system, and any period of oscillation within very wide limits may be secured by properly portioning these factors, as by varying the dimensions of the air chamber which is equivalent to varying the rigidity of the spring, or by adjusting the weight of the moving parts. These conditions are all readily determinable, and an engine constructed as herein described may be made to follow the principle of operation above stated and maintain a perfectly uniform period through very wide limits of pressure.

The pressure of the air confined in the cylinder when the plunger I is in its central position will always be practically that of the surrounding atmosphere, for while the cylinder is so constructed as not to permit such sudden escape of air as to sensibly impair or modify the action of the air spring there will still be a slow leakage of air into or out of it around the piston rod according to the pressure therein, so that the pressure of the air on opposite sides of the plunger will always tend to remain at that of the outside atmosphere.

To the piston rod H is secured a conductor or coil of wire D' which by the movements of the piston is oscillated in the magnetic field produced by two magnets B' B' which may be permanent magnets or energized by coils C' C' connected with a source of continuous currents E'. The movement of the coil D' across the lines of force established by the magnets gives rise to alternating currents in the coil. These currents, if the period of mechanical oscillation be constant will be of constant period, and may be utilized for any purpose desired.

In the case under consideration it is assumed as a necessary condition that the inertia of the movable element of the generator and the electro magnetic reaction which it exerts will not be of such character as to materially disturb the action of the engine.

Fig. 2 is an example of a combination in which the engine is not of itself capable of determining entirely the period of oscillation, but in which the generator contributes to this end. In this figure the engine is the same as in Fig. 1. The exterior air spring is however omitted and the air spaces at the ends of the cylinder A relied on for accomplishing the same purpose. As the pressure in these spaces is liable to variations from variations in the steam or gas used in impelling the piston they might affect the period of oscillation, and the conditions are not as stable and certain as in the case of an engine constructed as in Fig. 1. But if the natural period of vibration of the elastic system be made to approximately accord with the average period of the engine such tendencies to variation are very largely overcome and the engine will preserve its period oven through a considerable range of variations of pressure. The generator in this case is composed of a magnetic casing F' in which a laminated core G' secured to the piston rod H is caused to vibrate. Surrounding the plunger are two exciting coils C' C', and one or more induced coils D' D'. The coils C' C' are connected with a generator of continuous currents E' and are wound to produce consequent poles in the core G'. Any movement of the latter will therefore shift the lines of force through coils D' D' and produce currents therein.

In the circuit of coils D' is shown a condenser H' It need only be said that by the use of a proper condenser the self induction of this circuit may be neutralized. Such a circuit will have a certain natural period of vibration, that is to say that when the electricity therein is disturbed in any way an electrical or electro magnetic vibration of a certain period takes place, and as this depends upon the capacity and self induction, such period may be varied to approximately accord with the period of the engine.

In case the power of the engine be comparatively small, as when the pressure is applied through a very small fraction of the total stroke, the electrical vibration will tend to control the period, and it is clear that if the character of such vibration be not very widely different from the average period of vibration of the engine under ordinary working conditions such control may be entirely adequate to produce the desired results.

Having now described my invention, what I claim is—

1. The combination with the piston or equivalent element of an engine which is free to reciprocate under the action thereon of steam or a gas under pressure, of the moving conductor or element of an electric generator in direct mechanical connection therewith.

2. The combination with the piston or equivalent element of an engine which is free to reciprocate under the action of steam or a gas under pressure, of the moving conductor or element of an electric generator in direct mechanical connection therewith, the engine and generator being adapted by their relative adjustment with respect to period to produce currents of constant period, as set forth.

3. The combination with an engine comprising a piston which is free to reciprocate under the action of steam or a gas under pressure, and an electric generator having inducing and induced elements one of which is capable of oscillation in the field of force, the said movable element being carried by the piston rod of the engine, as set forth.

4. The combination with an engine operated by steam or a gas under pressure and having a constant period of reciprocation, of an electric generator, the moving element of which is carried by the reciprocating part of the engine, the generator and its circuit being so related to the engine with respect to the period of electrical vibration as not to disturb the period of the engine, as set forth.

5. The combination with a cylinder and a piston reciprocated by steam or a gas under pressure of a spring maintained in vibration by the movement of the piston, and an electric generator, the movable conductor or element of which is connected with the piston, these elements being constructed and adapted in the manner set forth for producing a current of constant period.

6. The method of producing electric currents of constant period herein described which consists in imparting the oscillations of an engine to the moving element of an electric generator and regulating the period of mechanical oscillation by an adjustment of the reaction of the electric generator, as herein set forth.

NIKOLA TESLA.

Witnesses:
PARKER W. PAGE,
R. F. GAYLORD.

P-145

(No Model.)

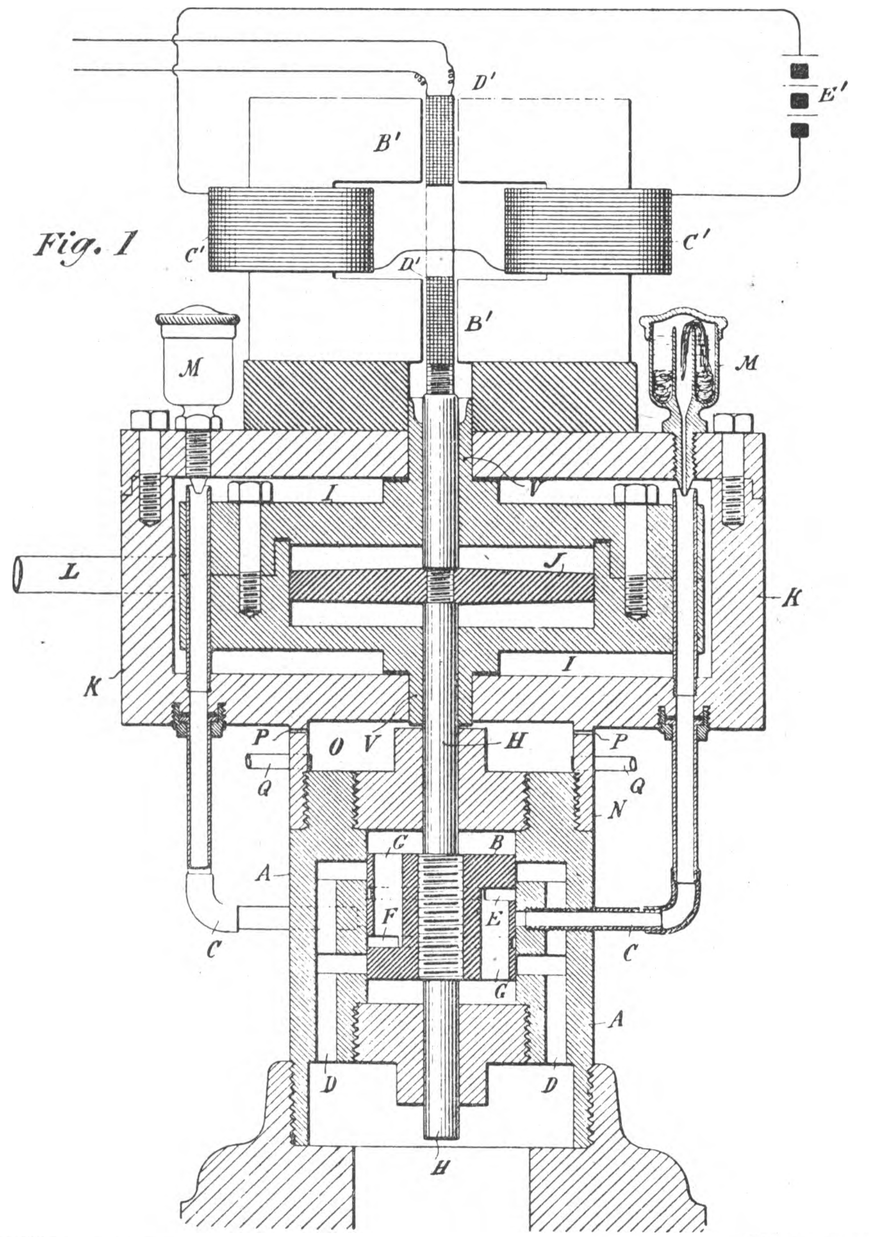
2 Sheets—Sheet 1

N. TESLA.
ELECTRIC GENERATOR.

No. 511,916.

Patented Jan. 2, 1894.

Fig. 1



Witnesses
Raphael Netter
R. F. Gaylord

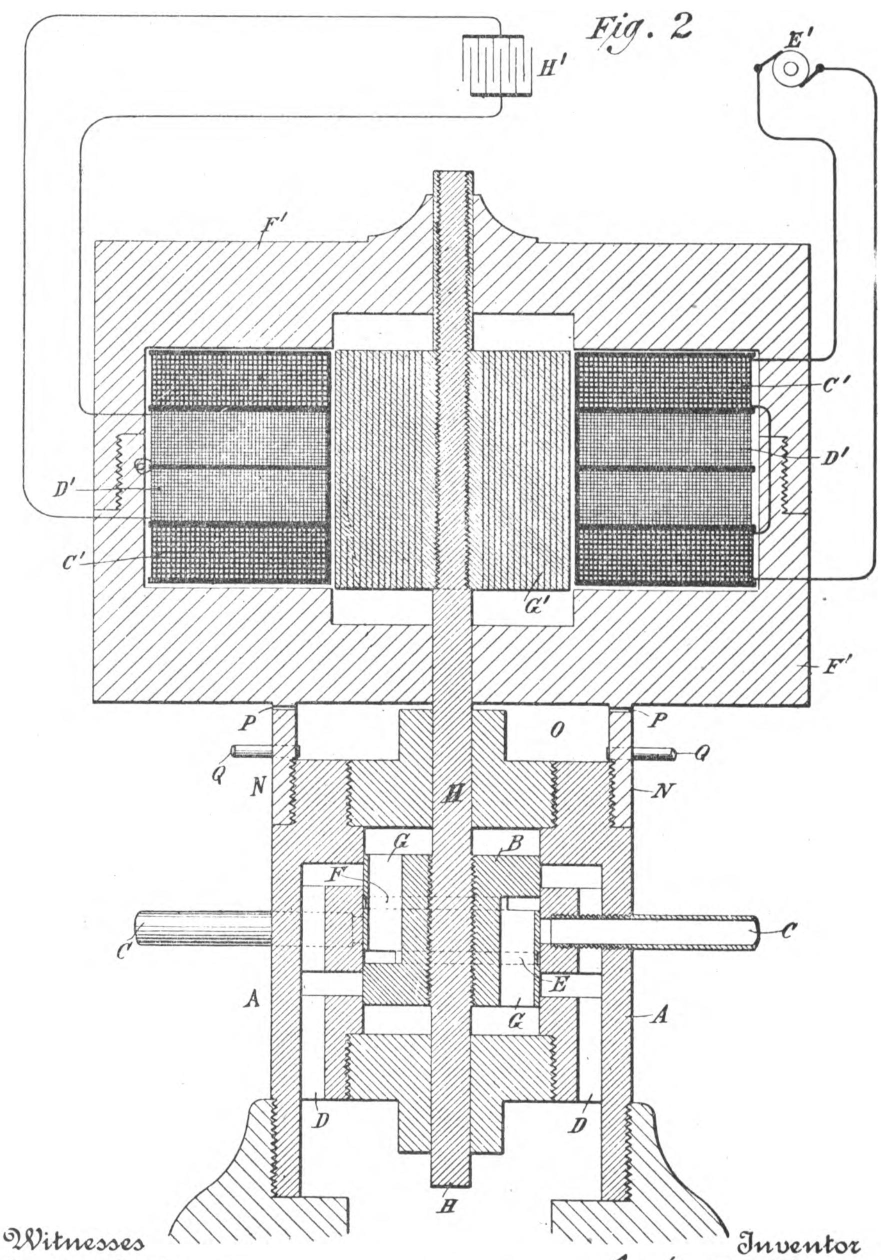
Inventor
Nikola Tesla
By his Attorneys
Duncan & Page

P-146

(No Model.) 2 Sheets—Sheet 2.

N. TESLA.
ELECTRIC GENERATOR.

No. 511,916. Patented Jan. 2, 1894.



Witnesses
Raphael Netter
R. F. Gaylord

Inventor
Nikola Tesla
By his Attorneys
Duncan & Page.

II
TRANSMISSION OF ELECTRIC POWER

UNITED STATES PATENT OFFICE.

NIKOLA TESLA, OP NEW YORK, N. Y.

ELECTRICAL TRANSMISSION OF POWER.

SPECIFICATION forming part of Letters Patent No. 382,280, dated May 1, 1888.

Original application filed October 12, 1867. Serial No. 252,132. Divided and this application filed March 9, 1888. Serial No. 266,755. (No model.)

To all whom it may concern:

Be it known that I, NIKOLA TESLA, from Smiljan, Lika, border country of Austria-Hungary and residing in the city, county, and State of New York, have invented certain new and useful Improvements in the Transmission of Power, of which the following is a specification, reference being had to the drawings accompanying and forming a part of the same.

This application is a division of an application filed by me October 12, 1887, No. 252,132.

The practical solution of the problem of the electrical conversion and transmission of mechanical energy involves certain requirements which the apparatus and systems heretofore employed have not been capable of fulfilling. Such a solution primarily demands a uniformity of speed in the motor irrespective of its load within its normal working limits. On the other hand, it is necessary, to attain a greater economy of conversion than has heretofore existed, to construct cheaper and more reliable and simple apparatus, and such that all danger from the use of currents of high tension, which are necessary to an economical transmission, may be avoided.

My present invention is a new method or mode of effecting the transmission of power by electrical agency, whereby many of the present objections are overcome and great economy and efficiency secured.

In carrying out my invention I employ a motor in which there are two or more independent energizing circuits, through which I pass, in the manner hereinafter described, alternating currents, effecting thereby a progressive shifting of the magnetism or of the "lines of force," which, in accordance with well-known theories, produces the action of the motor.

It is obvious that a proper progressive shifting of the lines of force may be utilized to set up a movement or rotation of either element of the motor, the armature, or the field-magnet, and that if the currents directed through the several circuits of the motor are in proper direction no commutator for the motor will be required; but to avoid all the usual commutating appliances in the system I connect the motor-circuits directly with those of a suitable alternating-current generator. The practical results of such a system, its economical advantages, and the mode of its construction and operation will be described more in detail by reference to the accompanying diagrams and drawings.

Figures 1 to 8 and 1^a to 8^a, inclusive, are diagrams illustrating the principle of the action of my invention. The remaining figures are views of the apparatus in various forms by means of which the invention may be carried into effect, and which will be described in their order.

Referring first to Fig. 9, which is a diagrammatic representation of a motor, a generator, and connecting-circuits in accordance with my invention, M is the motor, and G the generator for driving it. The motor comprises a ring or annulus, R, preferably built up of thin insulated iron rings or annular plates, so as to be as susceptible as possible to variations in its magnetic condition. This ring is surrounded by four coils of insulated wire symmetrically placed and designated by C C C' C'. The diametrically-opposite coils are connected up so as to co-operate in pairs in producing free poles on diametrically-opposite parts of the ring. The four free ends thus left are connected to terminals T T T' T', as indicated. Near the ring, and preferably inside of it, there is mounted on an axis or shaft a magnetic disk, C, generally circular in shape, but having two segments, cut away as shown. This disk is mounted so as to turn freely within the ring R. The generator G is of any ordinary type, that shown in the present instance having field-magnets N S and a cylindrical armature-core, A, wound with the two coils B B'. The free ends of each coil are carried through the shaft *a'* and connected, respectively, to insulated contact-rings *b b b' b'*. Any convenient form of collector or brush bears on each ring and forms a terminal by which the current to and from a ring is conveyed. These terminals are connected to the terminals of the motor by the wires, L and L' in the manner indicated, whereby two complete circuits are formed, one including, say, the coils B of the generator and C C of the motor and the other the remaining coils B' and C' C' of the generator and the motor.

It remains now to explain the mode of operation of this system, and for this purpose I refer to the diagrams, Figs. 1 to 8 and 1ª to 8ª, for an illustration of the various phases through which the coils of the generator pass when in operation, and the corresponding and resultant magnetic changes produced in the motor. The revolution of the armature of the generator between the field magnets N S obviously produces in the coils B B' alternating currents the intensity and direction of which depend upon well-known laws. In the position of the coils indicated in Fig. 1 the current in the coil B is practically *nil,* whereas the coil B' at the same time is developing its maximum current, and by the means indicated in the description of Fig. 9 the circuit including this coil may also include, say, the coils C C of the motor. Fig. 1ª. The result, with the proper connections, would be the magnetization of the ring R, the poles being on the line N S. The same order of connections being observed between the coil B and the coil C', the latter when traversed by a current tend to fix the poles at right angles to the line N S of Fig. 1ª. It results, therefore, that when the generator coils have made one eighth of a revolution, reaching the position shown in Fig. 2, both pairs of coils, C and C', will be traversed by current and act in opposition in so far as the location of the poles is concerned. The position of the poles will therefore be the resultant of the magnetizing forces of the coils—that is to say, it will advance along the ring to a position corresponding to one-eighth of the revolution of the armature of the generator.

In Fig. 3 the armature of the generator has progressed to one fourth of a revolution. At the point indicated the current in the coil B is maximum, while in B' it is *nil*, the latter coil being in its neutral position. The poles of the ring R in Fig. 3ª will in consequence be shifted to a position ninety degrees from that at the start, as shown. I have in like manner shown the conditions existing at each successive eighth of one revolution in the remaining figures. A short reference to these figures will suffice to an understanding of their significance.

Figs. 4 and 4ª illustrate the conditions which exist when the generator-armature has completed three-eighths of a revolution. Here both coils are generating currents; but the coil B', having now entered the opposite field, is generating a current in the opposite direction having the opposite magnetizing effect; hence the resultant pole will be on the line N S. a shown.

In Fig. 5 one-half of one revolution of the armature of the generator has been completed, and the resulting magnetic condition of the ring is shown in Fig. 5ª. In this phase coil B is in the neutral position, while coil B' is generating its maximum current, which is in the same direction as in Fig. 4. The poles will consequently be shifted through one half of the ring.

In Fig. 6 the armature has completed five-eighths of a revolution. In this position coil B' develops a less powerful current, but in the same direction as before. The coil B, on the other hand, having entered a field of opposite polarity, generates a current of opposite direction. The resultant poles will therefore be in the line N S, Fig. 6ª; or, in other words, the poles of the ring will be shifted along five-eighths of its periphery.

Figs. 7 and 7ª in the same manner illustrate the phases of the generator and ring at three-quarters of a revolution, and Figs. 8 and 8ª the same at seven-eighths of a revolution of the generator armature. These figures will be readily understood from the foregoing.

When a complete revolution is accomplished, the conditions existing at the start are re-established, and the same action is repeated for the next and all subsequent revolutions, and in general it will now be seen that every revolution of the armature of the generator produces a corresponding shifting of the poles or lines of force around the ring. This effect I utilize in producing the rotation of a body or armature in a variety of ways—for example, applying the principle above described to the apparatus shown in Fig. 9. The disk D, owing to its tendency to assume that position in which it embraces the greatest possible number of the magnetic lines, is set in rotation, following the motion of the lines or the points of greatest attraction.

The disk D in Fig. 9 is shown as cut away on opposite sides; but this I have found is not essential to effecting its rotation, as a circular disk, as indicated by dotted lines, is also set in rotation. This phenomenon I attribute to a certain inertia or resistance inherent in the metal to the rapid shifting of the lines of force through the same, which results in a continuous tangential pull upon the disk, causing its rotation. This seems to be confirmed by the fact that a circular disk, of steel is more effectively rotated than one of soft iron, for the reason that the former is assumed to possess a greater resistance to the shifting of the magnetic lines.

In illustration of other forms of apparatus by means of which I carry out my invention, I shall now describe the remaining figures of the drawings.

Fig. 10 is a view in elevation and part vertical section of a motor. Fig. 12 is a top view of the same with the field in section and a diagram of connections. Fig. 11 is an end or side view of a generator with the fields in section. This form of motor may be used in place of that shown.

D is a cylindrical or drum armature-core, which, for obvious reasons, should be split up as far as practicable to prevent the circulation within it of currents of induction. The core is wound longitudinally with two coils, E and E', the ends of which are respectively connected to insulated contact-rings *d d d' d',* carried by the shaft *a,* upon which the armature is mounted.

The armature is set to revolve within an iron shell, R, which constitutes the field-magnet or other element of the motor. This shell is preferably formed with a slot or opening, *r*; but it may be continuous, as shown by the dotted lines, and in this event it is preferably made of steel. It is also desirable that this shell should be divided up similarly to the armature, and for similar reasons. As a generator for driving this motor, I may use the device shown in Fig. 11. This represents an annular or ring armature, A, surrounded by four coils, F F F' F', of which those diametrically opposite are connected in series, so that four free ends are left, which are connected to the insulated contact rings *b b b' b'*. The ring is suitably mounted on a shaft, *a'*, between the poles N S. The contact-rings of each pair of generator coils are connected to those of the motor, respectively, by means of contact-brushes and the two pairs of conductors, L L and L' L', as indicated diagrammatically in Fig. 13.

Now, it is obvious from a consideration of the preceding figures that the rotation of the generator-ring produces currents in the coils F F', which, being transmitted to the motor-coils, impart to the core of the latter magnetic poles constantly shifting or whirling around the core. This effect sets up a rotation of the armature, owing to the attractive force between the shell and the poles of the armature; but inasmuch as the coils in this case move relatively to the shell or field-magnet the movement of the coils is in the opposite direction to the progressive shifting of the poles.

Other arrangements of the coils of both generator and motor are possible, and a greater number of circuits may be used, as will be seen in the two succeeding figures.

Fig. 13 is a diagrammatic illustration of a motor and a generator connected and constructed in accordance with my invention. Fig. 14 is an end view of the generator with its field-magnets in section.

The field of the motor M is produced by six magnetic poles, G' G', secured to or projecting from a ring or frame, H. These magnets or poles are wound with insulated coils, those diametrically opposite to each other being connected in pairs, so as to produce opposite poles in each pair. This leaves six free ends, which are connected to the terminals T T T' T' T'' T''. The armature which is mounted to rotate between the poles is a cylinder or disk, D, of wronght-iron, mounted on the shaft a. Two segments of the same are cut away, as shown. The generator for this motor has in this instance an armature, A, wound with three coils, K K' K'', at sixty degrees apart. The ends of these coils are connected, respectively, to insulated contact rings *e e e' e' e'' e''*. These rings are connected to those of the motor in proper order by means of collecting-brushes and six wires, forming three independent circuits. The variations in the strength and direction of the currents transmitted through these circuits and traversing the coils of the motor produce a steadily-progressive shifting of the resultant attractive force exerted by the poles G' upon the armature D, and consequently keep the armature rapidly rotating. The peculiar advantage of this disposition is in obtaining a more concentrated and powerful field. The application of this principle to systems involving multiple circuits generally will be understood from this apparatus.

Referring now to Figs. 15 and 18, Fig. 15 is a diagrammatic representation of a modified disposition of my invention. Fig. 16 is a horizontal cross-section of the motor. In this case a disk, D, of magnetic metal, preferably cut away at opposite edges, as shown in dotted lines in the figure, is mounted so as to turn freely inside two stationary coils, N' N'', placed at right angles to one another. The coils are preferably wound on a frame, O, of insulating material, and their ends are connected to the fixed terminals T T T' T'. The generator G is a representative of that class of alternating-current machines in which a stationary induced element is employed. That shown consists of a revolving permanent or electro-magnet, A, and four independent stationary magnets, P P', wound with coils, those diametrically opposite to each other being connected in series and having their ends secured to the terminals *t t t' t'*. From these terminals the currents are led to the terminals of the motor, as shown in the drawings. The mode of operation is substantially the same as in the previous cases, the currents traversing the coils of the motor having the effect to turn the disk D. This mode of carrying out the invention has the advantage of dispensing with the sliding, contacts in the system.

In the forms of motor above described only one of the elements—the armature or the field-magnet—is provided with energizing-coils. It remains, then, to show how both elements may be wound with coils. Reference is therefore had to Figs. 17, 18, and 19. Fig. 17 is an end view of such a motor. Fig. 18 is a similar view of the generator, with the field-magnets in section; and Fig. 19 is a diagram of the circuit-connections. In Fig. 17 the field-magnet of the motor consists of a ring, R, preferably of thin insulated iron sheets or bands, with eight pole-pieces, G, and corresponding recesses in which four pairs of coils, V, are wound. The diametrically-opposite pairs of coils are connected in series and the free ends connected to four terminals, *w*, the rule to be followed in connecting being the same as herein before explained. An armature, D, with two coils, E E', at right angles to each other, is mounted to rotate inside of the field-magnet R. The ends of the armature-coils are connected to two pairs of contact-rings, *d d d' d'*. The generator for this motor may be of any suitable kind to produce currents of the desired character. In the present instance it consists of a field-magnet, N S, and an armature, A, with two coils at right angles, the ends of which are connected to four contact-rings, *b b b′ b′*, carried by its shaft. The circuit-connections are established between the rings on the generator shaft and those on the motor-shaft by collecting brushes and wires, as previously explained. In order to properly energize the field-magnet of the motor, however, the connections are so made with the armature coils by wires leading thereto that while the points of greatest attraction or greatest density of magnetic lines of force upon the armature are shifted in one direction those upon the field-magnet are made to progress in an opposite direction. In other respects the operation is identically the same as in the other cases cited. This arrangement results in an increased speed of rotation.

In Figs. 17 and 19, for example, the terminals of each set of field coils are connected with the wires to the two armature-coils in such a way that the field-coils will maintain opposite poles in advance of the poles of the armature.

In the drawings the field-coils are in shunts to the armature; but they may be in series or in independent circuits.

It is obvious that the same principle may be applied to the various typical forms of motor hereinbefore described.

Having now described the nature of my invention and some of the various ways in which it is or may be carried into effect, I would call attention to certain characteristics which the applications of the invention possess, and the advantages which it offers.

In my motor, considering, for convenience, that represented in Fig. 9, it will be observed that since the disk D has a tendency to follow continuously the points of greatest attraction, and since these points are shifted around the ring once for each revolution of the armature of the generator, it follows that the movement of the disk D will be synchronous with that of the armature A. This feature by practical demonstration I have found to exist in all other forms in which one revolution of the armature of the generator produces a shifting of the poles of the motor through three hundred and sixty degree.

In the particular modification shown in Fig. 10, or in others constructed on a similar plan, the number of alternating impulses resulting from one revolution of the generator-armature is double as compared with the preceding cases, and the polarities in the motor are shifted around twice by one revolution of the generator armature. The speed of the motor will therefore be twice that of the generator. The same result is evidently obtained by such a disposition as that shown in Fig. 17, where the poles of both elements are shifted in opposite directions.

Again, considering the apparatus illustrated by Fig. 9 as typical of the invention, it is obvious that since the attractive effect upon the disk D is greatest when the disk is in its proper relative position to the poles developed in the ring R—that is to say, when its ends or poles immediately follow those of the ring—the speed of the motor for all loads within the normal working limits of the motor will be practically constant.

It is clearly apparent that the speed can never exceed the arbitrary limit as determined by the generator, and also that within certain limits, at least the speed of the motor will be independent of the strength of the current.

It will now be more readily seen from the above description how far the requirements of a practical system of electrical transmission of power are realised in my invention. I secure, first, a uniform speed under all loads within the normal working limits of the motor without the use of any auxiliary regulator; second, synchronism between the motor and the generator; third, greater efficiency by the more direct application of the current, no commutating devices being required on either the motor or the generator; fourth, cheapness and simplicity of mechanical construction; fifth, the capability of being very easily managed or controlled, and, sixth, diminution of danger from injury to persons and apparatus.

These motors may be run in series—multiple arc or multiple series—under conditions well understood by those skilled in the art.

I am aware that it is not new to produce the rotations of a motor by intermittently shifting the poles of one of its elements. This has been done by passing through independent energizing coils on one of the elements the current from a battery or other source of direct or continuous currents, reversing such current by suitable mechanical appliances, so that it is directed through the coils in alternately opposite directions. In such cases, however, the potential of the energizing currents remains the same, their direction only being changed. According to my invention, however, I employ true alternating currents; and my invention consists in the discovery of the mode or method of utilizing such currents.

The difference between the two plans and the advantages of mine are obvious. By producing an alternating current each impulse of which involves a rise and fall of potential I reproduce in the motor the exact conditions of the generator, and by such currents and the consequent production of resultant poles the progression of the poles will be continuous and not intermittent. In addition to this, the practical difficulty of interrupting or reversing a current of any considerable strength is such that none of the devices at present could be made to economically or practically effect the transmission of power by reversing in the manner described a continuous or, direct current. In so far, then, as the plan of acting upon one element of the motor is concerned, my invention involves the use of an alternating as distinguished from a reversed current, or a current which, while continuous and direct, is shifted from coil to coil by any form of commutator, reverser, or interrupter. With regard to that part of the invention which consists in acting upon both elements of the motor simultaneously, I regard the use of either alternating or reversed currents as within the scope of the invention, although I do not consider the use of reversed currents of any practical importance.

What I claim is—

The method herein described of electrically transmitting power, which consists in producing a continuously progressive shifting of the polarities of either or both elements (the armature or field magnet or magnets) of a motor by developing alternating currents in independent circuits, including the magnetizing-coils of either or both elements, as herein set forth.

NIKOLA TESLA

Witnesses:

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P-154

(No Model.)

4 Sheets—Sheet 1.

N. TESLA.

ELECTRICAL TRANSMISSION OF POWER.

No. 382,280. Patented May 1, 1888.

Fig 1.

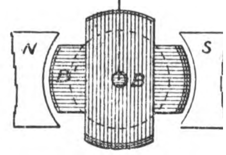


Fig. 1a

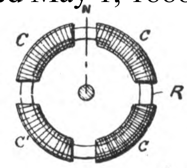


Fig. 2

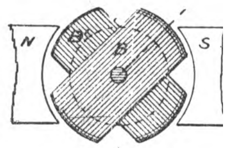


Fig 2a

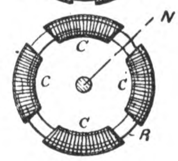


Fig. 3

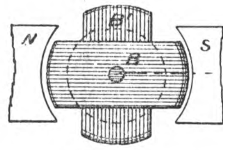


Fig 3a

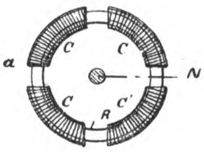


Fig. 4

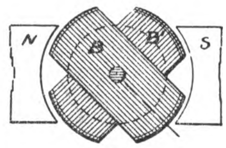


Fig. 4a

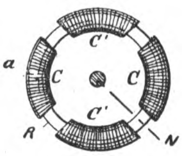


Fig. 5

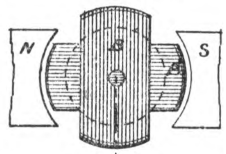


Fig 5a

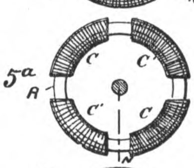


Fig. 6

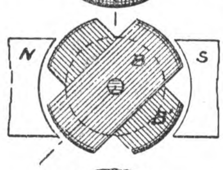


Fig. 6a

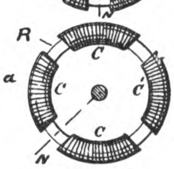


Fig. 7

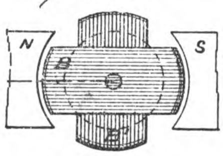


Fig. 7a

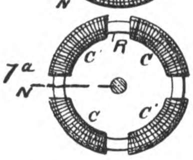


Fig. 8

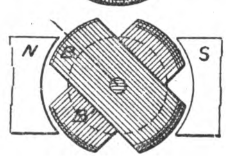
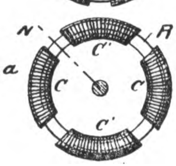


Fig 8a



WITNESSES:

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Marvin A. Custis.

INVENTOR.

Nikola Tesla

BY

Duncan, Curtis & Page

ATTORNEYS.

P-155

(No Model.) 4 Sheets—Sheet 2.

N. TESLA.
ELECTRICAL TRANSMISSION OF POWER.

No. 382.280 Patented May 1, 1888.

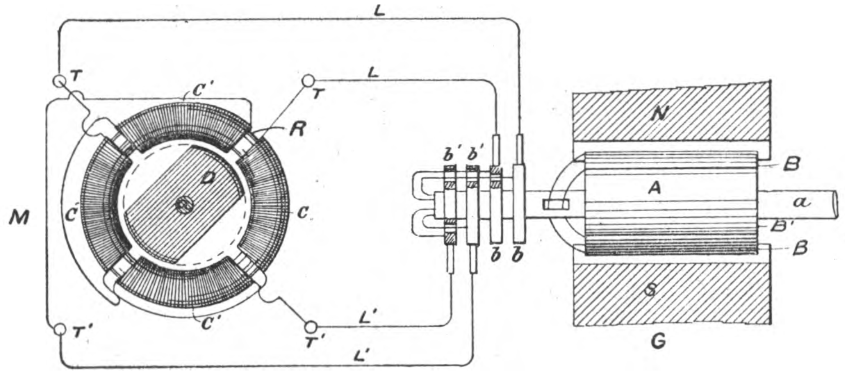

Fig. 9

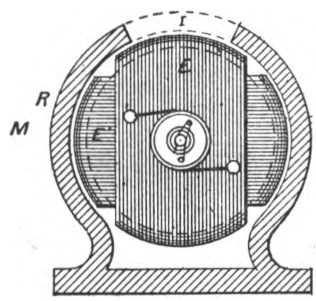

Fig. 10

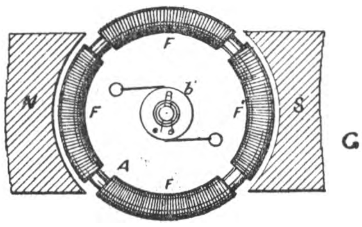

Fig 11

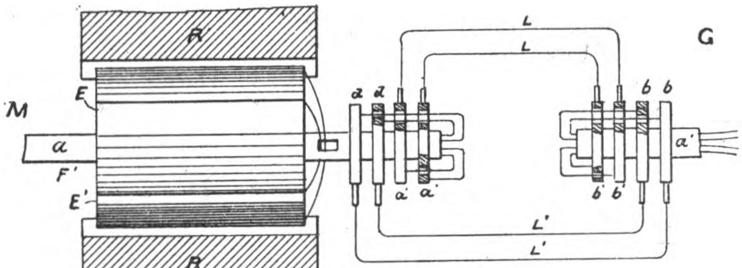

Fig. 12

WITNESSES:
D.H. Sherman.
Marvin A. Curtis.

INVENTOR.
Nikola Tesla.
BY
Duncan, Curtis & Page.
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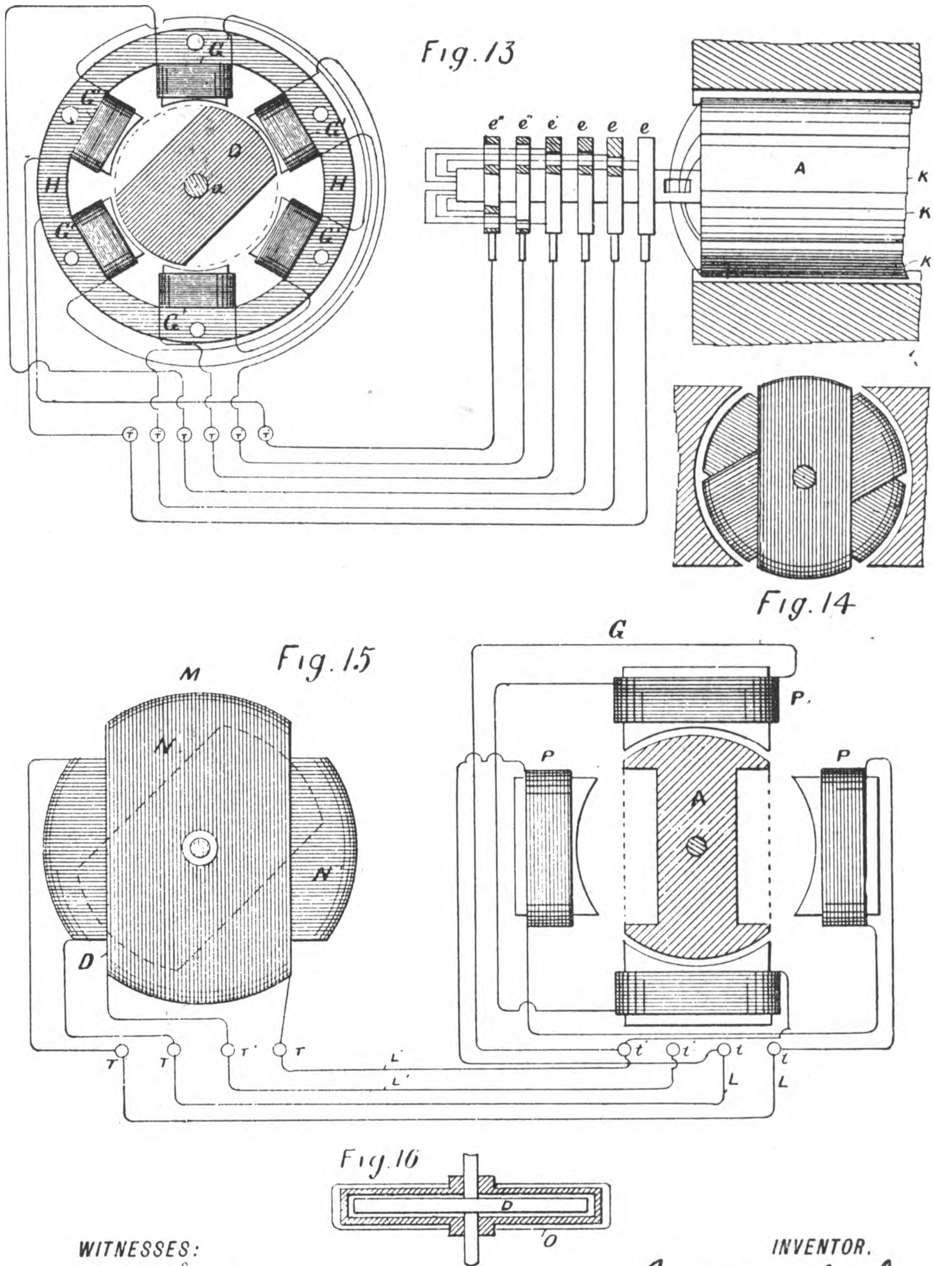
P-156

(No Model.) 4 Sheets—Sheet 3.

N. TESLA.

ELECTRICAL TRANSMISSION OF POWER.

No. 382,280. Patented May 1, 1888.



WITNESSES:

D. H. Sherman

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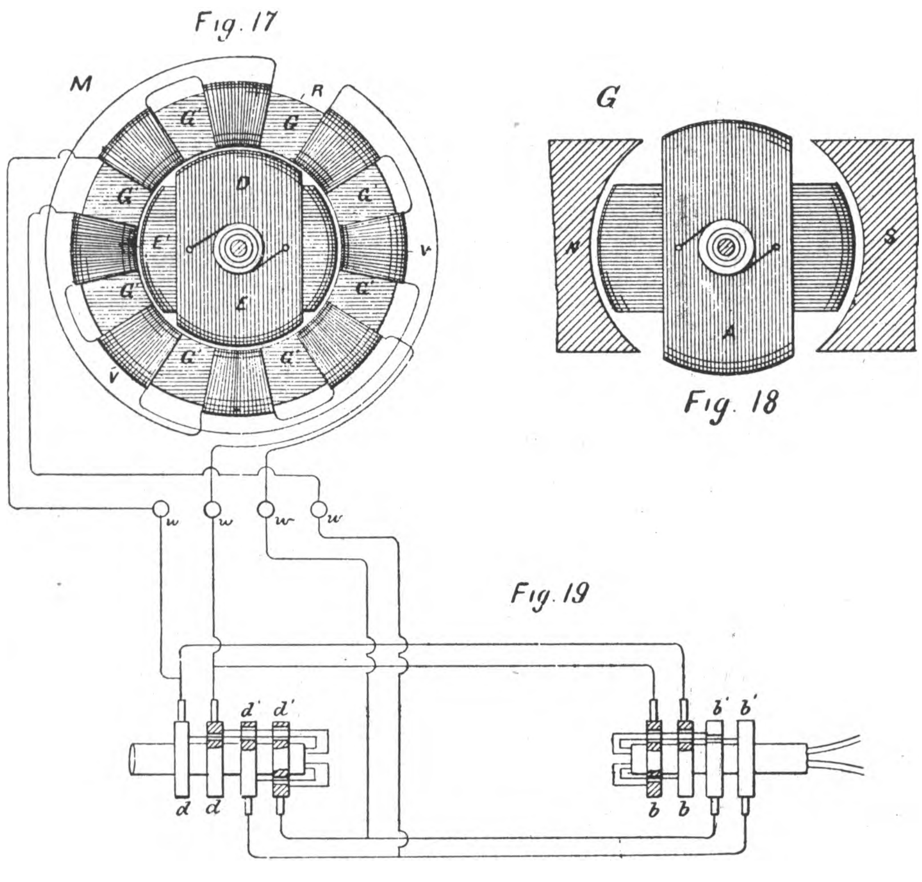
(No Model.) 4 Sheets—Sheet 4.

N. TESLA.

ELECTRICAL TRANSMISSION OF POWER.

No. 382,280. Patented May 1, 1888.



WITNESSES:
D. H. Sherman.
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UNITED STATES PATENT OFFICE.

NIKOLA TESLA, OF NEW YORK, N. Y.

ELECTRICAL TRANSMISSION OF POWER.

SPECIFICATION forming part of Letters Patent No. 382,281, dated May 1, 1888.

Original application filed November 30, 1881, Serial No. 256,562. Divided and this application filed March 9. 1888. Serial No. 260,756. (No model).

To all whom it may concern:

Be it known that I, NIKOLA TESLA, from Smiljan, Lika, border country of Austria Hungary, and residing in the city, county, and State of New York, have invented certain new and useful Improvements in the Electric Transmission of Power, of which the following is a specification, this application being a division of an application filed by me November 30, 1887, Serial No. 256,562.

In a previous application filed by me—viz., No. 252,132, filed October 12, 1887—I have set forth an improvement in motors and in the mode or method of operating the same, which, generally stated, consists in progressively and continuously shifting the poles or lines of maximum magnetic effect of either the field-magnets or armature, or both, of a motor, and thereby producing a movement of rotation in the motor. The means which I have shown for effecting this, while varying in detail, are exemplified in the following system, which, for present purposes, it will be sufficient to consider as a typical embodiment of the invention.

The motor is wound with coils forming independent energizing-circuits on the armature, which is a cylinder or disk mounted to rotate between two opposite magnetic poles. These coils are connected up with corresponding induced or current-producing circuits in an alternating-current generator. As a result of this, when the generator is set in motion, currents of alternately-opposite direction are directed through the energizing-coils of the motor in such manner as to produce a progressive shifting or rotation of the magnetic poles of the motor armature. This movement of the poles of the armature obviously tends to rotate the armature in the opposite direction to that in which the movement of the poles takes place, owing to the attractive force between said poles and the field-magnets, and the speed of rotation increases from the start until it equals that of the generator, supposing both motor and generator to be alike.

As the magnetic poles of the armature are shifted in a direction opposite to that in which the armature rotates, it will be apparent that when the normal speed is attained the poles of the armature will assume a fixed position relatively to the field-magnets, and that in consequence the field-magnets will be energized by magnetic induction, exhibiting two distinct poles, one on each of the pole-pieces. In starting the motor, however, the speed of the armature being comparatively slow, the pole-pieces are subjected to rapid reversals of magnetic polarity; but as the speed increases these reversals become less and less frequent and finally cease, when the movement of the armature becomes synchronous with that of the generator. This being the case, the field-cores or the pole-pieces of the motor become a magnet, but by induction only.

I have found that advantageous results are secured by winding the field magnets with a coil or coils and passing a continuous current through them, thus maintaining a permanent field, and in this feature my present invention consists.

I shall now describe the apparatus which I have devised for carrying out this invention and explain the mode of using or operating the same.

Figure 1 is an end view in elevation of my improved motor. Fig. 2 is a part horizontal central section, and Fig. 3 is a diagrammatic representation of the motor and generator combined and connected for operation.

Let A A in Fig. 1 represent the legs or pole-pieces of a field-magnet, around which are coils B B, included in the circuit of a continuous-current generator, C, which is adapted to impart magnetism to the said poles in the ordinary manner.

D D' are two independent coils wound upon a suitable cylindrical or equivalent armature-core, which, like all others used in a similar manner, should be split or divided up into alternate magnetic and insulating parts in the usual way. This armature is mounted in non-magnetic cross-bars E E, secured to the poles of the field-magnet. The terminals of the armature-coils D D' are connected to insulated sliding contact rings *a a b b,* carried by the armature-shaft, and brushes *c c* bear upon these rings to convey to the coils the currents which operate the motor.

The generator for operating this motor is or may be of precisely identical construction, and for convenience of reference I have marked in Fig. 3 its parts, as follows: F F, the field-magnets energized by a continuous current passing in its field coils G G; H H', the coils carried by the cylindrical armature; *d d e e,* the friction or collecting rings carried by the armature shaft and forming the terminals of the armature-coils; and *f f* the collecting-brushes which deliver the currents developed in the armature-coils to the two circuits *g g',* which connect the generator with the motor.

The operation of this system will be understood from the foregoing. The action of the generator by causing a progressive shifting of the poles in the motor-armature sets up in the latter a rotation opposite in direction to that in which the poles move. If, now, the continuous current be directed through the field-coils so as to strongly energize the magnet A A, the speed of the motor, which depends upon that of the generator, will not be increased, but the power which produces its rotation will be increased in proportion to the energy supplied through the coils B B. It is characteristic of this motor that its direction of rotation is not reversed by reversing the direction of the current through its field coils, for the direction or rotation depends not upon the polarity of the field, but upon the direction in which the poles of the armature are shifted. To reverse the motor the connections of either of the circuits *g g'* must be reversed.

I have found that if the field-magnet of the motor be strongly energized by its coils B B, and the circuits through the armature-coils closed, assuming the generator to be running at a certain speed, the motor will not start; but if the field be but slightly energized, or in general in such condition that the magnetic influence of the armature preponderates in determining its magnetic condition, the motor will start, and with sufficient current will reach its maximum or normal speed. For this reason it is desirable to keep at the start, and until the motor has attained its normal speed, or nearly so, the field-circuit open, or to permit but little current to pass through it. I have found, however, if the fields of both the generator and motor be strongly energized that starting the generator starts the motor, and that the speed of the motor is increased in synchronism with the generator.

Motors constructed and operated on this principle maintain almost absolutely the same speed for all loads within their normal working limits, and in practice I have observed that if the motor be overloaded to such an extent as to check its speed the speed of the generator, if its motive power be not too great, is diminished synchronously with that of the motor.

I have in other applications shown how the construction of these or similar motors may be varied in certain well-known ways—as, for instance, by rotating the field about a stationary armature or rotating conductors within the field—but I do not illustrate these features further herein, as with the illustration which I have given I regard the rest as within the power of a person skilled in the art to construct.

I am aware that a device embodying the characteristics of a motor and having a permanently-magnetized field-magnet has been operated by passing through independent coils on its armature a direct or continuous current in opposite directions. Such a system, however, I do not regard as capable of the practical applications for which my invention is designed, nor is it the same in principle or mode of operation, mainly in that the shifting of the poles is intermittent and not continous, and that there is necessarily involved a waste of energy.

In my present application I do not limit myself to any special form of motor, nor of the means for producing the alternating currents as distinguished from what are called "reversed currents," and I may excite or energize the field of the motor and of the generator by any source of current which will produce the desired result.

What I claim is—

The method herein described of transmitting power by electro-magnetic motors, which consists in continuously and progressively shifting the poles of one element of the motor by alternating currents and magnetizing the other element by a direct or continuous current as set forth.

NIKOLA TESLA.

Witnesses:
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P-160

(No Model.) 2 Sheets—Sheet 1.

N. TESLA.

ELECTRICAL TRANSMISSION OF POWER.

No. 382,281. Patented May 1, 1888.

Fig. 1

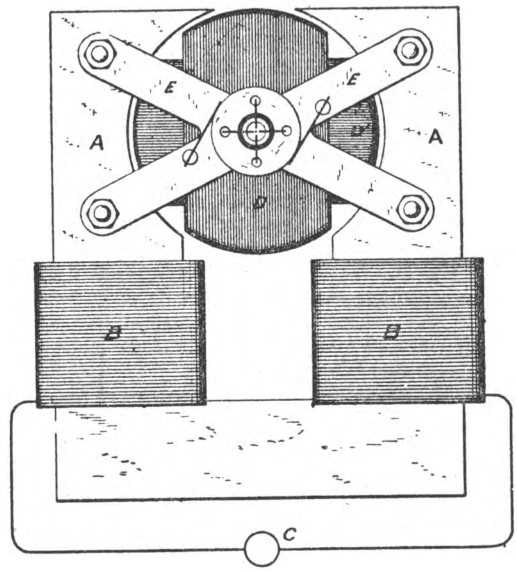
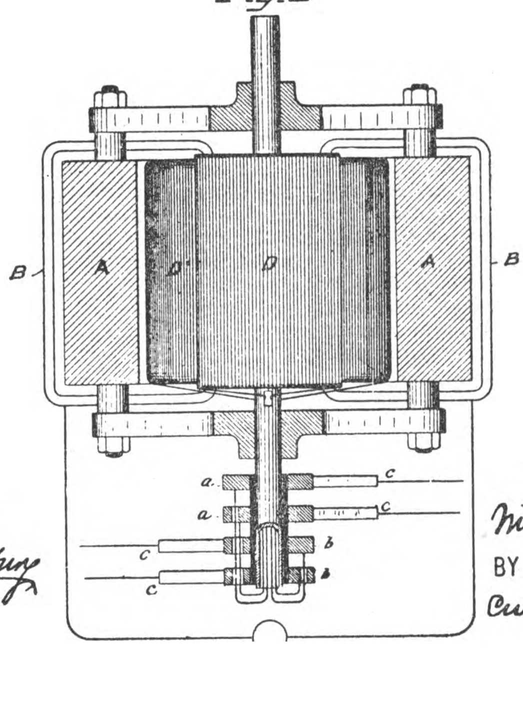


Fig. 2



WITNESSES:

Raphaël Netter

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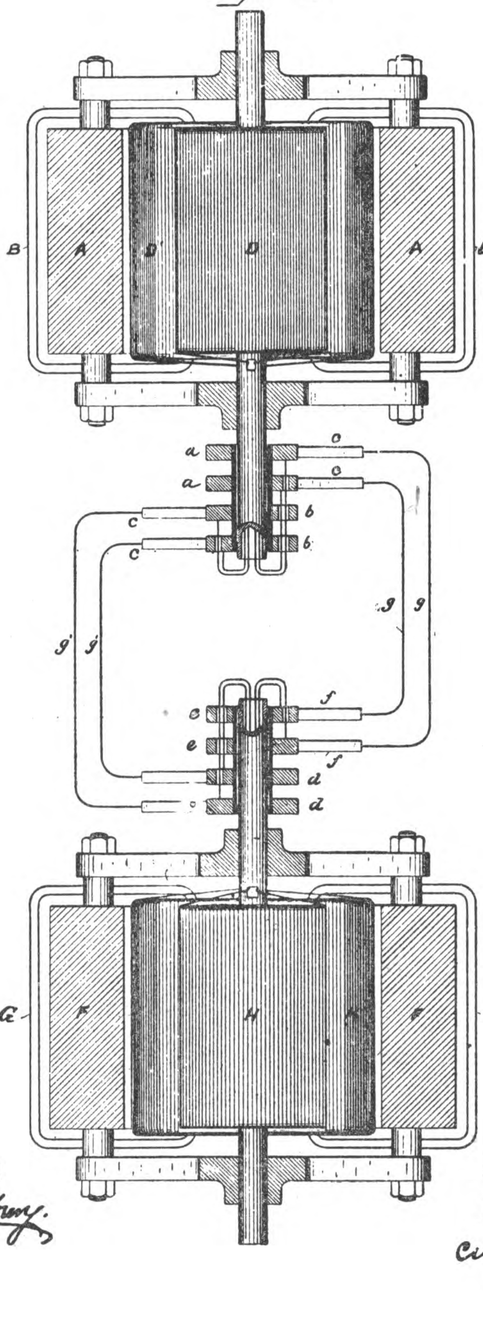
(No Model.)

2 Sheets—Sheet 2.

N. TESLA

ELECTRICAL TRANSMISSION OF POWER.

No. 382,281. Patented May 1, 1888



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Raphael Netter.

Henry F. Newbury.

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UNITED STATES PATENT OFFICE.

NIKOLA TESLA, OF NEW YORK, N. Y., ASSIGNOR OF ONE HALF TO CHARLES F. PECK, OF ENGLEWOOD, NEW JERSEY.

SYSTEM OF ELECTRICAL DISTRIBUTION.

SPECIFICATION forming part of Letters Patent No. 381,970, dated May 1, 1888.

Application filed December 23, 1887. Serial No. 238,787. (No model.)

To all whom, it may concern:

Be it known that I, NIKOLA TESLA, from Smiljan Lika, border country of Austria-Hungary, now residing at New York, in the county and State of New York, have invented certain new and useful Improvements in Systems of Electrical Distribution, of which the following is a specification, reference being had to the drawings accompanying and forming a part of the same.

This invention relates to those systems of electrical distribution in which a current from a single source of supply in a main or transmitting circuit is caused to induce by means of suitable induction apparatus a current or currents in an independent working circuit or circuits.

The main objects of the invention are the same as have been heretofore obtained by the use of these systems—viz., to divide the current from a single source, whereby a number of lamps, motors, or other translating devices may be independently controlled and operated by the same source of current, and in some cases to reduce a current of high potential in the main circuit to one of greater quantity and lower potential in the independent consumption or working circuit or circuits.

The general character of the devices employed in these systems is now well understood. An alternating-current magneto-machine is used as the source of supply. The current developed thereby is conducted through a transmission circuit to one or more distant points at which the transformers are located. These consist of induction-machines of various kinds. In some cases ordinary forms of induction-coil have been used with one coil in the transmitting-circuit and the other in a local or consumption circuit, the coils being differently proportioned according to the work to be done in the consumption-circuit—that is to say, if the work requires a current of higher potential than that in the transmission circuit the secondary or induced coil is of greater length and resistance than the primary, while, on the other hand, if a quantity current of lower potential is wanted the longer coil is made the primary. In lieu of these devices various forms of electro dynamic induction-machines, including the combined motors and generators, have been devised. For instance, a motor is constructed in accordance with well-understood principles, and on the same armature are wound induced coils which constitute a generator. The motor coils are generally of fine wire and the generator-coils of coarser wire, so as to prodace a current of greater quantity and lower potential than the line-current, which is of relatively high potential, to avoid loss in long transmission. A similar arrangement is to wind coils corresponding to those described in a ring or similar core, and by means of a commutator of suitable kind to direct the current through the inducing-coils successively, so as to maintain a movement of the poles of the core and of the lines of force which set up the currents in the induced coils.

Without enumerating the objections to these systems in detail, it will suffice to say that the theory or the principle of the action or operation of these devices has apparently been so little understood that their proper construction and use have up to the present time been attended with various difficulties and great expense. The transformers are very liable to be injured and burned out, and the means resorted to for curing this and other defects have almost invariably been at the expense of efficiency.

The form of converter or transformer which I have devised appears to be largely free from the defects and objections to which I have alluded. While I do not herein advance any theory as to its mode of operation, I would state that, in so far as the principal of construction is concerned, it is analogous to those transformers which I have above described as electro-dynamic induction-machines, except that it involves no moving parts whatever, and is hence not liable to wear or other derangement, and requires no more attention than the other and more common induction-machines.

In carrying out, my invention I provide a series of inducing-coils and corresponding induced coils, which, by preference, I wind upon a core closed upon itself—such as an annulus or ring subdivided in the usual manner. The two sets of coils are wound side by side or superposed or otherwise placed in well-known ways to bring them into the most effective relations to one another and to the core. The inducing or primary coils wound on the core are divided into pairs or sets by the proper electrical connections, so that while the coils of one pair or set to co-operate in fixing the magnetic poles of the core at two given diametrically opposite points, the coils of the other pair or set—assuming, forsake of illustration, that there are but two—tend to fix the poles ninety degrees from such points. With this induction device I use an alternating current generator with coils or sets of coils to correspond with those of the converter, and by means of suitable conductors I connect up in independent circuits the corresponding coils of the generator and converter. It results from this that the different electrical phases in the generator are attended by corresponding magnetic changes in the converter; or, in other words, that as the generator-coils revolve the points of greatest magnetic intensity in the converter will be progressively shifted or whirled around. This principle I have applied under variously-modified conditions to the operation of electro magnetic motors, and in previous applications, notably in those having Serial Nos. 252,132 and 256,561, I have described in detail the manner of constructing and using such motors. In the present application my object is to describe the best and most convenient manner of which I am at present aware of carrying out the invention as applied to a system of electrical distribution; but one skilled in the art will readily understand from the description by the modifications proposed in said applications, wherein the form of both the generator and converter in the present case may be modified.

In illustration therefore of the details of construction which my present invention involves, I now refer to the accompanying drawings.

Figure 1 is a diagrammatic illustration of the converter and the electrical connections of the same. Fig. 2 is a horizontal central cross-section of Fig. 1. Fig. 3 is a diagram of the circuits of the entire system, the generator being shown in section.

I use a core, A, which is closed upon itself—that is to say, of an annular cylindrical or equivalent form—and as the efficiency of the apparatus is largely increased by the subdivision of this core I make it of thin strips, plates, or wires of soft iron electrically insulated as far as practicable. Upon this core, by any well-known method, I wind, say, four coils, B B B' B', which I use as primary coils, and for which I use long lengths of comparatively fine wire. Over these coils I then wind shorter coils of coarser wire, C C C' C', to constitute the induced or secondary coils. The construction of this or any equivalent form of converter may be carried further, as above pointed out, by inclosing these coils with iron—as, for example, by winding over the coils a layer or layers of insulated iron wire.

The device is provided with suitable binding-posts, to which the ends of the coils are led. The diametrically-opposite coils B B and B' B' are connected, respectively, in series, and the four terminals are connected to the binding posts 1 2 3 4. The induced coils are connected together in any desired manner. For example, as shown in Fig. 3, C C may be connected in multiple arc when a quantity current is desired—as for running a group of incandescent lamps, D—while C' C' may be independently connected in series in a circuit including arc lamps or the like. The generator in this system will be adapted to the converter in the manner illustrated. For example, in the present case I employ a pair of ordinary permanent or electro magnets, E E, between which is mounted a cylindrical armature on a shaft, F, and wound with two coils, G G'. The terminals of these coils are connected, respectively, to four insulated contact or collecting rings, H H H' H', and the four line circuit-wires L connect the brushes K, bearing on these rings, to the converter in the order shown. Noting the results of this combination, it will be observed that at a given point of time the coil G is in its neutral position and is generating little or no current, while the other coil, G', is in a position where it exerts its maximum effect. Assuming coil G to be connected in circuit with coils B B of the converter, and coil G' with coils B' B', it is evident that the poles of the ring A will be determined by coils B' alone; but as the armature of the generator revolves, coil G dedelops more current and coil G' less, until G reaches its maximum and G' its neutral position. The obvious result will be to shift the poles of the ring A through one-quarter of its periphery. The movement of the coils through the next quarter of a turn, during which coil G' enters a field of opposite polarity and generates a current of opposite direction and increasing strength, while coil G, in passing from its maximum to its neutral position generates a current of decreasing strength and same direction as before, causes a further shifting of the poles through the second quarter of the ring. The second half-revolution will obviously be a repetition of the same action. By the shifting of the poles of the ring A a powerful dynamic inductive effect on the coils C C' is produced. Besides the currents generated in the secondary coils by dynamo-magnetic induction other currents will be set up in the same coils in consequence of any variations in the intensity of the poles in the ring A. This should be avoided by maintaining the intensity of the poles constant, to accomplish which care should be taken in designing and proportioning the generator and in distributing the coils in the ring A and balancing their effect. When this is done, the currents are produced by dynamo-magnetic induction only, the same result being obtained as though the poles were shifted by a commutator with an infinite number of segments.

The modifications which are applicable to other forms of converter are in many respects applicable to this. I refer more particularly to the form of. the, core, the relative lengths and resistances of the primary and secondary coils, and the arrangements for running or operating the same.

The new method of electrical conversion which this system involves I have made the subject of another application, and I do not claim it therefore herein.

Without limiting myself therefore to any specific form, what I claim is—

1. The combination, with a core closed upon itself, inducing or primary coils wound thereon and connected up in independent pairs or sets, and induced or secondary coils wound upon or near the primary coils, of a generator of alternating currents and independent connections to the primary coils, whereby by the operation of the generator a progressive shifting of the poles of the core is effected, as set forth.

2. The combination, with an annular or similar magnetic core and primary and secondary coils wound thereon, of an alternating-current generator having induced or armature coils corresponding to the primary coils, and independent circuits connecting the primary coils with the corresponding coils of the generator, as herein set forth.

3. The combination, with independent electric transmission circuits, of transformers consisting of annular or similar cores wound with primary and secondary coils, the opposite primary coils of each transformer being connected to one of the transmission-circuits, an alternating-current generator with independent induced or armature coils connected with the transmission circuits, whereby alternating currents may be directed through the primary coils of the transformers in the order and manner herein described.

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Witnesses:
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ROBT. F. GAYLORD.

P-165

(No Model.) 2 Sheets—Sheet 1.

N. TESLA

SYSTEM OF ELECTRICAL DISTRIBUTION.

No. 381,970. Patented May 1, 1888.

Fig: 1

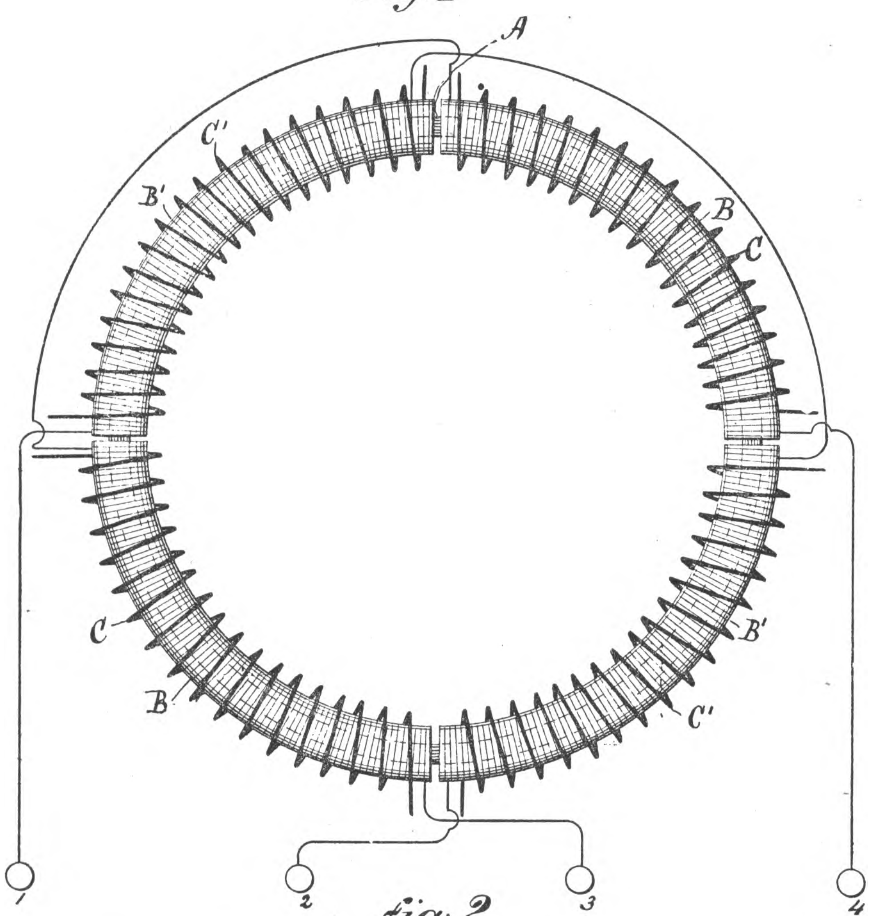
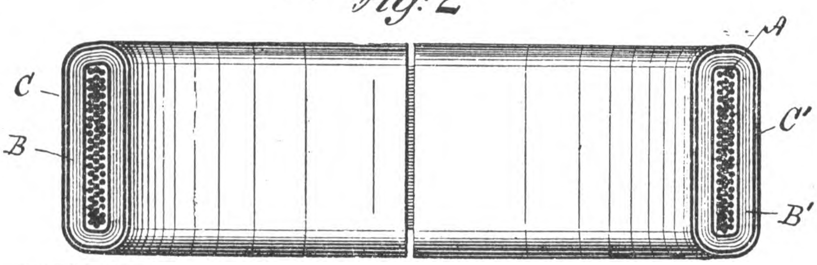


Fig: 2



WITNESSES:

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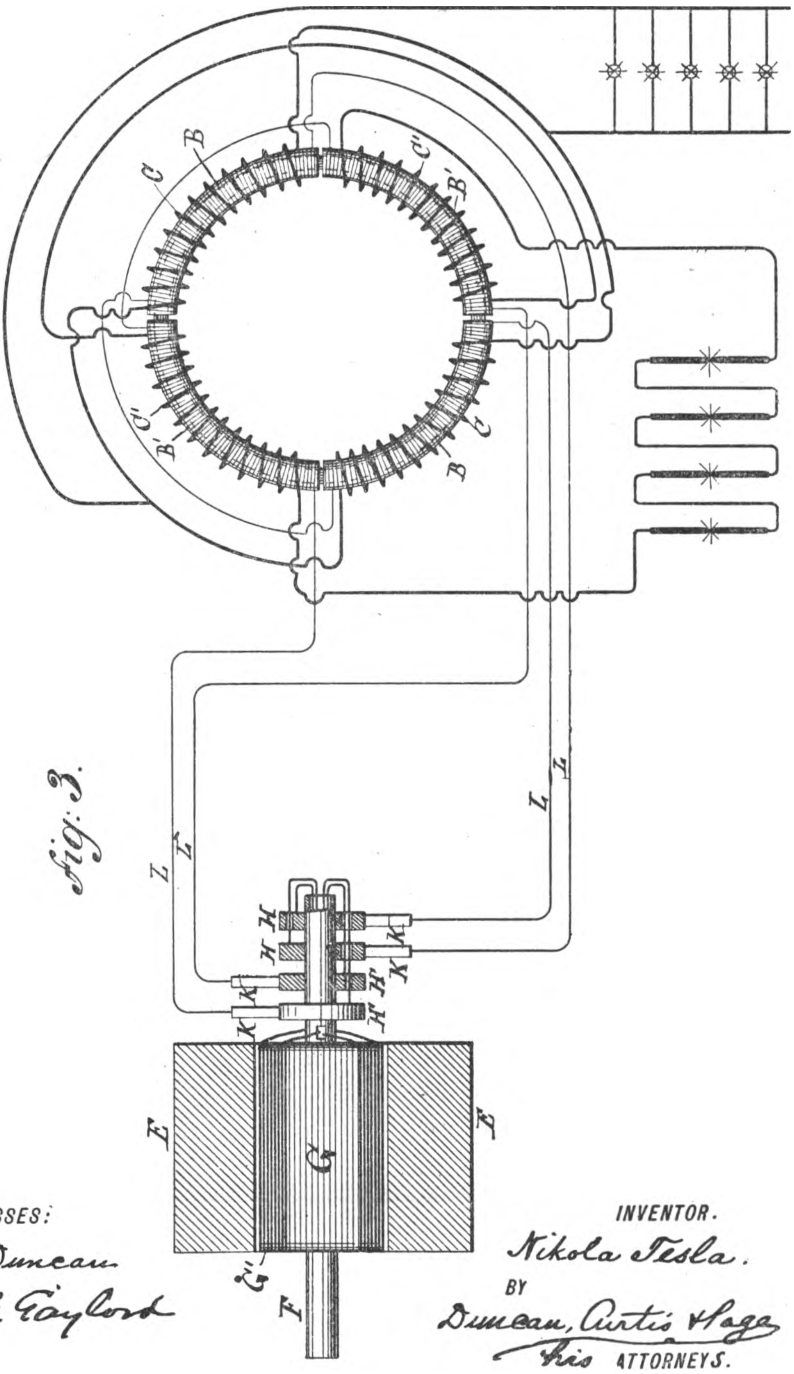
P-166

(No Model.) 2 Sheets—Sheet 2.

N. TESLA.

SYSTEM OF ELECTRICAL DISTRIBUTION.

No. 381,970. Patented May 1, 1888.



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NIKOLA TESLA, OF NEW YORK, N. Y., ASSIGNOR TO THE TESLA ELECTRIC COMPANY, OF SAME PLACE.

SYSTEM OF ELECTRICAL DISTRIBUTION.

SPECIFICATION forming part of Letters Patent No. 390,413, dated October 2, 1888.

Application filed April 10, 1888. Serial No. 270.187. (No model.)

To all, whom it may concern:

Be it known that I, NIKOLA TESLA, a subject of the Emperor of Austria, from Smiljan, Lika, border country of Austria-Hungary, residing in the city, county, and State of New York, have invented certain new and useful Improvements in Systems of Electrical Distribution, of which the following is a specification, reference being had to the drawings accompanying and forming a part of the same.

In previous applications for patents made by me I have shown and described electrical systems for the transmission of power and the conversion and distribution of electrical energy, in which the motors and the transformers contain two or more coils or sets of coils, which were connected Up in independent circuits with corresponding coils of an alternating-current generator, the operation of the system being brought about by the co-operation of the alternating currents in the independent circuits in progressively moving or shifting the poles or points of maximum magnetic effect of the motors or converters. In these systems, as I have described them, two independent conductors were employed for each of the independent circuits connecting the generator with the devices for converting the transmitted currents into mechanical energy or into electric currents of another character; but I have found that this is not always necessary, and that the two or more circuits may have a single return path or wire in common, with a loss, if any, which is so extremely slight that it may be disregarded entirely. For sake of illustration, if the generator have two independent coils and the motor two coils or two sets of coils in corresponding relations to its operative elements one terminal of each generator-coil is connected to the corresponding terminals of the motor coils through two independent conductors, while the opposite terminals of the respective coils are both connected to one return wire.

This invention is applicable to my system in various ways, as will be seen by reference to the drawings, in which—

Figure 1 is a diagrammatic illustration of a generator and single motor constructed and electrically connected in accordance with the invention. Fig. 2 is a diagram of the system as it is used in operating motors or convertors, or both, in parallel or multiple arc. Fig. 3 illustrates diagrammatically the manner of operating two or more motors or converters, or both, in series.

It is obvious that for purposes of this invention motors or transformers, which may be all designated as “converters”, are the same, and that either or both may be operated by the same system or arrangement of circuits.

Referring to Fig. 1, A A designate the poles of the field-magnets of an alternating-current generator, the armature of which, being in this case cylindrical in form and mounted on a shaft, C, is wound longitudinally with coils B B'. The shaft C carries three insulated contact-rings, *a b c,* to two of which, as *b c,* one terminal of each coil, as *e d,* is connected. The remaining terminals, *f g,* are both connected to the third ring, *a.*

A motor in this case is shown as composed of a ring, H, wound with four coils, I I J J, electrically connected, so as to co-operate in pairs, with a tendency to fix the poles of the ring at four points ninety degrees apart. Within the magnetic ring H is a disk or cylindrical core wound with two coils, G G', which may be connected to form two closed circuits. The terminals *j k* of the two sets or pairs of coils are connected, respectively, to the binding-posts E' F', and the other terminals, *h i,* are connected to a single binding-post, D'. To operate the motor, three line-wires are used to connect the terminals of the generator with those of the motor.

So far as the apparent action or mode of operation of this arrangement is concerned, the single wire D. which is, so to speak, a common return-wire for both circuits, maybe regarded as two independent wires. In illustration, with the order of connection shown, coil B' of the generator is producing its maximum current and coil B its minimum; hence the current which passes through wire *e,* ring *b*, brush *b'*, line-wire E, terminal E', wire *j,* coils I I, wire or terminal D', line-wire D, brush *a'*, ring *a*, and wire *f,* fixes the polar line of the motor midway between the two coils I I; but as the coil B' moves from the position indicated it generates less current, while coil B, moving into the field, generates more. The current from coil B passes through the devices and wires designated by the letters *d*, *c*, *c'*, F, F', *k,* J J, *i,* D', D, *a'*, *a,* and *g,* and the position of the poles of the motor will be due to the resultant effect of the currents in the two sets of coils—that is, it will be advanced in proportion to the advance or forward movement of the armature coils. The movement of the generator-armature through one quarter of a revolution will obviously bring coil B' into its neutral position and coil B into its position of maximum effect, and this shifts the poles ninety degrees, as they are fixed solely by coils B. This action is repeated for each quarter of a complete revolution.

When more than one motor or other device is employed, they may be run either in parallel or series. In Fig. 2 the former arrangement is shown. The electrical device is shown as a converter, L, constructed as I have described in my application Serial No. 258,787, filed December 23, 1887. The two sets of primary coils *p r* are connected, respectively, to the mains F E, which are electrically connected with the two coils of the generator. The cross-circuit wires *l m,* making these connections, are then connected to the common return-wire D. The secondary coils *p' p''* are in circuits *n o,* including, for example, incandescent lamps. Only one converter is shown entire in this figure, the others being illustrated diagrammatically.

When motors or converters are to be run in series, the two wires E F are led from the generator to the coils of the first motor or converter, then continued on to the next, and so on through the whole series, and are then joined to the single wire D, which completes both circuits through the generator. This is shown in Fig. 3, in which J I represent the two coils or sets of coils of the motors.

Obviously it is immaterial to the operation of the motor or equivalent device in Fig. 1 what order of connections is observed between the respective terminals of the generator or motor.

I have described the invention in its best and most practicable form of which I am aware; but there are other conditions under which it may be carried out. For example, in case the motor and generator each has three independent circuits, one terminal of each circuit is connected to a line wire and the other three terminals to a common return conductor. This arrangement will secure similar results to those attained with a generator and motor having but two independent circuits, as above described.

When applied to such machines and motors as have three or more induced circuits with a common electrical joint, the three or more terminals of the generator would be simply connected to those of the motor. Such forms of machines, when adapted in this manner to my system, I have, however, found to be less efficient than the others.

The invention is applicable to machines and motors of various types, and according to circumstances and conditions readily understood. with more or less efficient results. I do not therefore limit myself to any of the details of construction of the apparatus herein shown,

What I claim is—

1. The combination, with a generator having independent current-generating circuits and a converter or converters having independent and corresponding circuits, of independent conductors connecting one terminal of each generator-circuit with a corresponding terminal of the motor and a single conductor connecting the remaining generator and converter terminals, as set forth.

2. The combination, with a generator having independent current generating circuits and a converter or converters having independent and corresponding circuits, of independent line or connecting circuits formed in part through a conductor common to all, as set forth.

3. The system of electrical distribution herein set forth, consisting of the combination, with an alternating-current generator having independent generating circuits and electro magnetic motors or converters provided with corresponding energizing-circuits, of line-wires or conductors connecting the coils of the motors or converters, respectively, in series with one terminal of each circuit of the generator, and a single return wire or conductor connecting the said conductors with the other terminals of the generator, as set forth.

NIKOLA TESLA.

Witnesses:
ROBT. F. GAYLORD,
FRANK E. HARTLEY.

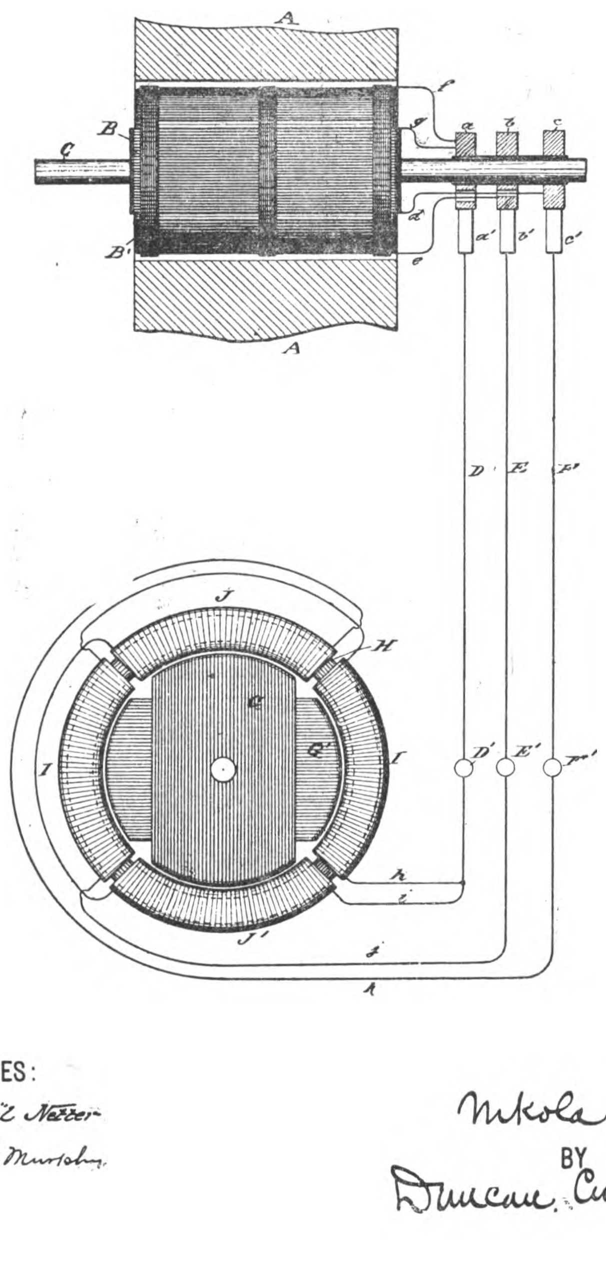
P-169

(No Model.) 3 Sheets—Sheet 1.

N. TESLA.

SYSTEM OF ELECTRICAL DISTRIBUTION.

No. 390,413. Patented Oct.2, 1888.



WITNESSES:

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Frank B. Murphy

INVENTOR

Nikola Tesla

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ATTORNEY

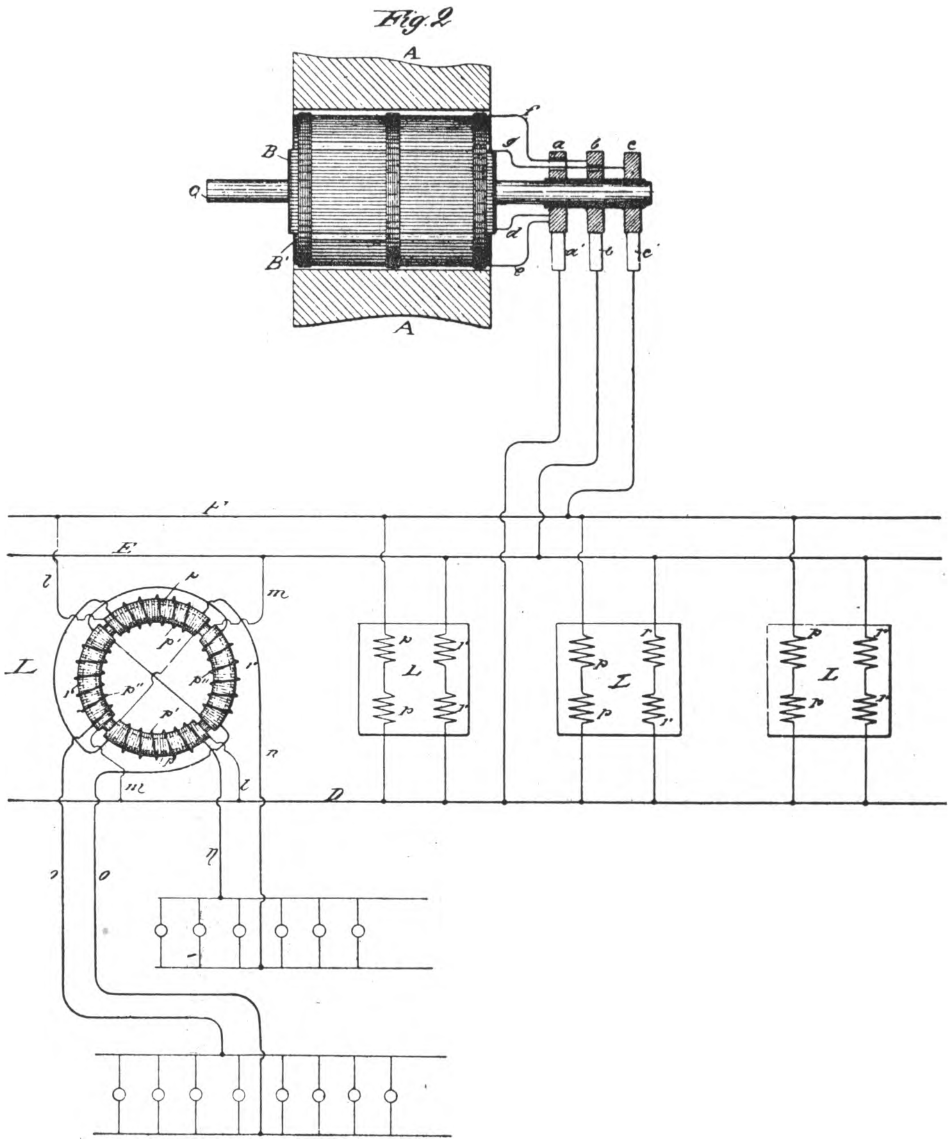
P-170

(No Model.) 3 Sheets—Sheet 2.

N. TESLA

SYSTEM OF ELECTRICAL DISTRIBUTION.

No. 390,413. Patented Oct. 2, 1888.



WITNESSES:

Raphael Netter

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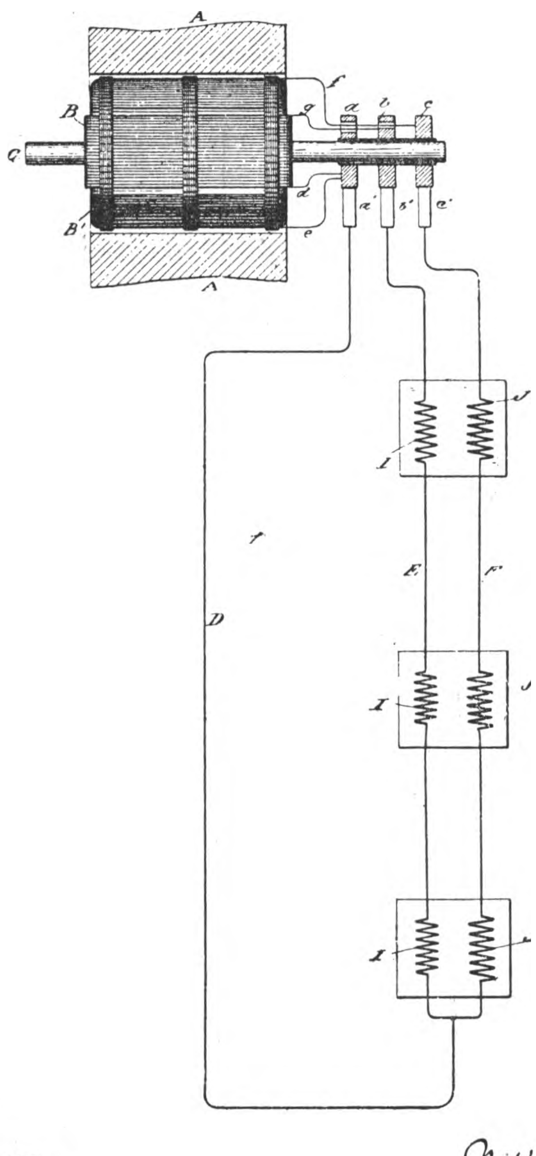
(No Model.) 3 Sheets—Sheet 3.

N. TESLA.

SYSTEM OF ELECTRICAL DISTRIBUTION.

No. 390,413. Patented Oct. 2, 1888.

Fig 3



WITNESSES

Raphaël Netter

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ATTORNEYS.

UNITED STATES PATENT OFFICE.

NIKOLA TESLA, OF NEW YORK, N. Y., ASSIGNOR TO THE TESLA ELECTRIC COMPANY, OF SAME PLACE.

SYSTEM OF ELECTRICAL TRANSMISSION OF POWER.

SPECIFICATION forming part of Letters Patent No. 487,786, dated December 13, 1898.

Application filed May 15, 1888. Serial So. 273,992. (No model.)

To all whom it may concern:

Be it known that I, NIKOLA TESLA, a subject of the Emperor of Austria-Hungary, formerly of Smiljan, Lika, border country of Austria-Hungary, but now residing at New York, in the county and State of New York, have invented certain new and useful Improvements in Systems for the Electrical Transmission of Power, of which the following is a specification, reference being had to the drawings accompanying and forming a part of the same.

This invention is an improvement in systems of electrical distribution of power wherein are employed motors having two or more independent energizing-circuits, through which are passed alternating currents differing in phase that are produced by a magneto-electric machine having independent induced circuits, or that are obtained from any other suitable source or by any other suitable means. In illustration of the various conditions which I regard as most important to an attainment of the best results from the use of motors of this character, I have heretofore used generally forms of generator in which the relations of the induced or current-generating coils and field-magnets were such that but two impulses or current are produced in each coil by a single revolution of the armature or field cores. The rate, therefore, at which the different phases or impulses of current in the line-circuits succeeded one another was so little greater than that at which the armature of the generator revolved that without special provision the generator required to be run at very high speed to obtain the best results. It is well known that the most efficient results are secured in the operation of such motors when they are run at high speeds; but as the practicable rate of speed is much limited by mechanical conditions, particularly in the case of large generators, which would be required when a number of motors are run from a single source, I have sought to produce a greater number of current impulses by a slow or slower speed than that at which the ordinary bipolar machines maybe economically operated. I therefore adapt to my system any of the various types of multipolar alternating-current machines which yield a considerable number of current reversals or impulses for each revolution of the armature by observing the main condition essential to the operation of my system that the phases of the currents in the independent induced circuits of the generator should not coincide, but exhibit a sufficient difference in phase to produce the desired results. I may Accomplish this in a variety of ways, which, however, vary only in detail, since they are based upon the same underlying principle. For example, to adapt a given type of alternating-current generator I may couple rigidly two complete machines, securing them so that the requisite difference in phase between the currents produced by each will be obtained, or I may secure two armatures to the same shaft within the influence of the same field and with an angular displacement that will produce the proper difference in phase between the two currents, or I may secure two armatures to the same shaft with their coils symmetrically disposed, and place two sets of field-magnets at such angle as to secure the same result, or, finally, I may wind on the same armature the two sets of coils alternately, or in such manner that they will develop currents, the phases of which differ in time sufficiently to produce rotation of the motor.

Another feature of my invention is in the plan which I have devised for utilizing generators and motors of this type, whereby a single generator may be caused to run a number of motors either at the same speed as its own or all at different speeds. This I accomplish by constructing the motors with fewer poles than the generator, in which case their speed will be greater than that of the generator, the rate of speed being higher as the number of their poles is relatively less. This will be understood from an example. Suppose the generator has two independent generating-coils which revolve between two pole-pieces oppositely magnetized and that the motor has energizing-coils that produce at any given time two magnetic poles in one element that tend to set up a rotation of the motor. A generator thus constructed yields four impulses or reversals of current by each revolution, two in each of its independent circuits, and I have demonstrated that the effect upon a motor such as that mentioned is to shift the magnetic poles through three hundred and sixty degrees. It is obvious that if the four reversals in the same order could be produced by each half-revolution of the generator the motor would make two revolutions to the generator's one. This would be readily accomplished by adding two intermediate poles to the generator or altering it in any of the other equivalent ways above indicated. The same rule applies to generators and motors with multiple poles. For instance, if a generator be constructed with two circuits, each of which produces twelve reversals of current to a revolution, and these currents be directed through the independent energizing-coils of a motor, the coils of which are so applied as to produce twelve magnetic poles at all times, the rotation of the two will be synchronous; but if the motor-coils produce but six poles the movable element will be rotated twice while the generator rotates once, or if the motor have four poles its rotation will be three times as fast as that of the generator.

These features, so far as it is necessary to an understanding of the invention, are illustrated in the accompanying drawings.

Figure 1 is a diagrammatic illustration of a generator constructed in accordance with my invention. Fig. 2 is a similar view of a correspondingly constructed motor. Fig. 3 is a diagram of a generator of modified construction. Fig. 4 is a diagram of a motor of corresponding character. Fig. 5 is a diagram of a system containing a generator and several motors adapted to run at various speeds.

In Fig. 1, let C represent a cylindrical armature-core wound longitudinally with insulated coils A A, which are connected up in series, the terminals of the series being connected to collecting-rings *a a* on the shaft G. By means of this shaft the armature is mounted to rotate between the poles of an annular field-magnet D, formed with polar projections wound with coils E, that magnetize the said projections. The coils E are included in the circuit of a generator F, by means of which the field-magnet is energized. If thus constructed, the machine is a well-known form of alternating-current generator. To adapt it to my system, however, I wind on armature C a second set of coils B B intermediate to the first, or, in other words, in such positions that while the coils of one set are in the relative positions to the poles of the field-magnet to produce the maximum current those of the other set will be in the position in which they produce the minimum current. The coils B are connected, also, in series and to two collecting-rings *b b,* secured generally to the shaft at the opposite end of the armature.

The motor shown in Fig 2 has an annular field-magnet H, with four pole-pieces wound with coils I. The armature is constructed similarly to that of the generator, but with two sets of two coils in closed circuits to correspond with the reduced number of magnetic poles in the field.

From the foregoing it is evident that one revolution of the armature of the generator producing eight current impulses in each circuit will produce two revolutions of the motor-armature.

The application of the principle of this invention is not confined to any particular form of machine. In Figs. 3 and 4 a generator and motor of another well-known type are shown. In Fig. 3, J J are magnets disposed in a circle and wound with coils K, which are in circuit with a generator which supplies the current that maintains the field of force. In the usual construction of these machines the armature-conductor L is carried by a suitable frame, so as to be rotated in face of the magnets J J or between these magnets and another similar set in face of them. The magnets are energized so as to be of alternately-opposite polarity throughout the series, so that as the conductor G is rotated the current impulses combine or are added to one another, those produced by the conductor in any given position being all in the same direction. To adapt such a machine to my system, I add a second set of induced conductors M, in all respects similar to the first, but so placed with reference to it that the currents produced in each will differ by a quarter-phase. With such relations it is evident that as the current decreases in conductor L it increases in conductor M, and conversely, and that any of the forms of motor invented by me for use in this system may be operated by such generator.

Fig. 4 is intended to show a motor corresponding to the machine in Fig. 3. The construction of the motor is identical with that of the generator, and if coupled thereto it will run synchronously therewith. J' J' are the field-magnets, and K' the coils thereon. L' is one of the armature-condutors and M' the other.

Fig. 5 shows in diagram other forms of machine. The generator N in this case is shown as consisting of a stationary ring O, wound with twenty-four coils P P', alternate coils being connected in series in two circuits. Within this ring is a disk or drum Q, with projections Q' wound with energizing-coils included in circuit with a generator R. By driving this disk or cylinder alternating currents are produced in the coils P and P', which are carried off to ran the several motors.

The motors are composed of a ring or annular field-magnet S, wound with two sets of energizing-coils T T', and armatures U, having projections U' wound with coils V, all connected in series in a closed circuit or each closed independently on itself.

Suppose the twelve generator-coils P are wound alternately in opposite directions, so that any two adjacent coils of the same set tend to produce a free pole in the ring O between them and the twelve coils P' to be similarly wound. A single revolution of the disk or cylinder Q, the twelve polar projections of which are of opposite polarity, will therefore produce twelve current impulses in each of the circuits W W' Hence the motor X, which has sixteen coils or eight free poles, will make one and a half turns to the generator's one. The motor Y, with twelve coils or six poles, will rotate with twice the speed of the generator, and the motor Z, with eight coils or four poles, will revolve three times as fast as the generator. These multipolar motors have a peculiarity which may be often utilized to great advantage. For example, in the motor X, Fig. 5, the eight poles may be either alternately opposite or there may be at any given time alternately two like and two opposite poles. This is readily attained by making the proper electrical connections. The effect of such a change, however, would be the same as reducing the number of poles one-half, and thereby doubling the speed of any given motor. In these and other respects it will be seen that the invention involves many important and valuable features.

It is obvious that the electrical transformers described in prior patents to me add which have independent primary currents may be used with the generators herein described.

It may be stated with respect to the devices hereinafter set forth that the most perfect and harmonious action of the generators and motors is obtained when the numbers of the poles of each are even and not odd. If this is not the case, there will be a certain unevenness of action which is the less appreciable as the number of poles is greater; but even this may be in a measure corrected by special provisions which it is not here necessary to explain. It also follows, as a matter of course, and from the above it is obvious, that if the number of the poles of the motor be greater than that of the generator the motor will revolve at a slower speed than the generator.

What I claim as my invention is—

1. The combination, with an alternating-current generator comprising independent armature-circuits formed by conductors alternately disposed, so that the currents developed therein will differ in phase, and field-magnet poles in excess of the number of armature-circuits, of a motor having independent energizing-circuits connected to the armature-circuits of the generator substantially as set forth.

2. The combination, with a source of alternating currents which differ in phase and comprising a rotating magneto-electric machine yielding a given number of current impulses or alternations for each turn or revolution, of a motor or motors having independent energizing-circuits through which the said currents are caused to flow, and poles which in number are less than the number of current impulses produced in each motor-circuit by one turn or revolution of the magneto-machine, as set forth.

3. The combination, with a multipolar alternating-current machine having independent induced or current-generating circuits, of motors having independent energizing-circuits and a smaller number of poles than the generator, as set forth.

4. The combination, with an alternating-current generator having independent induced circuits and constructed or adapted to produce a given number of current impulses or alternations for each turn or revolution, of motors having corresponding energizing-circuits and poles which in number are less than the number of current impulses produced in each circuit in a turn or revolution of the generator, as set forth.

NIKOLA TESLA.

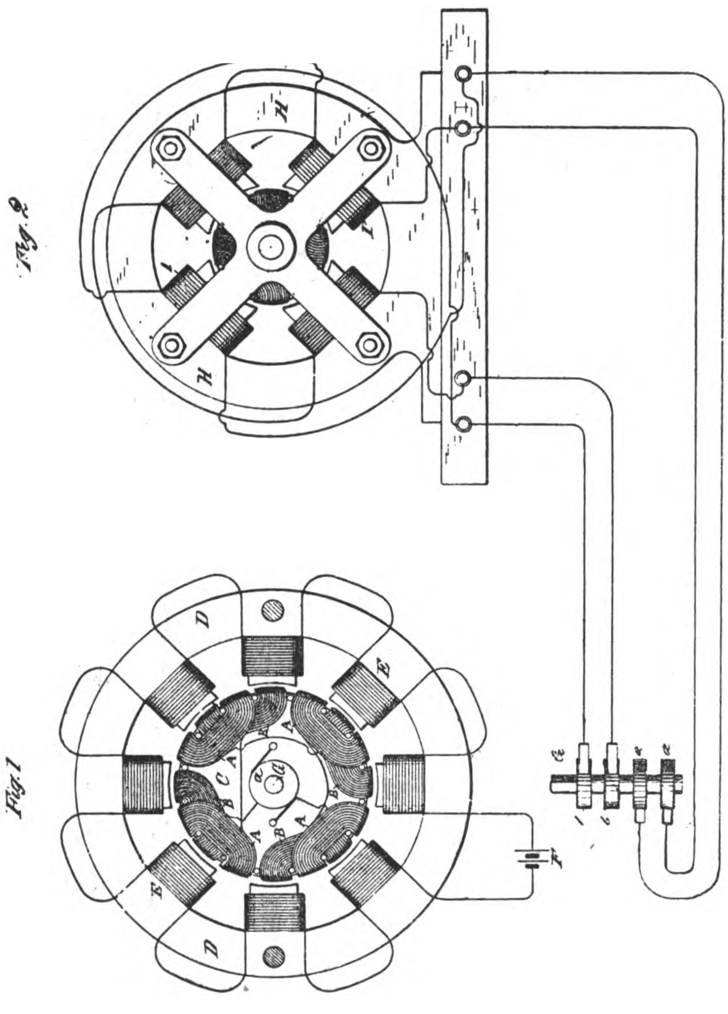
Witnesses.

FRANK E. HARTLEY,
FRANK B. MURPHY,

(No Model.) 3 Sheets—Sheet 1.

N. TESLA.
SYSTEM OF ELECTRICAL TRANSMISSION OF POWER.

No. 487,796 Patented Dec. 13, 1892.



WITNESSES:
Raphael Netter
Robt. F. Gaylord

INVENTOR
Nikola Tesla
BY
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P-176

(No Model.)

3 Sheets—Sheet 2

N. TESLA.

SYSTEM OF ELECTRICAL TRANSMISSION FF POWER.

No. 487 796

Patented Dec., 13, 1892.

Fig 4

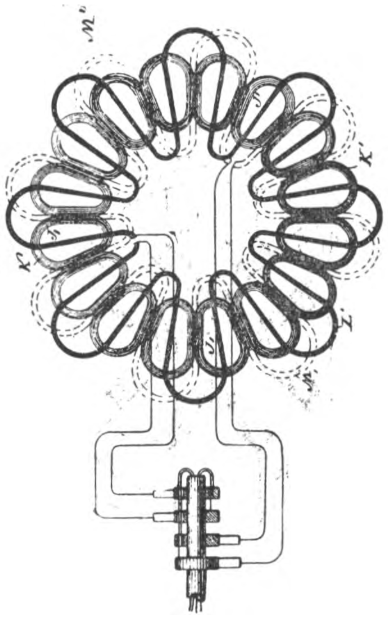
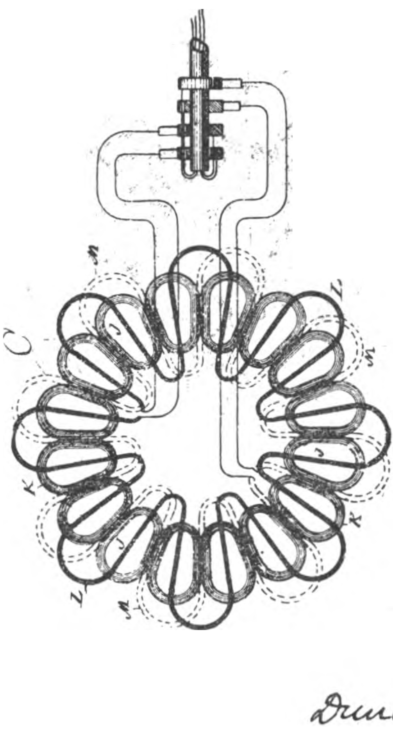


Fig 3



WITNESSES:

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Allan W. Paige

INVENTOR

Nikola Tesla

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ATTORNEYS

P-177

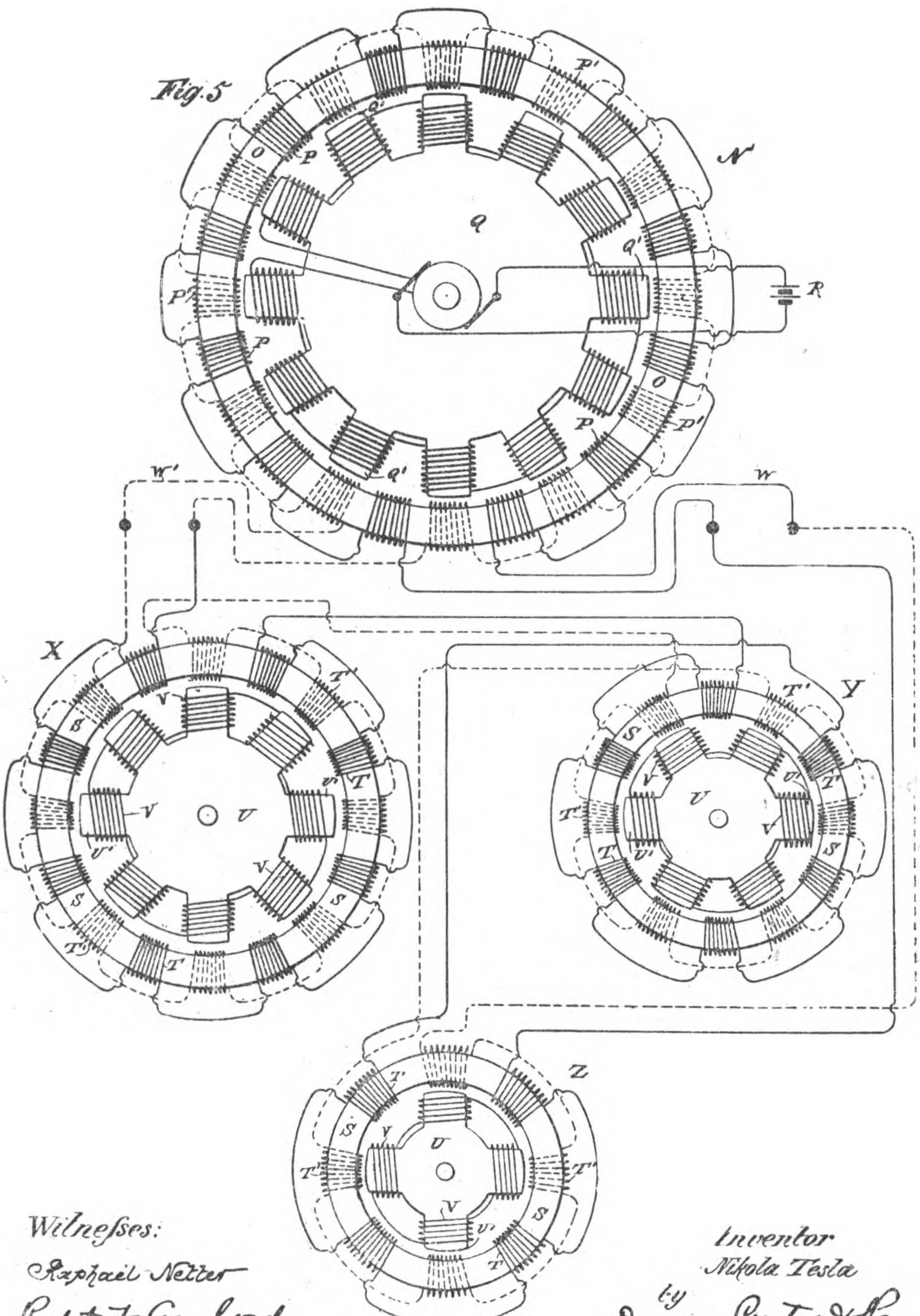
(No Model.)

3 Sheets—Sheet 3.

N. TESLA.
SYSTEM OF ELECTRICAL TRANSMISSION OF POWER.

No. 487,796 Patented Dec. 13, 1892.

Fig. 5



Witnesses:
Raphael Netter
Robt. F. Gaylord

Inventor
Nikola Tesla
by
Duncan, Curtis & Page
Attorneys.

UNITED STATES PATENT OFFICE.

NIKOLA TESLA. OF NEW YORK, N. Y., ASSIGNOR TO THE TESLA ELECTRIC COMPANY, OF SAME PLACE.

ELECTRICAL TRANSMISSION OF POWER.

SPECIFICATION forming part of Letters Patent No. 511,915, dated January 2, 1894.

Original application filed May 15, 1888, Serial No. 273,993, Divided and this application filed December 3, 1888. Serial No. 292,476. (No model.)

To all whom it may concern:

Be it known that I, NIKOLA TESLA, from Smiljan, Lika, border country of Austria-Hungary, a subject of the Emperor of Austria-Hungary, residing at New York, in the county and State of New York, have invented a new and useful Method of Electrical Transmission of Power, of which the following is a description, this application being a division of an application filed by me on May 15, 1888, Serial No. 273,993, and for the method of operating motors contained in such application.

In former patents granted to me I have shown and described a system for the electrical transmission of power characterized by the following particulars: The motor contains independent energizing circuits and the generator has corresponding induced or current generating circuits which are connected by independent line circuits with those of the motor. The disposition of the generator coils is such that the currents developed in the circuits including them will have a certain difference of phase, for example, that the maximum periods of the currents generated in one of its circuits coincide with the minimum periods of the currents produced in the other circuit, and the corresponding energizing circuits of the motor are so arranged that the two currents co-operate to effect a progressive shifting of the magnetic poles or the points of maximum magnetic effect in the motor in consequence of which a rotation of its movable element is maintained.

My present invention involves this system of electrical power transmission; its distinguishing characteristic being the mode or method of generating or producing the alternating currents which run or operate the motor.

This invention is carried out in the following way: Instead of generating directly the alternating currents in each of the circuits which include the energizing coils of the motor, as by means of the induced coils of a magneto electric machine, I generate or produce an alternating current in but one of such circuits directly and by means of such current induce the proper current in the other energizing motor circuit. When the independent currents are both produced in the magneto machine it will be observed that the two line or transmitting circuits will of necessity extend the entire distance from the generator to the motor, but that by the method herein provided, one line circuit may be dispensed with as one circuit or that from the generator may be brought into the proper inductive relation to the other at any desired point.

The following is illustrative of the manner in which I carry out this invention: I employ as a motor, for example, a subdivided annular field magnet within which is mounted a suitable armature, such as a cylinder or disk wound with two coils at right angles, each of which is closed upon itself. On opposite sides of the annular field magnet I wind two coils of insulated wire of a size adapted to carry the current from the generator. Over these coils or close to them in any of the well understood ways I wind secondary coils. I also wind on the annular field magnet midway between the first mentioned coils a pair of coils which I connect up in circuit with the secondary coils. The last pair of coils I make of finer wire than the main or line and secondary coils and with a greater number of convolutions that they may have a greater relative magnetizing and retarding effect than either of the others. By connecting up the main coils in circuit with a generator of alternating currents the armature of the motor will be rotated. It is probable that this action is explained by the following theory: A current impulse on the line passing through the main coils establishes the magnetic poles of the annular field magnets at points midway between said coils. But this impulse produces in the secondary coils a current which, circulating through the second pair of energizing coils tends to establish the poles at points ninety degrees removed from their first position with the result of producing a movement or shifting of the poles in obedience to the combined magnetizing effect of the two sets of coils. This shifting continued by each successive current impulse establishes what may be termed a rotary effort and operates to maintain the armature in rotation.

In the drawings annexed I have shown in Figure 1 an alternating current generator connected with a motor, shown diagrammatically and constructed in accordance with my invention, and in Fig. 2 a diagram of a modified form of motor.

A designates any ordinary form of alternating current generator and B B the line wires for connecting the same with the motor.

C is the annular field magnet of the motor.

D D are two main coils wound on opposite sides of the ring or annular field and connected up with the line, and having a tendency to magnetize the ring C with opposite poles midway between the two coils.

E E are two other magnetizing coils wound midway between coils D D, but having a stronger magnetizing influence for a current of given strength than coils D D.

F F are the secondary coils which are associated with the main coils D D. They are in circuits which include the coils E E respectively, the connections being made in such order that currents induced in coils F and circulating in coils E will act in opposition to those in coils D in so far only as the location of the magnetic poles in the ring C is concerned.

The Armature may be of any of the forms used by me in my alternating current system and is shown as wound with two closed coils G H at right angles to each other.

In order to prolong the magnetizing effect of the induced currents in producing a shifting of the poles, I have carried the principle of the construction exhibited in Fig. 1 farther, thereby obtaining a stronger and better rotary effect.

Referring to Fig. 2, C is an annular field magnet having three pairs or oppositely located sets of polar projections K L M. Upon one pair of these projections, as K, the main energizing coils D are wound. Over these are wound the secondary coils E. On the next polar projections L L are wound the second energizing coils F which are in circuit with coils E. Tertiary induced coils E' are then wound over the coils F and on the remaining polar projections M the third energizing coils F' are wound and connected up in the circuit of the tertiary coils E'. The cylindrical or disk armature core N in this motor has polar projections wound with coils O forming closed circuits. My object in constructing the motor in this way is to effect more perfectly a shifting of the points of maximum magnetic effect. For assuming the operation of the motor to be due to the action above set forth—the first effect of a current impulse in this motor will be to magnetize the pole pieces K K, but the current thereby induced in coils E magnetizes the pole pieces L and the current induced in turn in coils E' magnetizes the pole pieces M. The pole pieces are not magnetized, at least to their full extent, simultaneously by this means, but there is enough of a retardation or delay to produce a rotary effect or influence upon the armature. The application of this principle is not limited to the special forms of motor herein shown, as any of the double circuit alternating current motors invented by me and described in former Letters Patent to me may be adapted to the same purpose. This method or mode of producing the currents in the independent energizing circuits of the motor may be carried out in various ways, and it is not material to the invention broadly considered, what devices be employed in effecting the result, viz: the induction from or by the current from the generator or source, of the current or currents which co-operate therewith in producing the rotation of the motor.

I would state that in using the word generator, I mean either a primary generator, such as a magneto machine, or a secondary generator, such as an electrical converter, and in claiming protection for inducing the current in one set of energizing coils by the current which circulates in another, I would be understood as including the induction of the secondary current from the current from the same source as that which traverses the motor coils whether it be flowing in the same branch or part of the circuit or not.

What I claim is—

1. The method of operating electro-magnetic motors having independent energizing circuits, as herein described, which consists in passing an alternating current through one of the energizing circuits and inducing by such current the current in the other energizing circuit of the motor, as set forth.

2. The method of operating electro-magnetic motors having independent energizing circuits as herein described, which consists in developing an alternating current in one of said energizing circuits and inducing thereby currents in the other energizing circuit or circuits, as herein set forth.

NIKOLA TESLA.

Witnesses:
GEO. N. MONRO,
EDWARD T. EVANS.

P-180

(No Model.)

N. TESLA.

ELECTRICAL TRANSMISSION OF POWER.

No. 511,915. Patented Jan. 2, 1894.

Fig. 1

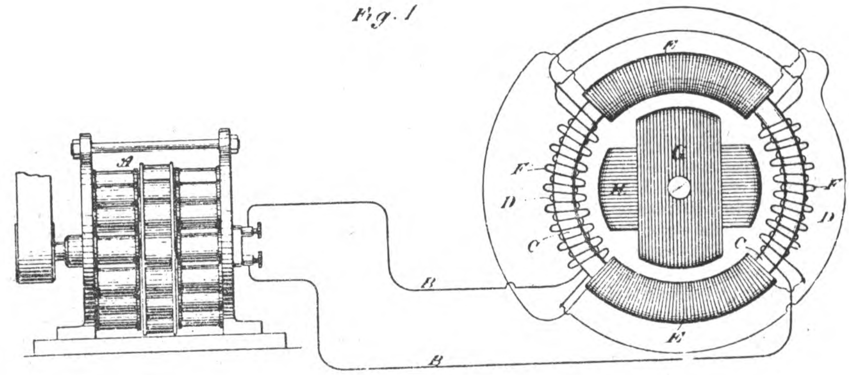
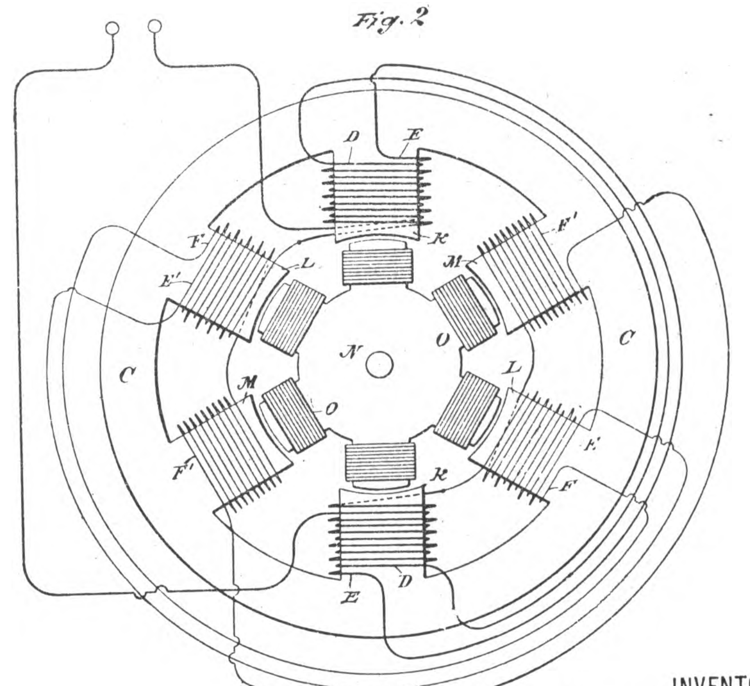


Fig. 2



WITNESSES:
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R. F. Newbury

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ATTORNEYS

UNITED STATES PATENT OFFICE.

NIKOLA TESLA, OF NEW YORK, N. Y, ASSIGNOR TO THE TESLA ELECTRIC COMPANY, OF SAME PLACE

ELECTRICAL TRANSMISSION OF POWER.

SPECIFICATION forming part of Letters Patent No. 511,659, dated December 26, 1893.

Application December 8, 1888. Serial No. 293,051. (No model.)

To all whom it may concern:

Be it known that I, NIKOLA TESLA, a subject of the Emperor of Austria-Hungary, from Smiljan, Lika, border country of Austria-Hungary, residing at New York, in the county and State of New York, have invented certain new and useful Improvements in the Electrical Transmission of Power, of which the following is a specification, reference being had to the drawings accompanying and forming a part of the same.

In certain patents heretofore granted, I have shown and described a system of electrical power transmission, in which each motor contained two or more independent energizing circuits through which were caused to pass alternating currents, having in each circuit such a difference of phase that by their combined or resultant action they produced a rotary progression of the poles or points of maximum magnetic effect of the motor and thereby maintained the rotation of its movable element. In the system referred to and described in said patents, the production or generation of the alternating currents upon the combined or resultant action of which the operation of the system depends, is effected by the employment of an alternating current generator with independent induced circuits which, by reason of the winding or other construction of the generator produced currents differing in phase, and these currents were conveyed directly from the generator to the corresponding motor coils by independent lines or circuits. I have, however, discovered another method of operating these motors, which dispenses with one of the line circuits and enables me to run the motors by means of alternating currents from a single original source.

Broadly stated this invention consists in passing alternating currents, obtained from one original source, through both of the energizing circuits of the motor, and retarding the phases of the current in one circuit to a greater or less extent than in the other.

The distribution of current between the two motor circuits may be effected by induction or by derivation. In other words, I may pass the alternating current from the source through one energizing circuit and induce by such current a second current in the other energizing circuit. Or, on the other hand, I may connect up the two energizing circuits of the motor in derivation or multiple arc with the main circuit from the source. In either event I make due provision for maintaining a difference of phase between the currents in the two circuits or branches.

In carrying out my invention I have used various means for securing this result. For example, when I induce a current in one of the circuits from the current flowing in the other, I employ a form of converter or bring the two circuits into such inductive relations as will produce the necessary difference of phase. Or, when I obtain the two energizing currents by derivation, I make the two circuits of different degrees of self induction by inserting a resistance or a self induction coil in one of said circuits, or I combine these devices in different ways as I shall more specifically describe hereinafter.

The accompanying drawings to which I now refer in further illustration of my invention, are a series of diagrams illustrating, not the specific construction of the particular devices which I may or may not have used, but rather, the electrical connections and relations to be adopted in carrying out the present system by means of devices which are now well known.

Figure 1 is a diagram illustrating the method of operating the motors by inducing one of the energizing currents by the other. Fig. 2 is a similar diagram of the method of operating the motors where the two energizing currents are obtained by derivation from a single source. Fig. 3 is a modified application of this principle.

Referring to Fig. 1 let A represent the source of alternating currents which are to be utilized in operating the motor or motors. It will be understood that considered as a source of current it may be either a primary or secondary generator.

B B designate the conductors of the circuit which convey the alternating currents to one or more motors. The motor has two energizing circuits or sets of coils C D. One of these circuits as C is connected directly with the circuit B. The other set of coils as D, is connected up in the secondary circuit of an electrical transformer or induction coil T. The primary coil P of this transformer, is included in the circuit B. The alternations of current in the circuit B tend to establish in their passage through the coils C, a polarity at right angles to that set up by the coils D, and if the currents in the two sets of coils accorded in their phases, no rotary effect would be produced. But the secondary current developed in the coil P' of the transformer, will lag behind that in the primary which lag or retardation may be increased as I have shown in another application, to a sufficient extent to practically obtain the same result as though two independent alternating currents were used to energize the motor.

In Fig. 2 the two energising circuits of the motor are shown connected in multiple arc to the circuit B B, and in one of these circuits is a resistance R. Assuming the two motor circuits to have the same self induction and resistance no rotary effect will be produced by the passage through them of an alternating current from the source A. But if one of the motor circuits, as C, be varied or modified by the introduction of a dead resistance R, the self-induction of that circuit or branch is reduced, and the phases of current therein retarded to a correspondingly less extent. The relative degrees of retardation of the phases of the current. In the two motor circuits with respect to those of the unretarded current in the circuit B thus produced, will set up a rotation of the motor which may be practically utilized for many purposes.

In Fig. 3, the arrangement of the parts is similar to that shown in Fig. 2, except that a self-induction coil as S is introduced into one branch or energizing circuit of the motor. The effect of thus increasing the self-induction in one of the circuits is to retard the phases of the current passing therein to a greater extent than in the other circuit, and in this way to secure the necessary difference in phase between the two energizing currents to produce the rotation of the motor.

In an application filed, of even date herewith, I have shown and described other ways of accomplishing this result, among which may be noted the introduction of a resistance capable of variation in each motor circuit, or the use of a resistance in one circuit and a self-induction coil in the other.

In the above description I have referred mainly to motors with two energizing circuits, but it is evident that the invention applies equally to those in which there are more than two of such circuits, the adaptation of the same being a matter well understood by those skilled in the art.

I do not claim in this application the specific devices employed by me in carrying out the invention, having made these the subjects of other applications.

What I claim herein is—

1. The method of operating motors having independent energizing circuits, as herein set forth, which consists in passing alternating currents through both of the said circuits and retarding the phases of the current in one circuit to a greater or less extent than in the other.

2. The method of operating motors having independent energizing circuits, as herein set forth, which consists in directing an alternating current from a single source through both circuits of the motor and varying or modifying the relative resistance or self-induction of the motor circuits and thereby producing in the currents differences of phase, as set forth.

NIKOLA TESLA.

Witnesses:

FRANK E. HARTLEY,

FRANK B. MURPHY.

(No Model.)

N. TESLA.
ELECTRICAL TRANSMISSION OF POWER.

No. 611,559. Patented Dec. 26, 1893.

Fig. 1

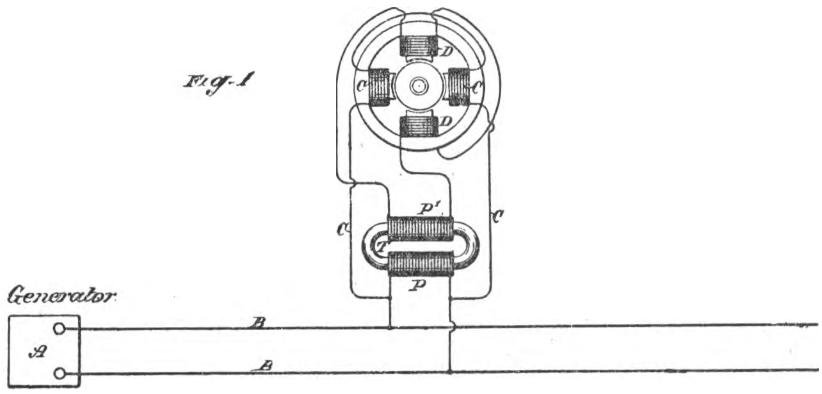


Fig. 2

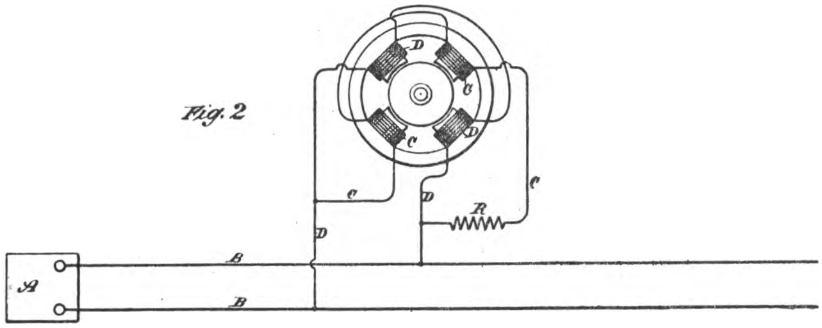
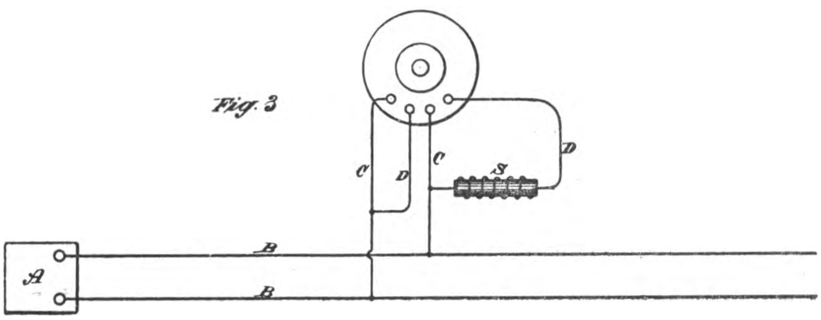


Fig. 3



WITNESSES:
Raphaël Netter
Ernest Hopkinson

INVENTOR
Nikola Tesla
BY
Duncan, Curtis & Page
ATTORNEYS.

UNITED STATES PATENT OFFICE.

NIKOLA TESLA. OF NEW YORK, N Y., ASSIGNOR TO THE TESLA ELECTRIC COMPANY, OF SAME PLACE

SYSTEM OF ELECTRICAL POWER TRANSMISSION.

SPECIFICATION forming part of Letters Patent No. 511,560, dated December 26. 1893.

Application filed December 8, 1888. Serial No. 293,052. (No model.)

To all whom it may concern:

Be it known that I, NIKOLA TESLA, a subject of the Emperor of Austria-Hungary, from Smiljan, Lika, border country of Austria-Hungary, residing at New York, in the county and State of New York, have invented certain new and useful Improvements in Systems of Electrical Power Transmission, of which the following is a specification, reference being had to the drawings accompanying and forming a part of the same.

In certain patents heretofore granted, I have shown and described a system of electrical power transmission in which each motor contained two or more independent energizing circuits through which were caused to pass alternating currents having in each circuit such difference of phase that by their combined or resultant action they produced a rotary progression of the poles or points of maximum magnetic effect of the motor and thereby maintained the rotation of its movable element. In the system referred to and described in the said patents the production or generation of the alternating currents, upon the combined or resultant effect of which the operation of the system depends, is effected by the employment of an alternating current generator with independent induced circuits which, by reason of the winding or other construction of the generator, produces currents differing in phase, and these currents are conveyed directly from the generator to the corresponding motor coils by independent lines or circuits. I have, however, discovered that I may produce the same or a similar result by an alternating current from a single original source using between the generator and motors but one line or transmission circuit. Broadly stated, this system or method involves a source of alternating or equivalent currents, a single transmission circuit, a motor having independent energizing circuits connected with or adapted for connection with the transmission circuit, means for rendering the magnetic effects due to the energizing circuits of different phase, and an armature within the influence of the energizing circuits; the means for accomplishing this result being of such a nature as to retard the current in one energizing circuit to a greater or less extent than in the other. The distribution of the main or original current through the two motor circuits may be effected by induction or by derivation. In other words, I may pass the alternating current from the source through one energizing circuit, and induce by such current a second current in the other energizing circuit. Or, on the other hand, I may connect up the two energizing circuits of the motor in derivation or multiple arc with the main circuit from the source. In either event I make due provision for maintaining a difference of phase between the currents in the two circuits or branches.

In an application filed by me May 15, 1888, Serial No. 273,993, I have shown and described the means which I have employed for securing this result by inducing one energizing current from the other.

My present application relates to the means employed when the two energizing currents are obtained from a single original source by derivation.

In explanation of what appears to be the principle of the operation of my invention and of the functions of the several instrumentalities comprised thereby, let it be assumed that the two energizing circuits of an alternating current motor, such, for example, as I have described in my Patent No. 382,280, dated May 1, 1888, are connected up in derivation or multiple arc with the conductors of a circuit including an alternating current generator. It is obvious that if both circuits are alike and offer the same resistance to the passage of the current no rotary effect will be produced, for although the periods of the currents in both circuits will lag or be retarded to a certain extent with respect to an unretarded current from the main circuit, their phases will coincide. If, however, the coils of one circuit have a greater number of convolutions around the cores, or a self induction coil be included in one of the circuits, the phases of the current in that circuit are retarded by the increased self induction. The degree of retardation may readily be secured by these means which will produce the difference in electrical phase between the two currents necessary for the practical operation of the motor. If in lieu of increasing the self induction of one circuit a dead resistance be inserted, the self induction of such circuit exerts a correspondingly diminished effect, and the phases of the current flowing in that branch are brought more nearly in unison with those of an unretarded current from the main line and the necessary difference of phase between the currents in the two energizing circuits thus secured. I take advantage of these results in several ways. For example, I may insert variable resistances in both branches or energizing circuits and by varying one or the other so as to bring the phases of the two currents more or less in unison with those of the unretarded current, I may thus vary the direction of the rotation of the motor. In lieu of resistances I may employ variable self induction coils, in both circuits. Or I may use a resistance in one and a self induction coil in the other and vary either or both. This system or means of operating the motors is rendered of great practical value by employing an armature wound with energizing coils closed upon themselves, in which currents are induced by the alternating currents passing in the field coils that serve to greatly increase the mutual attractive effect between the armature and the field magnets. This use of the armature with closed coils I regard as an important feature of my invention. These several features of the invention I shall now describe more in detail by reference to the accompanying drawings.

Figure 1 is a diagram of the system in which the motor coils or energizing circuits are in derivation to the main line with a dead resistance inserted in one circuit. Fig. 2 is a diagram showing dead resistances in both motor circuits. Fig. 3 is a diagram showing a self induction coil in one motor circuit. Fig. 4 is a diagram showing a dead resistance in one circuit and a self induction coil in the other. Fig. 5 in like manner shows a self induction coil in each motor circuit. Fig. 6 is a diagram showing the two motor circuits of different electrical character. Fig. 7 is a diagram illustrating means, for varying at will the electrical character of the motor circuits.

Referring to Fig. 1, A designates a suitable source of alternating currents and B B the line wires running therefrom. It will be understood that the generator A may be a primary or secondary generator, and the line B B may be the main transmission circuit or a local circuit from a transformer connected at any point in the line of a main or transmission circuit. For convenience in this case, it will be considered as a line from a given source of current to one or more motors. The motor contains a given number of pole pieces wound with two sets of coils C and D. The armature is wound with permanently closed energizing coils E in which currents are developed by inductive action when the motor is in operation which magnetize the armature core and greatly increase the efficiency of the motor. Assuming the two motor circuits to have the same degree of self induction and resistance no rotary effect will be produced by the passage through them of an alternating current from the source A. But if in one of the motor circuits, as D, a dead resistance represented by R be introduced, the self induction of that circuit or branch is reduced and the phases of current therein retarded to a correspondingly less extent. The relative degrees of retardation of the phases of the current in the two motor circuits with respect to those of an unretarded current from the circuit B thus produced will set up a rotation of the motor which may be practically utilized for many purposes.

If, as in Fig. 2, a dead resistance R, R' be introduced into each motor circuit, no rotary effect will be produced as long as the resistances are equal, but by varying the resistance in one circuit the retardation of the current in that circuit will be varied, and corresponding effects produced. For example, a reduction of the resistance in one circuit imparts to the motor rotation in one direction while a reduction of the resistance in the other circuit will produce a rotation in the opposite direction. By means of the two resistances, therefore, capable of variation or of being bodily withdrawn from or inserted in the circuits by any well known means, a perfect regulation of the motors is secured.

In Fig. 3 the arrangement of all the parts is similar to that shown in Fig. 1 except that a self induction coil as S is introduced into one branch or energizing circuit of the motor. The effect of thus increasing the self induction in one of the circuits is to retard the phases of the current passing therein to a greater extent than in the other circuit and in this way to secure the necessary difference in phase between the two energizing currents to produce the rotation of the motor.

In Fig. 4 a self induction coil S is included in one of the motor circuits and a dead resistance R in the other. The increased self induction in one circuit thus produced acts to increase the difference of phase between the current in such motor circuit and the unretarded current in the main line B. On the other hand, the introduction of the dead resistance in the other motor circuit reduces the retardation and brings the phases of the current therein more closely in accord with those of the unretarded current, thus producing a correspondingly greater difference of phase between the two currents in the energizing circuits C and D.

In Fig. 5, two self induction coils S, S' are shown, one in each motor or energizing circuit. One of these coils as S' is much smaller than the other and has less self induction or counter electro motive force than the other, so that the phases of current will be retarded to a less extent than in the other. The two self induction coils may be of the same character or size if it is desired to use but one at a time for the purpose of reversing the motor, or if they be constructed in well known ways so that they may be varied.

In Fig. 7 the usual means for varying the resistance or self-induction of the motor circuits at will are indicated by the lever M sliding over a series of resistance plates, and by a core N which is adapted to be moved in and out of the induction coil S.

Similar results may be secured by such a construction or organization of the motor as will yield the necessary differences of phase. For example, one set of energizing coils may be of finer wire than the other, or have a greater number of convolutions, or each circuit may contain the same number of convolutions, but composed of different conductors, as, for instance, one of copper, the other of German silver. I have represented this in Fig. 6, in which the coils C are indicated by closer lines than coils D.

There are other ways of varying the retardation due to the self induction in the two energizing circuits. For example, the motor coils may be all alike, but those of one energizing circuit connected in parallel while the others are connected in series, or the connection in each energizing circuit may be alike, but the currents directed through them may be of different strength, as when one of the currents is supplied from a source of higher electro-motive force.

In the above description I have referred mainly to motors with two energizing circuits, but it is evident that the invention applies equally to those in which there are more than two of such circuits, the adaptation of the same being a matter well understood by those skilled in the art.

In using in the claims the term active resistance as applied to the motor circuits in this case, it will be understood that the term refers to the opposing or retarding force existing in the circuits to the passage of the alternating currents. Thus, the two circuits may have the same dead resistance, but different degrees of self induction.

What I claim as my invention is—

1. The combination with a source of alternating currents, and a circuit from the same, of a motor having independent energizing circuits connected with the said circuit, and means for rendering the magnetic effects due to said energizing circuits of different phase and an armature within the influence of said energizing circuits.

2. The combination with a source of alternating currents and a circuit from the same, of a motor having independent energizing circuits connected in derivation or multiple arc with the said circuit, the motor or energizing circuits being of different electrical character whereby the alternating currents therein will have a difference of phase, as set forth.

3. The combination with a source of alternating currents and a circuit from the same, of a motor having independent energizing circuits connected in derivation or multiple arc with the said circuit and of different active resistance, as set forth.

4. In an alternating current motor, the combination with field magnets, of independent energizing circuits, adapted to be connected in multiple arc with the conductors of the line or transmission circuit and a resistance or self induction coil in one or both of the said motor circuits, as set forth.

5. In an alternating current motor, the combination with the field magnets or cores of independent energizing coils adapted to be connected in multiple arc with the line or transmission circuit, and a variable resistance or self induction coil included in one or both of the motor circuits as set forth.

6. In an alternating current motor, the combination with the field magnets or cores and independent energizing circuits of different active resistance and adapted to be connected with the line or transmission circuit, of an armature wound with closed energizing coils or conductors, as set forth.

7. The combination of a generator of alternating currents, a pair of mains connected thereto, a multiple circuit differential phase, and an electric motor having one circuit connected directly to said mains, and the other circuit connected to said mains through an interposed electro-motive phase-changing device adapted to change the time period of the currents passing through it.

NIKOLA TESLA.

Witnesses:
FRANK E. HARTLEY,
FRANK B. MURPHY.

Correction in Letters Patent No. 511.560

It is hereby certified that in Letters Patent No. 511,560, granted December 26, 1893, upon the application of Nikola Tesla, of New York, N. Y., for an improvement in "Systems of Electrical Power Transmission," an error appears in the printed specification requiring correction, as follows: In line 95, page 3, the words "and an" should be stricken out; and that the said Letters Patent should be read with this correction therein that the same may conform to the record of the case in the Patent Office.

Signed and sealed this 9th day of June, A. D., 1903.

[SEAL.]

F. I. ALLEN,
Commissioner of Patents.

(No Model.)

3 Sheets—Sheet 1

N. TESLA.

SYSTEM OF ELECTRICAL POWER TRANSMISSION.

No. 511,560.

Patented Dec. 26, 1893.

Fig. 1

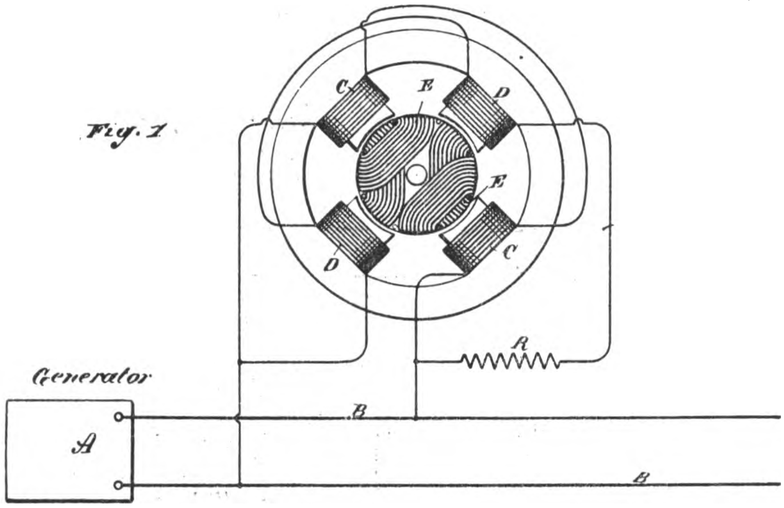
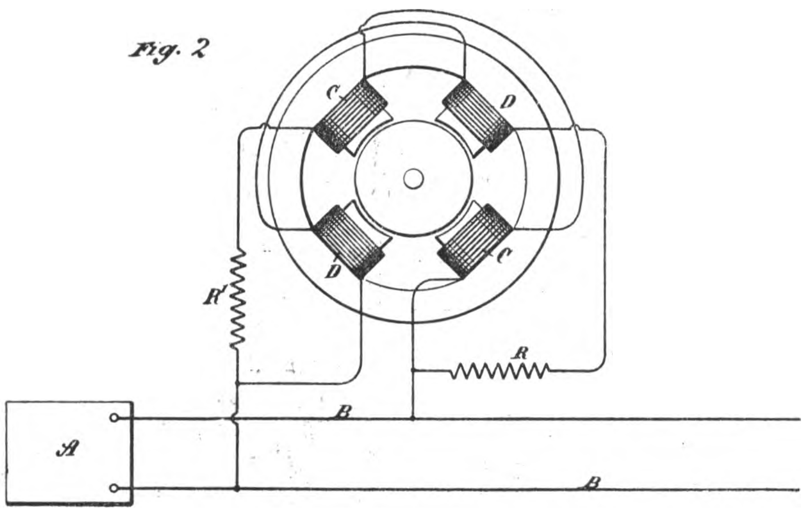


Fig. 2



WITNESSES:

Raphaël Netter

Ernest Hopkinson

INVENTOR

Nikola Tesla

BY

Duncan, Curtis & Page,

ATTORNEYS.

P-188

(No Model.)

3 Sheets—Sheet 2.

N. TESLA.

SYSTEM OF ELECTRICAL POWER TRANSMISSION.

No. 511,560. Patented Dec. 26, 1893.

Fig. 3

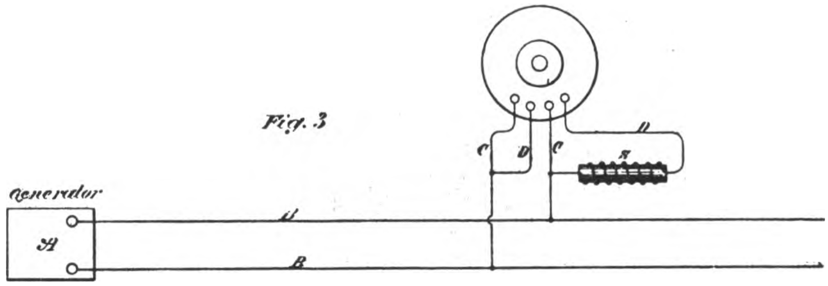


Fig. 4

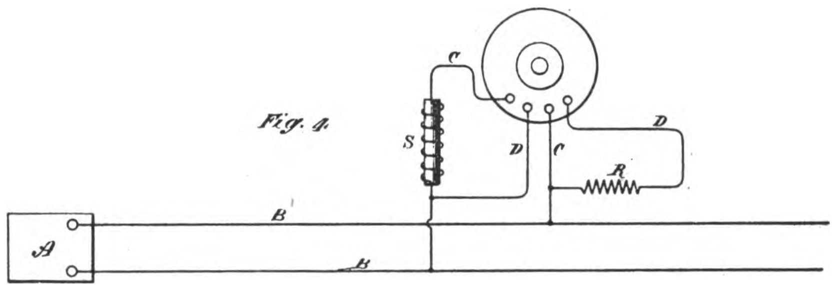


Fig. 5

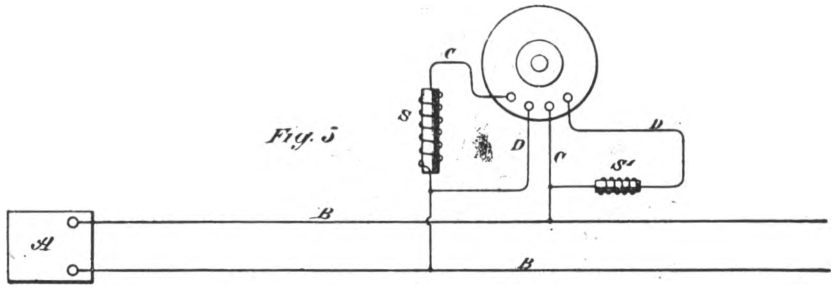
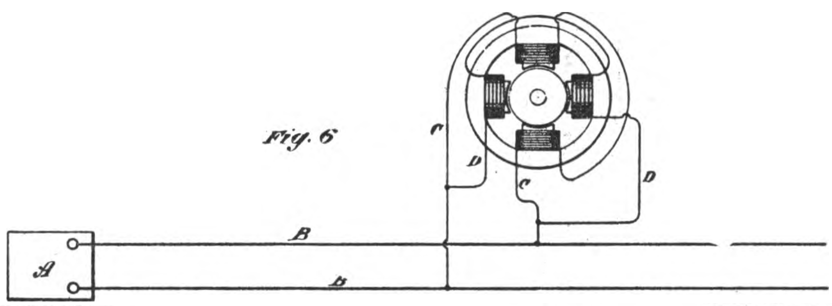


Fig. 6



WITNESSES:

Raphaël Netter

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(No Model.) 3 Sheets—Sheet 3

N. TESLA

SYSTEM OF ELECTRICAL POWER TRANSMISSION.

No. 511,560 Patented Dec. 26, 1893.

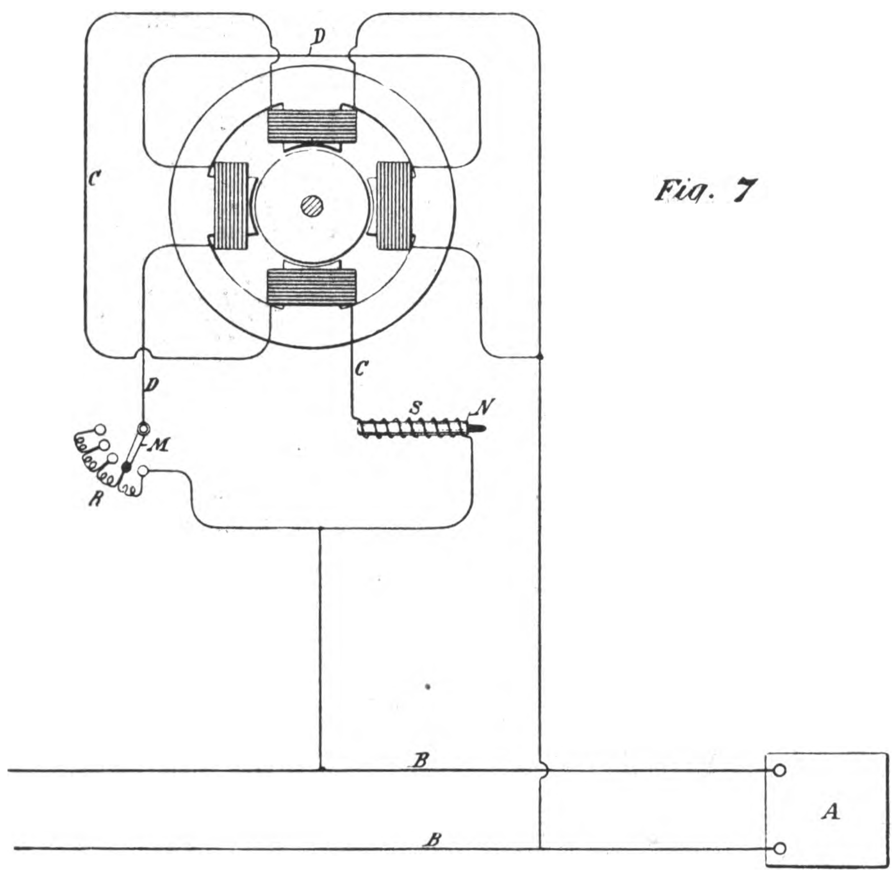


Fig. 7

WITNESSES

Raphael Netter

James N. Catlow

INVENTOR

Nikola Tesla

BY

Duncan & Page

ATTORNEYS

UNITED STATES PATENT OFFICE.

NIKOLA TESLA, OF NEW YORK, N. Y., ASSIGNOR TO THE TESLA ELECTRIC COMPANY, OF SAME PLACE

METHOD OF ELECTRICAL POWER TRANSMISSION.

SPECIFICATION forming part of Letters Patent No. 405,859, dated June 26, 1889.

Application filed March 14, 1889. Serial No. 303,251 (No model.)

To all whom it may concern:

Be it known that I, NIKOLA TESLA, a subject of the Emperor of Austria, from Smiljan, Lika, border country of Austria-Hungary, residing at New York, in the county and State of New York, have invented certain new and useful Improvements in Methods of Electrical Power Transmission, of which the following is a specification, reference being had to the drawing accompanying and forming a part of the same.

This application is for a specific method of transmitting power electrically, shown and described in, and covered broadly by the claims of, an application filed by me February 18, 1880, No 300,220.

As is well known, certain forms of alternating-current machines have the property, when connected in circuit with an alternating-current generator, of running as a motor in synchronism therewith; but, while the alternating current will run the motor after it has attained a rate of speed synchronous with that of the generator, it will not start it; hence, in all instances heretofore where these "synchronizing motors", as they are termed, have been run, some means have been employed to bring the motors up to synchronism with the generator, or approximately so, before the alternating current of the generator is applied to drive them. In some instances mechanical appliances have been utilized for this purpose. In others special and complicated forms of motor have been constructed.

My present invention is an improvement in methods of operating these motors and involves a new and improved plan of bringing the motor up to the proper rate of speed, that it may be run in synchronism with the generator.

The expression "synchronism with the generator" is used herein in its ordinary acceptation—that is to say, a motor is said to synchronize with the generator when it preserves a certain relative speed determined by its number of poles and the number of alternations produced per revolution of the generator. Its actual speed, therefore, may be faster or slower than that of the generator, but it is said to be synchronous so long as it preserves the same relative speed.

In carrying out my present invention I construct a generator with two coils or sets of coils and a motor with corresponding energizing coils or sets of coils. By means of two line-wires one terminal of each generator-coil or set of coils is connected to one terminal of its corresponding motor-coil or set of coils, while the opposite terminals of the generator-coils are joined together and likewise those of the motor.

To start the motor I establish temporarily an electrical connection between the points of connection between, the coils in the generator and those in the motor, so that the system becomes an ordinary double-circuit system identical with that described in my patent, No. 390,413, of October 2, 1888, except that the generator and motor are constructed in any well-known way with a strong tendency to synchronize. When by this plan of connection the motor has attained the desired speed, the earth-connection is severed, by which means the system becomes an ordinary single-circuit synchronizing system

In the drawing I have illustrated this method by a diagram.

Let G represent an ordinary alternating-current generator having four field-poles A, permanently or artificially magnetized, and an armature wound with two coils C connected together in, series.

Let M represent an alternating-current motor with, say, four poles D, the coils on which are connected in pairs and the pairs connected in series. The motor-armature should have polar projections and closed coils E.

From the common joint or union between the two coils or sets of coils of both the generator and motor an earth-connection F is established, while the terminals or ends of the said coils or circuits which they form are connected to the line-conductors H H.

Assuming that the motor is a synchronizing motor, or one that has the capability of running in synchronism with the generator, but not of starting, it may be started by the above described plan by closing the ground connection from both generator and motor. The system thus becomes one with a two-circuit generator and motor, the ground forming a common return for the currents in the two wires H H. When by this arrangement of circuits the motor is brought to speed, the ground-connection is broken between the generator or motor or both and ground, switches K K being employed for this purpose. The motor then runs as a synchronizing motor.

This system is capable of various useful applications which it is not necessary to describe in detail; but it will be enough to say that the convertibility of the system from double circuit to single circuit is a feature in itself of great value and utility.

I do not wish to be understood as confining myself to the precise arrangement or order of connections herein set forth, as these may be obviously varied in many respects.

What I claim is—

1. The method of operating synchronizing motors herein described, which consists in electrically connecting intermediate points of the inducing-circuit of the generator and the energizing-circuit of the motor until the motor has reached a desired speed and then interrupting such connection, as set forth.

2. The method herein described of starting or operating synchronizing motors, which consists in electrically connecting intermediate points of the inducing-circuit of the generator and the energizing-circuit of the motor to earth until the motor has reached the desired speed and then interrupting either or both of the ground-connections, as set forth.

NIKOLA TESLA.

Witnesses:

EDWARD T. EVANS,

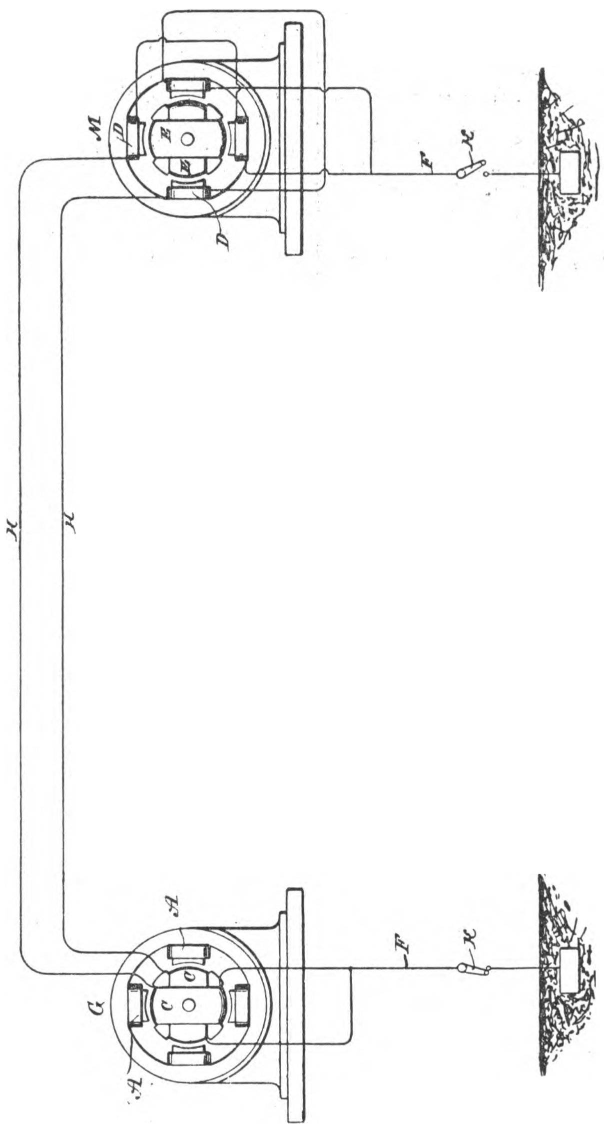
E. C. UPSTILL

P-192

(No Model.)

N. TESLA.
METHOD OF ELECTRICAL POWER TRANSMISSION.

No. 405,859. Patented June 25, 1889.



Witnesses:
Raphael Netter
Robt. F. Gaylord

Inventor
Nikola Tesla
By
Duncan, Curtis & Page
Attorneys.

III
LIGHTING

UNITED STATES PATENT OFFICE.

NIKOLA TESLA, OF SMILJAN LIKA, AUSTRIA-HUNGARY, ASSIGNOR TO THE TESLA ELECTRIC LIGHT AND MANUFACTURING COMPANY, OF RAHWAY, NEW JERSEY.

ELECTRIC-ARC LAMP.

SPECIFICATION forming part of Letters Patent No. 335,786, dated February 9, 1885.

Application filed March 30, 1885. Serial No. 160,574. (No model.)

To all whom it may concern:

Be it known that I, NIKOLA TESLA, of Smiljan Lika, border country of Austria-Hungary, have invented certain new and useful Improvements in Electric-Arc Lamps, of which the following is a specification.

My invention relates more particularly to those arc lamps in which the separation and feed of the carbon electrodes or their equivalents is accomplished by means of electro-magnets or solenoids in connection with suitable clutch-mechanism; and it is designed to remedy certain faults common to the greater part of the lamps heretofore made.

The objects of my invention are to prevent the frequent vibrations of the movable electrode and flickering of the light arising therefrom, to prevent the falling into contact of the electrodes, to dispense with the dash-pot, clock-work, or gearing and similar devices heretofore used, and to render the lamp extremely sensitive, and to feed the carbon almost imperceptibly, and thereby obtain a very steady and uniform light.

In that class of lamps where the regulation of the arc is effected by forces acting in opposition on a free movable rod or lever directly connected with the electrode, all or some of the forces being dependent on the strength of the current, any change in the electrical condition of the circuit causes a vibration and a corresponding flicker in the light. This difficulty is most apparent when there are only a few lamps in circuit. To lessen this difficulty; lamps have been constructed in which the lever or armature, after the establishing of the arc, is kept in a fixed position and cannot vibrate during the feed operation, the feed mechanism acting independently; but in these lamps, when a clamp is employed, it frequently occurs that the carbons come into contact and the light is momentarily extinguished, and, frequently, parts of the circuit are injured. In both these classes of lamps it has been customary to use dash-pot, clock-work, or equivalent retarding devices; but these are generally unreliable and objectionable, and increase the cost of construction.

My invention is intended to effect the desired objects and to remedy the before-mentioned defects. I combine two electro-magnets—one of low resistance in the main or lamp circuit, and the other of comparatively high resistance in a shunt around the arc—a movable armature-lever, and a novel feed mechanism, the parts being arranged so that in the normal working position of the armature-lever the same is kept almost rigidly in one position, and is not effected even by considerable changes in the electric circuit; but if the carbons fall into contact the armature will be actuated by the magnets so as to move the lever and start the arc, and hold the carbons until the arc lengthens and the armature-lever returns to the normal position. After this the carbon-rod holder is released by the action of the feed mechanism, so as to feed the carbon and restore the arc to its normal length.

My invention consists, mainly, in the particular manner in which the armature is combined with the magnets and acted upon by them and in the feed-controlling mechanism.

In the drawings, Figure 1 is an elevation of the mechanism made use of in the electric lamp. Fig. 2 is a plan view of the same below the line *x x*. Fig. 3 is an elevation of the balancing lever and spring, and Fig. 4 is a detached plan view of the pole-pieces and armatures upon the friction-clamp, and Fig. 5 is a section of the clamping-tube.

M is a helix of coarse wire in a circuit from the lower-carbon holder to the negative binding-screw –.

N is a helix of fine wire in a shunt between the positive binding-screw + and the negative binding-screw –. The upper-carbon holder S is a parallel rod sliding through the plates S' S' of the frame of the lamp, and hence the electric current passes from the positive binding post + through the plate S^2, carbon-holder S, and upper carbon to the lower carbon, and thence by the holder and a metallic connection to the helix M.

The carbon holders are of any desired character, and to insure electric connections the springs *l* are made use of to grasp the upper-carbon holding rod S, but to allow the rod to slide freely through the same. These springs *l* may be adjusted in their pressure by the screw *m,* and the spring *l* may be sustained upon any suitable support. I have shown them as connected with the upper end of the core of the magnet N.

Around the carbon-holding rod S, between the plates S' S', there is a tube, R, which forms a clamp. This tube is counterbored, as seen in the section Fig. 5, so that it bears upon the rod S at its upper end and near the middle, and at the lower end of this tubular clamp K there are armature-segments *r* of soft iron. A frame or arm, *n,* extending, preferably, from the core N^2, supports the lever A by a fulcrum pin, *o.* This lever A has a hole, through which the upper end of the tubular clamp R passes freely, and from the lever A is a link, *q,* to the lever *t,* which lever is pivoted at *y* to a ring upon one of the columns S^3. This lever *t* has an opening or bow surrounding the tubular clamp R, and there are pins or pivotal connections *w* between the lever *t* and this clamp R, and a spring, r^2, serves to support or suspend the weight of the parts and balance the same, or nearly so. This spring is preferably adjustable.

At one end of the lever A is a soft iron armature block, *a,* over the core M' of the helix M, and there is preferably a limiting screw, *c*, passing through this armature block a, and at the other end of the lever A is a soft-iron armature block, *b*, with the end tapering or wedge-shaped, and the same comes close to and in line with the lateral projection *e* on the core N^2. The lower ends of the cores M' N' are made with lateral projecting pole-pieces M^3 N^3, respectively, and these pole pieces are concave at their outer ends, and are at opposite sides of the armature segments *r* at the lower end of the tubular clamp R.

The operation of these devices is as follows: In the condition of inaction the upper carbon rests upon the lower one, and when the current is turned on the electricity passes freely, by the frame and spring *l*, through the rod S and carbons to the coarse wire and helix M, and to the negative binding post V, and the core M' thereby is energized. The pole piece M^3 attracts the armature *r*, and by the lateral pressure causes the clamp R to grasp the rod S', and the lever A is simultaneously moved from the position shown by dotted lines, Fig. 1, to the normal position shown in full lines, and in so doing the link *q* and lever *t* are raised, lifting the clamp R and rod S, separating the carbons and forming the arc. The magnetism of the pole piece *e* tends to hold the lever A level, or nearly so, the core N^2 being energized by the current in the shunt which contains the helix N. In this position the lever A is not moved by ordinary variation in the electric current because the armature *b* is strongly attracted by the magnetism of *e*, and these parts are close to each other, and the magnetism of *e* acts at right angles to the magnetism of the core M'. If, now, the arc becomes too long, the current through the helix M is lessened, and the magnetism of the core N^3 is increased by the greater current passing through the shunt, and this core N^3 attracting the segmental armature *r* lessens the hold of the clamp R upon the rod S, allowing the latter to slide and lessen the length of the arc, which instantly restores the magnetic equilibrium and causes the clamp R to hold the rod S. If it happens that the carbons fall into contact, then the magnetism of N^2 is lessened so much that the attraction of the magnet M will be sufficient to move the armature *a* and lever A so that the armature *b* passes above the normal position, so as to separate the carbons instantly; but when the carbons burn away a greater amount of current will pass through the shunt until the attraction of the core N^2 will overcome the attraction of the core M' and bring the armature-lever A again into the normal horizontal position, and this occurs before the feed can take place. The segmental armature pieces *r* are shown as nearly semicircular. They may be square or of any other desired shape, the ends of the pole-pieces M^3 N^3 being made to correspond in shape.

I claim as my invention—

1. The combination, in an electric-arc lamp, of the electro-magnets in the main and shunt circuits, respectively, an armature-lever and connection to the movable carbon holder, the core of the shunt magnet passing across the end of the armature lever, substantially as set forth, so that the two magnets act in conjunction on the armature lever in moving the carbon to form the arc and in opposition to each other beyond the normal position of the armature-lever, substantially as specified.

2. The combination, with the carbon-holders, of two magnets, one in the main circuit and the other in a shunt circuit, and an armature lever to draw the arc, and a feeding mechanism and pole pieces upon the electro-magnets to act upon the feeding mechanism substantially as specified.

3. The combination, with the carbon holders, of two magnets, one in the main circuit and the other in a shunt-circuit, and an armature-lever between two poles of such electro-magnets to draw the arc, and a feeding mechanism and pole pieces upon the other two poles of the electro-magnets to act upon the feeding mechanism, substantially as specified.

4. The combination, with the carbon holding rod in an electric arc lamp, of the clamp R, lever *t,* spring r^2, armature-lever A, and electro-magnets M N in the main and shunt circuits, respectively, the pole pieces M^3 N^3, and armature segments r, substantially as set forth.

5. The combination, with the carbon holder, of a tubular clamp surrounding the same, an armature-lever connected to said tubular clamp, and electro magnets in the main and shunt circuits, respectively, and armature seg-

ments upon the tubular clamp adjacent to the lateral poles of the electro-magnets, substantially as set forth.

6. In an electric-arc lamp, the combination, with the carbon-holding rod, of a clamp, two armatures upon the clamp, and electro-magnets in the main and shunt circuits, respectively, the poles of which act upon the armatures of the clamp for bringing the same into action or releasing it, substantially as set forth.

Signed by me this 25th day of March, A. D. 1885.

NIKOLA TESLA.

Witnesses:
GEO. T. PINCKNEY,
CHAS. H. SMITH.

P-198

(No Model.) 2 Sheets—Sheet 1.

N. TESLA.
ELECTRIC ARC LAMP.

No. 335,786. Patented Feb. 9, 1886.

Fig. 1.

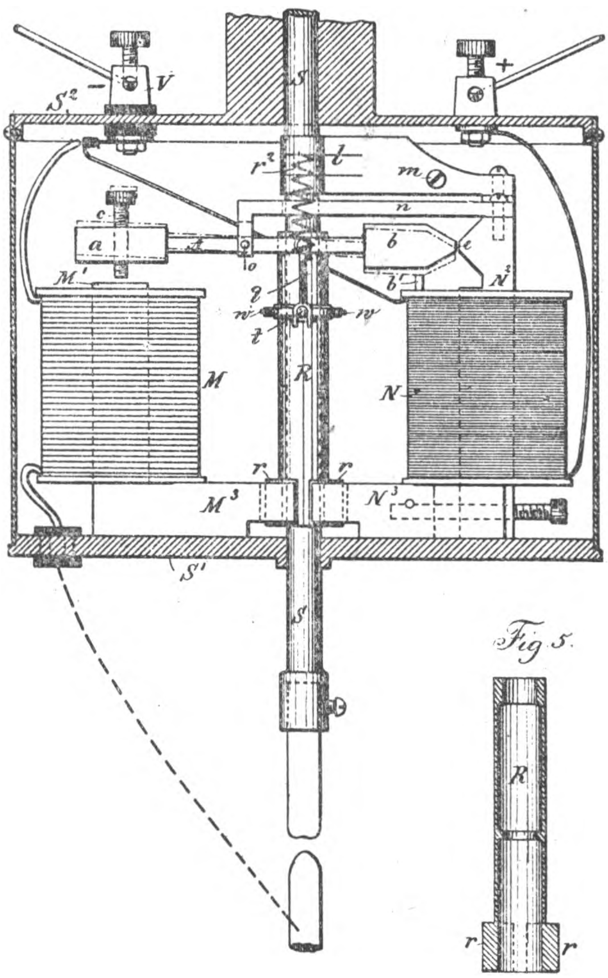
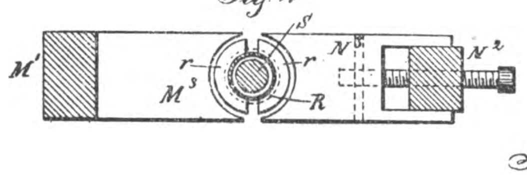


Fig. 5.

Fig. 4



Witnesses:
I. Staib
Chas. H. Smith

Inventor
Nikola Tesla
per: Lemuel W. Serrell
atty

P-199

(No Model.) 2 Sheets—Sheet 2.

N. TESLA.

ELECTRIC ARC LAMP.

No. 335,786. Patented Feb. 9. 1886.

Fig. 2

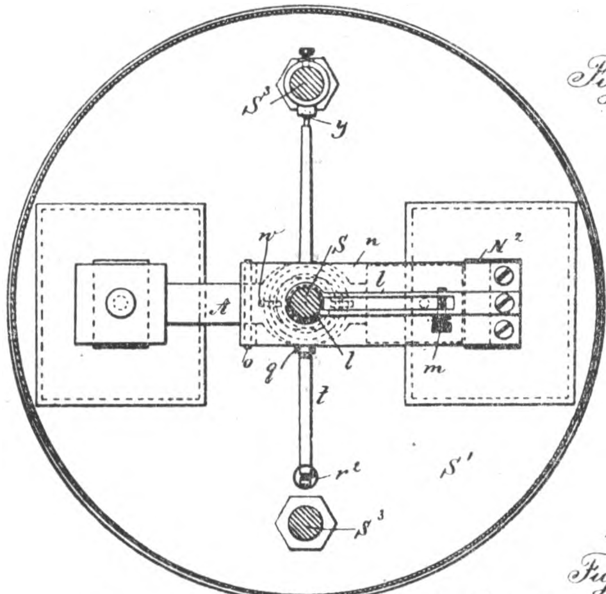
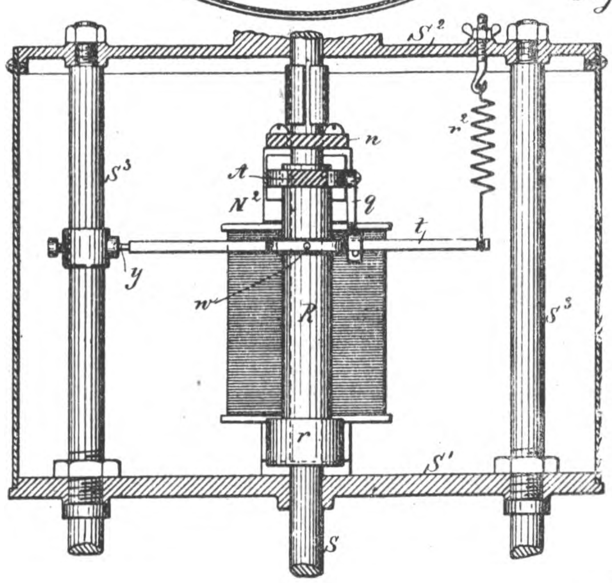


Fig. 3



Witnesses
J Staub
Chs H. Smith

Inventor
Nikola Tesla
per Lemuel W. Serrell atty

UNITED STATES PATENT OFFICE.

NIKOLA TESLA, OF SMILJAN LIKA, AUSTRIA-HUNGARY, ASSIGNOR TO THE TESLA ELECTRIC LIGHT AND MANUFACTURING COMPANY, OF RAHWAY, NEW JERSEY.

ELECTRIC-ARC LAMP.

SPECIFICATION forming part of Letters Patent No. 335,787, dated February 9, 1886.

Application filed July 13, 1885. Serial No. 171,416. (No model.)

To all whom it may concern:

Be it known that I, NIKOLA TESLA, of Smiljan Lika, border country of Austria-Hungary, have invented certain Improvements in Electric-Arc Lamps, of which the following is a specification.

In another application, No. 160,574, filed by me March 30, 1885, I have shown and described a lamp having two magnets, in the main and shunt circuits, respectively, an armature-lever, and feed mechanism connected to the armature-lever.

My present invention consists in some modifications of and improvements upon the devices shown in the application referred to.

In my present invention I further provide means for automatically withdrawing a lamp from the circuit, or cutting out the same, when, from a failure of the feed, the arc reaches an abnormal length, and also means for automatically reinserting such lamp in the circuit when the rod drops and the carbons come into contact.

My invention will be understood with reference to the accompanying drawings.

In the drawings, Figure 1 is an elevation of the lamp with the case in section. Fig. 2 is a sectional plan at the line *x x*. Fig. 3 is an elevation, partly in section, of the lamp at right angles to Fig. 1. Fig. 4 is a sectional plan at the line *y y* of Fig. 1. Fig. 5 is a section of the clamp in about full size. Fig. 6 is a detached section illustrating the connection of the spring to the lever that carries the pivots of the clamp, and Fig. 7 is a diagram showing the circuit-connections of the lamp.

In the drawings, Fig. 1, M represents the main and N the shunt magnet, both securely fastened to the base A, which, with its side columns, S S, is preferably cast in one piece of brass or other diamagnetic material. To the magnets are soldered or otherwise fastened the brass washers or disks *a a a a*. Similar washers, *b b*, of fiber or other insulating material, serve to insulate the wires from the brass washers.

The magnets M and N are made very flat, so that their width exceeds three times their thickness, or even more. In this way a comparatively small number of convolutions is sufficient to produce the required magnetism, besides a greater surface is offered for cooling off the wires.

The upper pole-pieces, *m n*, of the magnets are curved, as indicated in the drawings, Fig. 1. The lower pole-pieces, *m′ n′*, are brought near together, tapering toward the armature *g*, as shown in Figs. 2 and 4. The object of this taper is to concentrate the greatest amount of the developed magnetism upon the armature, and also to allow the pull to be exerted always upon the middle of the armature *g*. This armature *g* is a piece of iron in the shape of a hollow cylinder, having on each side a segment cut away, the width of which is equal to the width of the pole-pieces *m′ n′*.

The armature is soldered or otherwise fastened to the clamp *r*, which is formed of a brass tube, provided with gripping-jaws *e e*, Fig. 5. These jaws are arcs of a circle of the diameter of the rod R, and are made of some hard metal, preferably of hardened German silver. I also make the guides *f f*, through which the carbon-holding rod R slides, of the same material. This has the advantage to reduce greatly the wear and corrosion of the parts coming in frictional contact with the rod, which frequently causes trouble. The jaws *e e* are fastened to the inside of the tube *r*, so that one is a little lower than the other. The object of this is to provide a greater opening for the passage of the rod when the same is released by the clamp. The clamp *r* is supported on bearings *w w*, Figs. 1, 3 and 5, which are just in the middle between the jaws *e e*. I find this disposition to be the best. The bearings *w w* are carried by a lever, *t*, one end of which rests upon an adjustable support, *q*, of the side columns, S, the other end being connected by means of the link *e′* to the armature-lever L. The armature-lever L is a flat piece of iron in **Z** shape, having its ends curved so as to correspond to the form of the upper pole-pieces of the magnets M and N. It is hung upon the pivots *v v*, Fig. 2, which are in the jaw *x* of the top plate, B. This plate B, with the jaw, is preferably cast in one piece and screwed to the side columns, S S, that extend up from the base A. To partly balance the overweight of the moving parts a spring, *s′*, Figs. 2 and 6, is fastened to the top plate, B, and hooked to the lever *t*. The hook *o* is toward one side of the lever or bent a little sidewise, as seen in Fig. 6. By this means a slight tendency is given to swing the armature toward the pole-piece *m′* of the main magnet.

The binding-posts K K' are preferably screwed to the base A. A manual switch, for short-circuiting the lamp when the carbons are renewed, is also to be fastened to the base. This switch is of ordinary character, and is not shown in the drawings.

The rod R is electrically connected to the lamp-frame by means of a flexible conductor or otherwise. The lamp-case receives a removable ornamental cover, around the same to inclose the parts.

The electrical connections are as indicated diagrammatically in Fig. 7.

The wire in the main magnet consists of two parts, *x′* and *p′*. These two parts may be in two separated coils or in one single helix, as shown in the drawings. The part *x′* being normally in circuit, is, with the fine wire upon the shunt-magnet, wound and traversed by the current in the same direction, so as to tend to produce similar poles, *n n* or *s s*, on the, corresponding pole-pieces of the magnets M and N. The part *p′* is only in circuit when the lamp is cut out, and then the current being in the opposite direction produces in the main magnet magnetism of the opposite polarity.

The operation is as follows: At the start the carbons are to be in contact, and the current passes from the positive binding-post K to the lamp-frame, carbon holder, upper and lower carbon, insulated return-wire in one of the side rods, and from there through the part *x′* of the wire on the main magnet to the negative binding-post. Upon the passage of the current the main magnet is energized and attracts the clamping-armature *g*, swinging the clamp and gripping the rod by means of the gripping jaws *e e*. At the same time the armature-lever L is pulled down and the carbons separated. In pulling down the armature lever L the main magnet is assisted by the shunt-magnet N, the latter being magnetized by magnetic induction from the magnet M.

It will be seen that the armatures L and *g* are practically the keepers for the magnets M and N, and owing to this fact both magnets with either one of the armatures L and *g* may be considered as one horseshoe magnet, which we might term a "compound magnet." The whole of the soft-iron parts *m*, *m′*, *g*, *n′*, *n*, and L form a compound magnet.

The carbons being separated, the fine wire receives a portion of the current. Now, the magnetic induction from the magnet M is such as to produce opposite poles on the corresponding ends of the magnet N; but the current traversing the helices tends to produce similar poles on the corresponding ends of both magnets, and therefore as soon as the fine wire is traversed by sufficient current the magnetism of the whole compound magnet is diminished.

With regard to the armature *g* and the operation of the lamp, the pole *m′* may be termed as the "clamping" and the pole *n′* as the "releasing" pole.

As the carbons burn away, the fine wire receives more current and the magnetism diminishes in proportion. This causes the armature-lever L to swing and the armature *g* to descend gradually under the weight of the moving parts until the end *p*, Fig. 1, strikes a stop on the top plate, B. The adjustment is such that when this takes place the rod R is yet gripped securely by the jaws *e e*. The further downward movement of the armature-lever being prevented, the arc becomes longer as the carbons are consumed, and the compound magnet is weakened more and more until the clamping-armature *g* releases the hold of the gripping-jaws *e e* upon the rod R, and the rod is allowed to drop a little, shortening thus the arc. The fine wire now receiving less current, the magnetism increases, and the rod is clamped again and slightly raised, if necessary. This clamping and releasing of the rod continues until the carbons are consumed. In practice the feed is so sensitive that for the greatest part of the time the movement of the rod cannot be detected without some actual measurement. During the normal operation of the lamp the armature-lever L remains stationary, or nearly so, in the position shown in Fig. 1.

Should it arise that, owing to an imperfection in the rod, the same and the carbons drop too far, so as to make the arc too short, or even bring the carbons in contact, then a very small amount of current passes through the fine wire, and the compound magnet becomes sufficiently strong to act as on the start in pulling the armature-lever L down and separating the carbons to a greater distance.

It occurs often in practice that the rod sticks in the guides. In this case the arc reaches a great length, until it finally breaks. Then the light goes out and frequently the fine wire is injured. To prevent such an accident, I provide my lamp with an automatic cut-out. This cut out operates as follows: When, upon a failure of the feed, the arc reaches a certain predetermined length, such an amount of current is diverted through the fine wire that the polarity of the compound magnet is reversed. The clamping-armature *g* is now moved against the shunt-magnet N until it strikes the releasing-pole *n*. As soon as the contact is established, the current passes from the positive binding-post, over the clamp *r*, armature *g*, insulated shunt-magnet, and the helix *p′* upon the main magnet M to the negative binding-post. In this case the current passes in the opposite direction and changes the polarity of the magnet M, at the same time maintaining by magnetic induction in the core of shunt-magnet the required magnetism without reversal of polarity, and the armature *g* remains against the shunt-magnet pole *n'*. The lamp is thus cut out as long as the carbons are separated. The cut-out may be used in this form without any further improvement; but I prefer to arrange it so that if the rod drops and the carbons come in contact the arc is started again. For this purpose I proportion the resistance of the part *p'* and the number of the convolutions of the wire upon the main magnet so that when the carbons come in contact a sufficient amount of current is diverted through the carbons and the part *x'* to destroy or neutralize the magnetism of the compound magnet. Then the armature *g*, having a slight tendency to approach to the clamping-pole *m'*, comes out of contact with the releasing pole *n'*. As soon as this happens, the current through the part *p'* is interrupted, and the whole current passes through the part *x*. The magnet M is now strongly magnetized, the armature *g* is attracted, and the rod clamped. At the same time the armature-lever L is pulled down out of its normal position and the arc started. In this way the lamp cuts itself out automatically when the arc gets so long, and reinserts itself automatically in the circuit if the carbons drop together.

It will be seen that the cut-out may be modified without departing from the spirit of my invention, as long as the shunt-magnet closes a circuit including a wire upon the main magnet and continues to keep the contact closed, being magnetized by magnetic induction from the main magnet. It is also obvious to say that the magnets and armatures may be of any desired shape.

I claim as my invention—

1. The combination, in an arc lamp, of a main and a shunt magnet, an armature lever to draw the arc, a clamp, and an armature to act upon the clamp, a damping pole and a releasing pole upon the respective cores, the cores, poles, armature-lever, and clamping-armature forming a compound electro-magnet, substantially as set forth.

2. The combination, in an electric arc lamp, of a carbon holder and its rod, a clamp for such carbon holder, a clamping-armature connected to the clamp, a compound electro-magnet controlling the action of the clamping armature, and electric-circuit connections, substantially as set forth, for lessening the magnetism of the compound magnet when the arc between the carbons lengthens and augmenting the magnetism of the same when the arc is shortened, substantially as described.

3. The combination, with the carbon holders in an electric lamp, of a clamp around the rod of the upper-carbon holder, the clamping-armature connected with said clamp, the armature-lever and connection from the same to the clamp, the main and shunt magnets, and the respective poles of the same to act upon the clamping armature and armature lever, respectively, substantially as set forth.

4. In an electric-arc lamp, a cut out consisting of a main magnet, an armature, and a shunt-magnet having an insulated pole piece, and the cut-out circuit-connections through the pole piece and armature, substantially as set forth.

5. In an electric-arc lamp, the combination, with the carbon holder and magnets, of the armatures L and *g*, link *e'*, clamp *r*, and lever *t*, and the spring *s'*, for the purpose set forth.

6. In an electric arc lamp, the combination, with two upright magnets in the main and shunt circuits, respectively, having curved pole-pieces on one end and converging pole pieces on the other end, of a flat **Z**-shaped armature-lever between the curved pole-pieces and a clamping armature between the convergent pole pieces, substantially as described.

7. The combination, in an electric arc lamp, of an electromagnet in the main circuit and an electro-magnet in the shunt-circuit, an armature under the influence of the poles of the respective magnets, and circuit-connections controlled by such armature to cut out or shunt the lamp, substantially as specified, whereby the branch circuit is closed by the magnetism of the shunt-magnet, and then kept closed by induced magnetism from the main magnet, substantially as set forth.

8. The combination, with the carbon holder and rod and the main and shunt magnets, of a feeding-clamp, an armature for the same, clamping and releasing poles upon the cores of the respective magnets, and circuit connections through the clamping armature, substantially as specified, for shunting the current when the electric arc between the carbons becomes abnormally long, substantially as set forth.

9. The combination, with the carbon-holding rod and a clamp for the same, of an armature upon the clamp, a shunt magnet the pole of which acts to release the clamp, and a main magnet with a two-part helix, one portion being in the main circuit and the other portion in a shunt or cut-out circuit, the clamping armature acting to close said cut out circuit when the arc becomes too long and to break the shunt-circuit when the carbons come together, substantially as set forth.

Signed by me this 11th day of July, A. D. 1885.

NIKOLA TESLA.

Witnesses:

GEO. T. PINCKNEY,
WILLIAM G. MOTT.

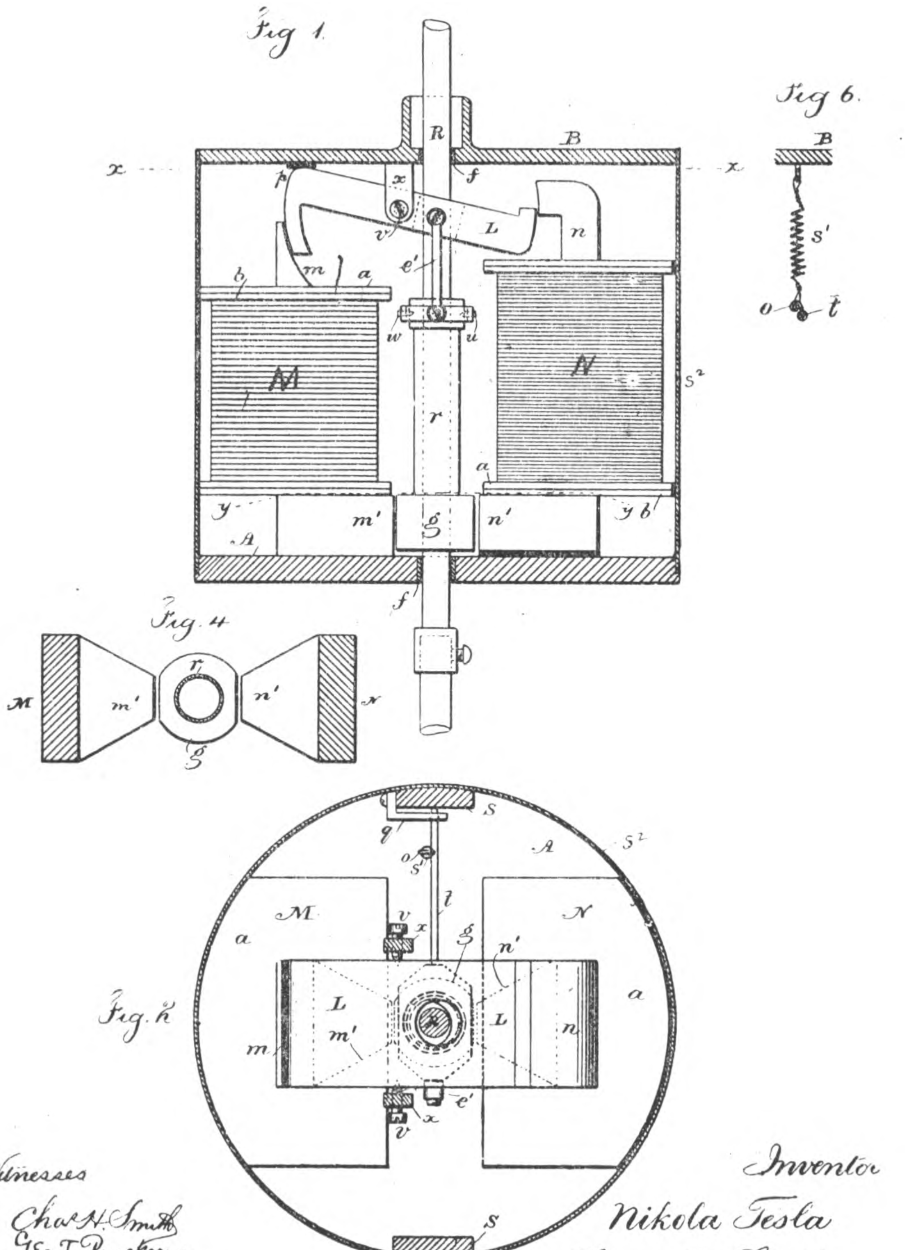
P-203

(No Model.) 2 Sheets—Sheet 1.

N. TESLA.

ELECTRIC ARC LAMP.

No. 335,787. Patented Feb. 9, ,1886.



Witnesses
Chas H. Smith
Geo T Pinckney

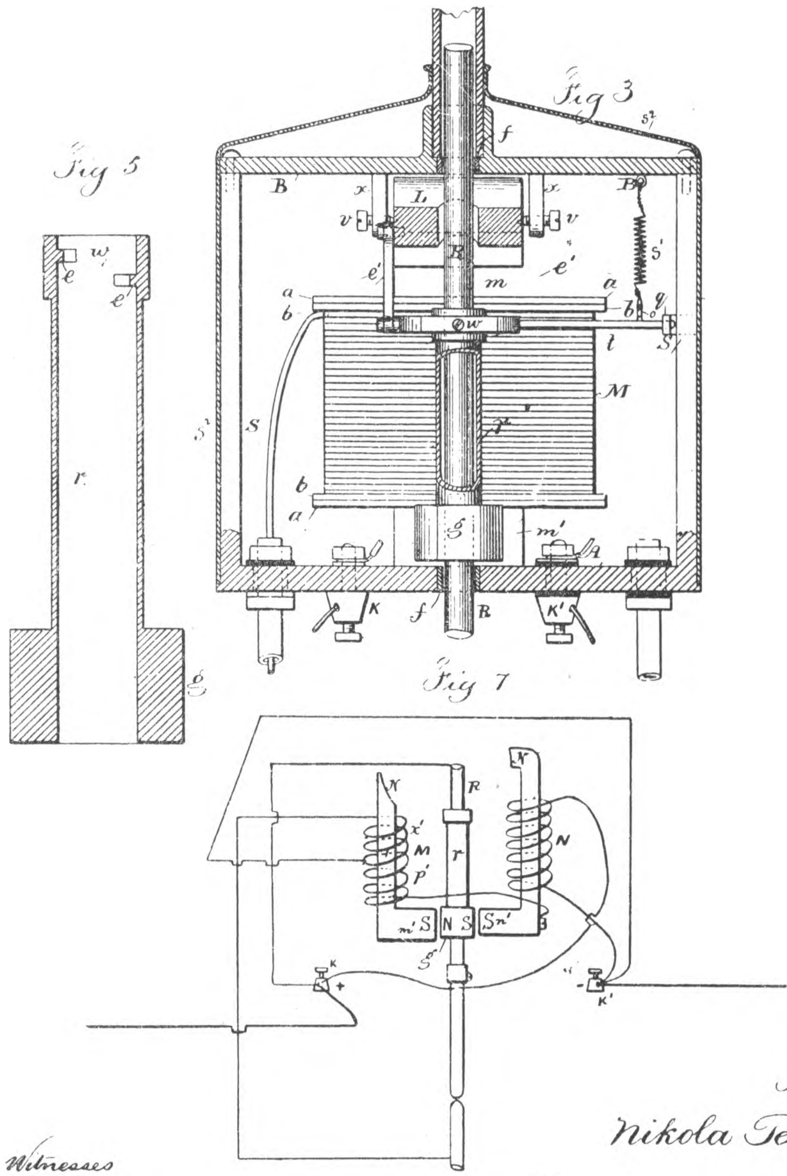
Inventor
Nikola Tesla
per Lemuel W. Serrell
atty

P-204

(No Model.) 2 Sheets—Sheet 2

N. TESLA.
ELECTRIC ARC LAMP.

No. 335,787. Patented Feb. 9, 1886.



Witnesses
Chas H Smith
Geo T Pinckney

Inventor
Nikola Tesla
per Lemuel W. Serrell
att

UNITED STATES PATENT OFFICE

NIKOLA TESLA, OF. NEW YORK, N. Y.

METHOD OF OPERATING ARC LAMPS.

SPECIFICATION forming part of Letters Patent No. 447,920, dated March 10, 1891.

Application filed October 1, 1890. Serial No. 366,734. (No model.)

To all whom it may concern:

Be it known that I, NIKOLA TESLA, a subject of the Emperor of Austria-Hungary, residing at New York, in the county and State of New York, have invented certain new and useful Improvements in Methods of Operating Arc Lamps, of which the following is a specification.

This invention consists in an improved method of operating electric-arc lamps which are supplied with alternating or pulsating currents.

It has now become a common practice to run arc lamps by alternating or pulsating as distinguished from continuous currents; but an objection to such systems exists in the fact that the arcs emit a pronounced sound, varying with the rate of the alternations or pulsations of current, but under any circumstances constituting an objectionable and disagreeable feature, for which heretofore no effective remedy has been found or proposed. This noise is probably due to the rapidly alternating heating and cooling and consequent expansion and contraction of the gaseous matter forming the arc which corresponds with the periods or impulses of the current, for I have succeeded in abating it and producing quiet and smoothly-acting lamps by increasing, per unit of time, the number of alternations or pulsations of the current producing the arc to such an extent that the rate of the vibrations or changes in the arc producing the noise approximately equals or exceeds that which is generally regarded as the limit of audition. For example, I may use a generator which produces ten thousand or more alternations of current per second. In such a case the periodical heating and cooling of the arc would occur with such rapidity as to produce little or no perceptible effect upon the ear.

There are a number of ways in which the current may be varied at a rate exceeding the limit of audition, but probably the most practicable known to me at present is by the use of an alternating-current generator with a, large number of poles, and specially constructed for the purpose. Such a generator, for the purpose of the illustration of this case, I have shown in the accompanying drawings.

Figure 1 is a view of the generator in side elevation. Fig. 2 is a vertical cross-section of the same with a diagram of the circuit-connections. Fig. 3 is an enlarged view, in side elevation, of a part of the machine. Fig. 4 is an enlarged sectional detail of the armature and field. Fig. 5 is a detail section of the field-magnets exhibiting the plan of winding.

A is an annular magnetic frame supported by the cross-bars or brackets B, provided with feet C, upon which the machine rests. The interior of the annulus A is provided with a large number of projections or pole-pieces D. These may be formed or applied in a variety of ways—as, for example, by milling transverse grooves E.

Owing to the very large number and small size of the poles and the spaces between them, I apply the exciting or field coils by winding an insulated conductor F zigzag through the grooves, as shown in Fig. 5, carrying said wire around the annulus to form as many layers as is desired. In this way the pole-pieces D will be energized with alternately opposite polarity around the entire ring.

For the armature I employ a spider or circular frame G on a driving-shaft H, mounted in bearings in the brackets B. This spider carries a ring J, turned down, except at its edges, to form a trough like receptacle for a mass of fine annealed iron wires K, which are wound in the groove to form the core proper for the armature-coils. Pins L are set in the sides of the ring J, and the coils M are wound over the periphery of the armature-structure and around the pins. The coils M are connected together in series, and these terminals N carried through the hollow shaft H to contact-rings P P, from whence the currents are taken off by brushes O. In this way a machine with a very large number of poles may be constructed. It is easy, for instance, to obtain in this manner three hundred and seventy-five to four hundred poles in a machine that may be safely driven at a speed of fifteen hundred or sixteen hundred revolutions per minute, which will produce ten thousand or eleven thousand alternations of current per second. Arc lamps R R are shown in diagram as connected up in series with the machine in Fig. 2. If such a current be applied to running arc lamps, the sound produced by or in the arc becomes practically inaudible, for by increasing the rate of change in the current, and consequently the number of vibrations per unit of time of the gaseous material of the arc up to or beyond ten thousand or eleven thousand per second, or to what is regarded as the limit of audition, the sound due to such vibrations will not be audible. The exact number of changes or undulations necessary to produce this result will vary somewhat according to the size of the arc—that is to say, the smaller the arc the greater the number of changes that will be required to render it inaudible within certain limits. Of course, as the rate of alternations or undulations for a given size of arc becomes very high the sound produced is less perceptible, and hence for some purposes the actual limit of audition may only be approached, provided the sound be rendered practically inaudible.

Another advantage gained by increasing as above set forth the number of alterations is that the arc acts more like that produced by a continuous current, in that it is more persistent, owing to the fact that the time interval between undulations is so small that the gaseous matter cannot cool down so far as to increase very considerably in resistance.

I claim—

The method of abating or rendering inaudible the sound emitted by arc lamps supplied with or operated by an alternating or pulsating current by increasing the rate of such alternations or pulsations up to that of the limit of audition, as set forth.

NIKOLA TESLA.

Witnesses:

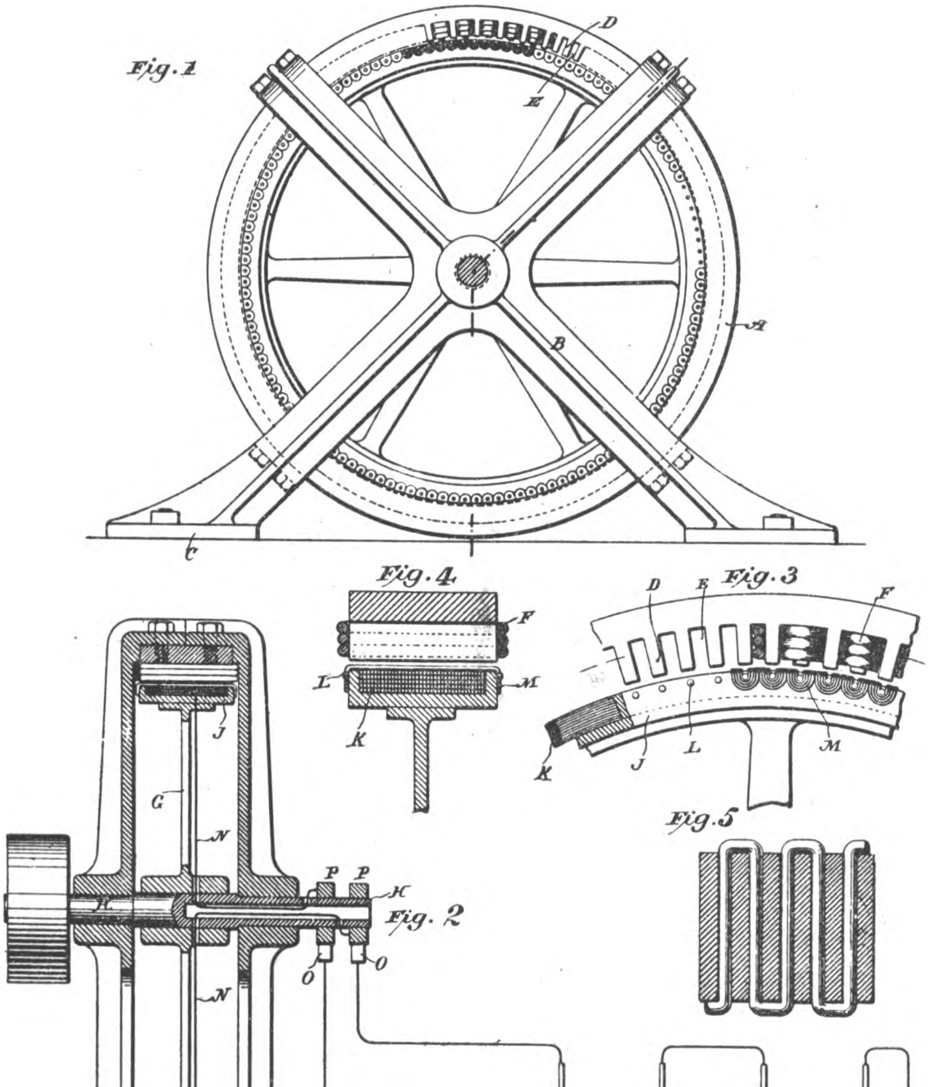
FRANK B. MURPHY,
RAPHAËL NETTER

(No Model.)

N. TESLA.

METHOD OF OPERATING ARC LAMPS.

No. 447,920. Patented Mar. 10, 1891.



Witnesses:
Raphaël Netter
M. G. Tracy

Inventor
Nikola Tesla
by
Duncan & Page
Attorneys.

UNITED STATES PATENT OFFICE.

NIKOLA TESLA, OF NEW YORK, N Y.

SYSTEM OF ELECTRIC LIGHTING.

SPECIFICATION forming part of Letters Patent No. 464,633, dated June 23, 1891.

Application filed April 25, 1891. Serial No. 390,414. (No model.)

To all whom it may concern.

Be it known that I, NIKOLA TESLA, a subject of the Emperor of Austria-Hungary, from Smiljan, Lika, border country of Austria-Hungary, and a resident of New York, in the county and State of New York, have invented certain new and useful Improvements in Methods of and Apparatus for Electric Lighting, of which the following is a specification, reference being had to the drawings accompanying and forming a part of the same.

This invention consists in a novel method of and apparatus for producing light by means of electricity.

For a better understanding of the invention it may be stated, first, that heretofore I have produced and employed currents of very high frequency for operating translating devices, such as electric lamps, and, second, that currents of high potential have also been produced and employed for obtaining luminous effects, and this, in a broad sense, may be regarded for purposes of this case as the prior state of the art; but I have discovered that results of the most useful character may be secured under entirely practicable conditions by means of electric currents in which both the above-described conditions of high frequency find great difference of potential are present. In other words, I have made the discovery that an electrical current of an excessively small period and very high potential may be utilized economically and practicably to great advantage for the production of light.

It is difficult for me to define the exact limits of frequency and potential within which my discovery is comprised, for the results obtained are due to both conjointly; but I would make it clear that as to the inferior limits of both, the lowest frequency and potential that I contemplate using are far above what have heretofore been regarded as practicable. As an instance of what I regard as the lowest practicable limits I would state that I have obtained fairly good results by a frequency as low os fifteen thousand to twenty thousand per second and a potential of about twenty thousand volts. Both frequency and potential may be enormously increased above these figures, the practical limits being determined *by* the character of the apparatus and its capability of standing the strain. I do not mean by the term "excessively small period" and similar expressions herein to imply that I contemplate any number of pulsations or vibrations per second approximating to the number of light waves, and this will more fully appear from the description of the nature of invention which is hereinafter contained.

The carrying out of this invention and the full realization of the conditions necessary to the attainment of the desired results involve, first, a novel method of and apparatus for producing the currents or electrical effects of the character described; second, a novel method of utilizing and applying the same for the production of light, and, third, a new form of translating device or light-giving appliance. These I shall now describe.

To produce a current of very high frequency and very high potential, certain well-known devices may be employed. For instance, as the primary source of current or electrical energy a continuous-current generator may be used, the circuit of which may be interrupted with extreme rapidity by mechanical devices, or a magneto-electric machine specially constructed to yield alternating currents of very small period may be used, and in either case, should the potential be too low, an induction-coil may be employed to raise it; or, finally, in order to overcome the mechanical difficulties, which in such cases become practically insuperable before the best results are reached, the principle of the disruptive discharge may be utilized. By means of this latter plan I produce a much greater rate of change in the current than by the other means suggested, and in illustration of my invention I shall confine the description of the means or apparatus for producing the current to this plan, although I would not be understood as limiting myself to its use. The current of high frequency, therefore, that is necessary to the successful working of my invention I produce by the disruptive discharge of the accumulated energy of a condenser maintained by charging said condenser from a suitable source and discharging it into or through a circuit under proper relations of self-induction, capacity, resistance, and period in well-understood ways. Such a discharge is known to be, under proper conditions, intermittent or oscillating in character, and in this way a current varying in strength at an enormously rapid rate may be produced. Having produced in the above manner a current of excessive frequency, I obtain from it by means of an induction-coil enormously high potentials—that is to say, in the circuit through which or into which the disruptive discharge of the condenser takes place I include the primary of a suitable induction-coil, and by a secondary coil of much longer and finer wire I convert to currents of extremely high potential. The differences in the length of the primary and secondary coils in connection with the enormously rapid rate of change in the primary current yield a secondary of enormous frequency and excessively high potential. Such currents are not, so far as I am aware, available for use in the usual ways; but I have discovered that if I connect to either of the terminals of the secondary coil or source of current of high potential the leading-in wires of such a device, for example, as an ordinary incandescent lamp, the carbon may be brought to and maintained at incandescence, or, in general, that any body capable of conducting the high-tension current described and properly inclosed in a rarefied or exhausted receiver may be rendered luminous or incandescent, either when connected directly with one terminal of the secondary source of energy or placed in the vicinity of such terminals so as to be acted upon inductively.

Without attempting a detailed explanation of the causes to which this phenomenon may be ascribed, I deem it sufficient to state that, assuming the now generally accepted theories of scientists to be correct, the effects thus produced are attributable to molecular bombardment, condenser action, and electric or etheric disturbances. Whatever part each or any of these causes may play in producing the effects noted, it is, however, a fact that a strip of carbon or a mass of any other shape, either of carbon or any more or less conducting substance in a rarefied or exhausted receiver and connected directly or inductively to a source of electrical energy such as I have described, may be maintained at incandescence if the frequency and potential of the current be sufficiently high.

I would here state that by the terms "currents of high frequency and high potential" and similar expressions which I have used in this description I do not mean, necessarily, currents in the usual acceptance of the term, but, generally speaking, electrical disturbances or effects such as would be produced in the secondary source by the action of the primary disturbance or electrical effect.

It is necessary to observe in carrying out this invention that care must be taken to reduce to a minimum the opportunity for the dissipation of the energy from the conductors intermediate to the source of current and the light-giving body. For this purpose the conductors should be free from projections and points and well covered or coated with a good insulator.

The body to be rendered incandescent should be selected with a view to its capability of withstanding the action to which it is exposed without being rapidly destroyed, for some conductors will be much more speedily consumed than others.

I now refer to the accompanying drawings, in which—

Figure 1 is a diagram of one of the special arrangements that I have employed in carrying out my discovery, and Figs. 2 and 3 are vertical sectional views of modified forms of light-giving devices that I have devised for use with the system.

I would state that as all of the apparatus herein shown, with the exception of certain special forms of lamp invented by me, is or may be of well-known construction and in common use for other purposes, I have indicated such well-known parts therefor by conventional representations.

G is the primary source of current or electrical energy. I have explained above how various forms of generator might be used for this purpose; but in the present illustration I assume that G is an alternating-current generator of comparatively low electro-motive force. Under such circumstances I raise the potential of the current by means of an induction-coil having a primary P and a secondary S. Then by the current developed in this secondary I charge a condenser C, and this condenser I discharge through or into a circuit A, having an air-gap *a*, or, in general, means for maintaining a disruptive discharge. By the means above described a current of enormous frequency is produced. My object is next to convert this into a working-circuit of very high potential, for which purpose I connect up in the circuit A the primary P' of an induction-coil having a long fine wire secondary S'. The current in the primary P' develops in the secondary S' a current or electrical effect of corresponding frequency, but of enormous difference of potential, and the secondary S' thus becomes the source of the energy to be applied to the purpose of producing light.

The light-giving devices may be connected to either terminal of the secondary S'. If desired, one terminal may be connected to a conducting-wall W of a room or space to be lighted and the other arranged for connection of the lamps therewith. In such case the walls should be coated with some metallic or conducting substance in order that they may have sufficient conductivity.

The lamps or light-giving devices may be an ordinary incandescent lamp; but I prefer to use specially-designed lamps, examples of which I have shown in detail in the drawings. This lamp consists of a rarefied or exhausted bulb or globe which incloses a refractory conducting body, as carbon, of comparatively small bulk and any desired shape. This body is to be connected to the secondary by one or more conductors sealed in the glass, as in ordinary lamps, or is arranged to be inductively connected thereto. For this last-named purpose the body is in electrical contact with a metallic sheet in the interior of the neck of the globe, and on the outside of said neck is a second sheet which is to be connected with the source of current. These two sheets form the armatures of a condenser, and by them the currents or potentials are developed in the light-giving body. As many lamps of this or other kinds may be connected to the terminal of S'. as the energy supplied is capable of maintaining at incandescence.

In Fig. 3, *b* is a rarefied or exhausted glass globe or receiver, in which is a body of carbon or other suitable conductor e. To this body is connected a metallic conductor *f*, which passes through and is sealed in the glass wall of the globe, outside of which it is united to a copper or other wire *g*, by means of which it is to be electrically connected to one pole or terminal of the source of current. Outside of the globe the conducting-wires are protected by a coating of insulation *h*, of any suitable kind, and inside the globe the supporting-wire is inclosed in and insulated by a tube or coating *k* of a refractory insulating substance, such as pipe-clay or the like. A reflecting-plate *l* is shown applied to the outside of the globe *b*. This form of lamp is a type of those designed for direct electrical connection with one terminal of the source of current; but, as above stated, there need not be a direct connection, for the carbon or other illuminating body may be rendered luminous by inductive action of the current thereon, and this may be brought about in several ways. The preferred form of lamp for this purpose, however, is shown in Fig. 2. In this figure the globe *b* is formed with a cylindrical neck, within which is a tube or sheet *m* of conducting material on the side and over the end of a cylinder or plug *n* of any suitable insulating material. The lower edges of this tube are in electrical contact with a metallic plate *o*, secured to the cylinder *n*, all the exposed surfaces of such plate and of the other conductors being carefully coated and protected by insulation. The light-giving body *e*, in this case a straight stem of carbon, is electrically connected with the said plate by a wire or conductor similar to the wire *f*, Fig. 3, which is coated in like manner with a refractory insulating material *k*. The neck of the globe fits into a socket composed of an insulating tube or cylinder *p*, with a more or less complete metallic lining *s*, electrically connected by a metallic head or plate *r* with a conductor *a*, that is to be attached to one pole of the source of current. The metallic lining *s* and the sheet *m* thus compose the plates or armatures of a condenser.

This invention is not limited to the special means described for producing the results hereinabove set forth, for it will be seen that various plans and means of producing currents of very high frequency are known, and also means for producing very high potentials; but I have only described herein certain ways in which I have practically carried out the invention.

What I claim is—

1. The improvement in the art of electric lighting herein described, which consists in generating or producing for the operation of the lighting devices currents of enormous frequency and excessively high potential, substantially as herein described.

2. The method of producing an electric current for practical application, such as for electric lighting, which consists in generating or producing a current of enormous frequency and inducing by such current in a working circuit, or that to which the lighting devices are connected, a current of corresponding frequency and excessively high potential, as set forth.

3. The method of producing an electric current for practical application, such as for electric lighting, which consists in charging a condenser by a given current, maintaining an intermittent or oscillatory discharge of said condenser through or into a primary circuit, and producing thereby in a secondary working circuit in inductive relation to the primary very high potentials, as set forth.

4. The method of producing electric light by incandescence by electrically or inductively connecting a conductor inclosed in a rarefied or exhausted receiver to one of the poles or terminals of a source of electric energy or current of a frequency and potential sufficiently high to render said body incandescent, as set forth.

5. A system of electric lighting, consisting in the combination, with a source of electric energy or current of enormous frequency and excessively high potential, of an incandescent lamp or lamps consisting of a conducting body inclosed in a rarefied or exhausted receiver and connected directly or inductively to one pole or terminal of the source of energy, as set forth.

6. In a system of electric lighting, the combination, with a source of currents of enormous frequency and excessively high potential, of incandescent lighting devices, each consisting of a conducting body inclosed in a rarefied or exhausted receiver, said conducting body being connected directly or inductively to one pole or terminal of the source of current, and a conducting body or bodies in the vicinity of said lighting devices connected to the other pole or terminal of said source, as set forth.

7. In a system of electric lighting, the combination, with a source of currents of enormous frequency of excessively high potential, of lighting devices, each consisting of a conducting body inclosed in a rarefied or exhausted receiver and connected by conductors directly or inductively with one of the terminals of said source, all parts of the conductors intermediate to the said source and the light-giving body being insulated and protected to prevent the dissipation of the electric energy, as herein set forth.

NIKOLA TESLA.

Witnesses:
PARKER W. PAGE,
M. G. TRACY.

P-212

(No Model.)

N TESLA

SYSTEM OF ELECTRIC LIGHTING

No 454,622 Patented June 23, 1891.

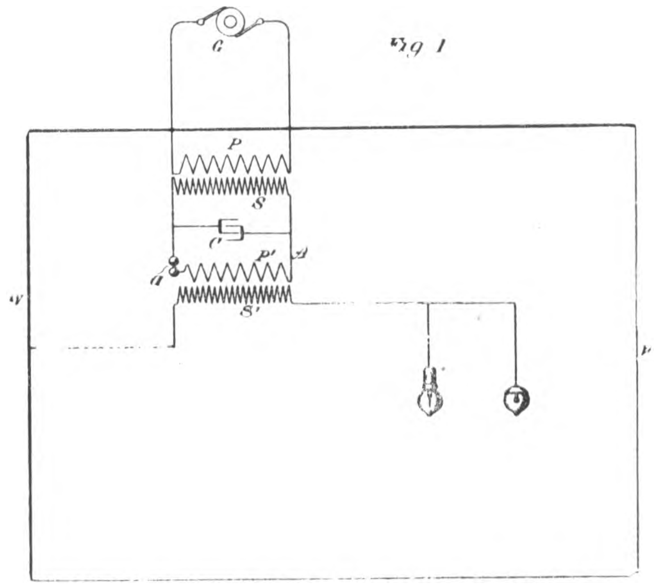


Fig. 2

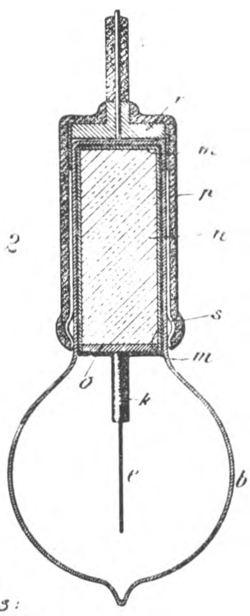
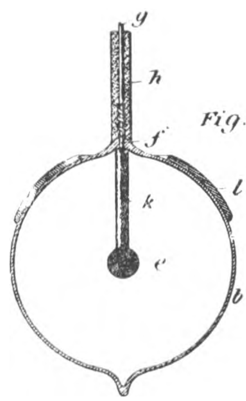


Fig. 3



Witnesses:
Raphaël Netter
Ernest Hopkinson

Inventor
Nikola Tesla
by Duncan & Page,
Attorneys

UNITED STATES PATENT OFFICE

NIKOLA TESLA, OF NEW YORK, N. Y.

ELECTRIC INCANDESCENT LAMP

SPECIFICATION forming part of Letters Patent No. 455,069, dated June 30, 1891.

Application filed May 14, 1891. Serial No. 392,069. (No model.)

To all whom it may concern:

Be it known that I, NIKOLA TESLA, a subject of the Emperor of Austria, from Smiljan, Lika, border country of Austria-Hungary, residing at New York, in the county and State of New York, have invented certain new and useful Improvements in Electric Incandescent Lamps, of which the following is a specification, reference being had to the drawings accompanying and forming a part of the same.

My invention is a new form of lamp for giving light by the incandescence of carbon or other suitable refractory conductor produced by electrical energy.

In order to more distinctly point out those features which distinguish my invention, I would state that heretofore electric lamps have been made, first, by mounting a refractory conductor on metallic supporting-wires leading into a hermetically-sealed receiver from which the air has been exhausted or replaced by an inert gas, and, second, by placing two independent conductors in a receiver or globe and partially exhausting the air therefrom. In the first case the carbon or other conductor is rendered incandescent by the actual flow or passage of a current through it, while in the second the luminous effects, as heretofore produced, or, in fact, the only luminous effects that could be produced by any means heretofore known, were due to an actual discharge of current from one conductor to the other across the intermediate space of rarefied air or gas.

It may be further remarked that in various forms of Geissler or vacuum tubes the terminals or points within the tube become or have a tendency to. become heated by the action of the high-tension secondary discharge. In such tubes, however, the degree of exhaustion is comparatively low, as a high vacuum prevents the well-known Geissler discharge or effect. Moreover, with such low degrees of exhaustion the points or wires, if healed and allowed to become incandescent, are speedily destroyed.

I have discovered that two conducting-bodies mounted in a very highly exhausted receiver may be rendered incandescent and practically utilized as a source of light if connected directly or inductively to the terminals of a source of current of very great frequency and very high potential.

The practical requirements of this invention are widely different from those employed in producing any of the phenomena heretofore observed, such differences being mainly in respect to the current, which must be one of enormous frequency and of excessively high potential, and also to the degree of exhaustion of the globe or receiver, which must be carried at least beyond the point at which a spark will pass, or to the condition known as a "non-striking vacuum," and it may be as much farther as possible.

This application is confined to a particular form of lamp which I employ in a new system invented by me, which system involves, as one of its essential characteristics, the employment of currents or electric effects of a novel kind. In an application filed by me April 25, 1891, No. 390,414, I have shown and described this system in detail, and I therefore deem it sufficient for the present case to say that the lamps herein described, while utterly inoperative on any of the circuits now, or, so far as I am aware, heretofore employed become highly efficient sources of light if the frequency of the current by which they are operated be sufficiently great and the potential sufficiently high. To produce such currents, any known means may be utilized of the plan described in my said application followed of disruptively discharging the accumulated energy in a condenser into or through a primary circuit to produce a current of very high frequency, and inducing from this cur rent a secondary current of a very much higher potential.

I now refer to the drawings in illustration of the invention.

Figure 1 is a vertical sectional view of a lamp constructed with leading-in wires for direct connection with a circuit or source of current Fig. 2 is a similar view of a form of lamp arranged for inductive connection with such source.

The common methods or steps followed in the manufacture of the ordinary incandescent lamps and Geissler tubes may be employed in the manufacture of these improved lamps as far as applicable.

A is a glass globe or receiver with a neck or base B. Conducting-wires C C enter this globe and are sealed in the walls thereof. The entering wires C are surrounded by small tubes or cups D. The joints between the wires C and the incandescing conductors are made within these cups in any ordinary manner, and the lower parts of the cups are tilled with bronze-powder E or other suitable material to effect a good electrical connection. The cups are then filled up with fire-clay or other refractory non-conductor F, which is molded around the carbons G. The carbons or other refractory conductors or semi-conductors G are completely isolated from one another. They are here shown as slender strips; but they may have any other desired shape. Lamps thus made are attached to a vacuum-pump in the usual way. After the process of exhaustion has been carried on for some time they are brought to incandescence by a suitable current, by which the fire-clay is thoroughly baked and the occluded gases are driven off. The exhaustion is carried to the highest possible point, and the globe finally sealed off at H. Inasmuch as there is a tendency to sparking when the current is turned on before the exhaustion has been carried very high, it is well, when the character of the carbon admits of it, to cause their ends to approach, in order that the sparks may leap across between such points, whereby the danger of injury to the carbons or the lamp is lessened. The conductors outside the globe, as well as all those which convey the current, from the source, should be carefully insulated to prevent the dissipation of the current.

In lieu of connecting the two carbons directly to the circuit through leading-in wires, provision may be made for inductively connecting them, as by means of condensers. Fig. 2 shows a form of lamp of this description that I have employed. The globe A has two extended tubular portions B B'. Inside of these tubular extensions are condenser-coatings K K'.

J J are plugs of fire-clay or the like contained in the extensions B B'. The two conductors G G are supported by these plugs and connected by metallic strips M with the condenser-coatings K K', respectively. Over the outside of the extensions B B' are fitted insulating-caps N N', having metallic linings O O', with terminals adapted for connection with the circuit-wires. With such currents as are employed to operate these lamps condensers of small capacity, such as those thus made, transmit the energy from the outside circuit to the carbons within the globe with little loss. This lamp is exhausted and sealed off from the pump in the same manner as that first described. There is no electrical connection at any time between the two carbons of this lamp and no visible discharge or transfer of current from one to the other through the highly-rarefied medium between them. The fact, therefore, of their being rendered incandescent by the action of such a current as I have described seems to be mainly attributable to condenser action.

The carbons, or whatever substance may be used in their stead, may be of any desired form and may be placed in different relative positions.

The manner of making the lamp and the general form of the lamp as a whole may be varied in numberless ways. I have merely shown herein typical forms which embody the principle of the invention and which by experience I have demonstrated to be practical lamps.

As the lamps which I employ and which are made as above described are absolutely inoperative in any system from which the hereinbefore-described conditions of potential and frequency are absent, so the various lamps heretofore devised for use with high-potential currents, in which the exhaustion, of necessity, has not been carried to or beyond the non-striking point, are practically worthless in my new system, and this is the distinguishing feature of novelty in my lamps viz., that they are exhausted to or beyond the non-striking point.

What I claim as my invention is—

1. An incandescent lamp consisting of two isolated refractory conductors contained in a non-striking vacuum and adapted to produce light by incandescence, each being provided with a terminal for connection with a source of electrical energy, as set forth.

2. The combination, with a globe or receiver exhausted to the non-striking point, of two isolated bodies of refractory conducting material adapted to emit light by incandescence and mounted within said globe, and means for connecting said bodies with the two poles or terminals, respectively, of a source of electrical energy.

3. In an incandescent electric lamp, the combination, with a globe or receiver exhausted to the non-striking point, of metallic wires sealed therein, a refractory body mounted on or electrically connected to each wire, the said wires within the globe and such parts of the refractory body as are not to be rendered incandescent being coated or covered with insulation, as set forth.

4. The combination, with a globe or receiver exhausted to the non-striking point, of metallic wires sealed therein, a refractory conductor united to each of said wires within the globe, an insulating-covering around the wires and joint, and a refractory insulating-body surrounding the refractory conductors near the joint, as set forth.

NIKOLA TESLA.

Witnesses:

ROBT F. GAYLORD,
PARKER W. PAGE.

P-215

(No Model.)

N. TESLA.

ELECTRIC INCANDESCENT LAMP.

No. 455,069. Patented June 30, 1891

Fig. 1

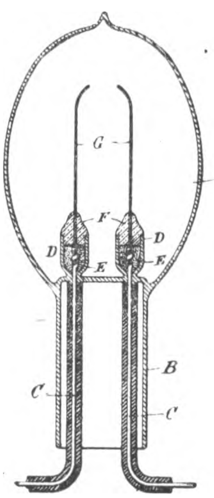
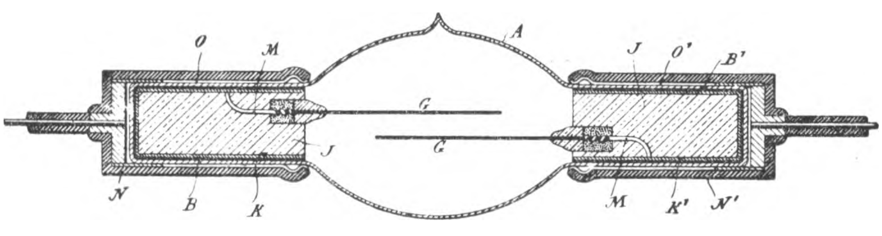


Fig. 2



Witnesses:
Raphaël Netter
Frank B. Murphy.

Inventor
Nikola Tesla
by
Duncan & Page
Attorneys.

UNITED STATES PATENT OFFICE.

NIKOLA TESLA, OF NEW YORK, N. Y.

INCANDESCENT ELECTRIC LIGHT.

SPECIFICATION forming part of Letters Patent No. 514,170, dated February 6, 1894.

Application filed January 2, 1892. Renewed December 15, 1893. Serial No. 493,776. (No model.)

To all whom it may concern:

Be it known that I, NIKOLA TESLA, a citizen of the United States, residing at New York, in the county and State of New York, have invented a certain new and useful Improvement in Incandescent Electric Lamps, of which the following is a specification, reference being had to the drawings accompanying and forming a part of the same.

This invention is an improvement in the particular class of electric lamps or lighting devices invented by me and for which I have heretofore obtained Letters Patent, notably No. 454,622, dated June 23, 1891.

The invention applies more particularly to that form of lamp in which a small body or button of refractory material is supported by a conductor entering a very highly exhausted globe or receiver, but is also applicable generally to other forms of lamp adapted for use with similar systems in which currents of very high potential and great frequency are employed. I have found in the practical applications of this system that a considerable dissipation of energy takes place from the conductors conveying the currents of great potential and frequency, even when such conductors are thoroughly insulated both within and without the lamp globes, and the subject of my present invention is a means for preventing such dissipation within the lamp, or rather for confining it to the particular parts or part of the conductor which is designed to give light. This object I find I may readily accomplish by surrounding the leading-in and supporting conductors with a conductor which acts as a static screen. By this means the light-giving body or button which lies beyond the influence of the screen is quickly and efficiently brought to and maintained at higher incandescence by a suitable electrical current or effect, by reason of the fact that the electrical action to which the incandescence is due is confined mainly to the button.

A description of the ordinary form of lamp which I employ will serve to illustrate the principle and nature of this improvement, and for each description I now refer to the drawings which show such lamp in central vertical section.

A is a glass globe of the usual form, in the base of which is sealed a very thin conducting wire B, passing up through a stem of glass or other refractory insulator C. To the upper or inner end of this wire is united, as by means of a mass of carbon paste D, a carbon or other refractory stem E, that supports or carries a small button of carbon or other suitable substance F. Over the stem C is passed, at any convenient stage in the manufacture of the lamp and in any well understood way, a metallic tube G. I prefer to use for this purpose a very thin cylinder or tube of aluminum and it should entirely surround all parts of the conductor within the globe except the button itself, extending to or nearly up to the point of union of the stem E with the button F. Such a device by reason of its electrostatic action reduces the loss of energy supplied to the bulb, preventing its radiation or dissipation into space except through the exposed or unprotected button. The tube or screen G is entirely insulated from the conductors within the globe and from all external conductors or bodies. The globe, by means of a suitable air pump, is exhausted to as high a degree as practicable, or until a non-striking vacuum is attained. It is connected with the pump by the usual tube which is sealed off at K.

The lamp may be made in different forms and in different ways, and the invention, as may be readily understood from its above described nature and purpose, is not confined to the specific form of lamp herein shown.

What I claim is—

1. In an incandescent electric lamp, the combination of an exhausted globe, a refractory light-giving body therein, a conductor leading into the globe and connected to or supporting the said body, and a conducting screen surrounding the said conductor, as set forth.

2. In an incandescent electric lamp, the combination of an exhausted globe, a refractory light-giving body or button therein, a conducting support for said button within the

globe, and a metallic tube surrounding or inclosing the said conductor up to the point of union with the button, as set forth.

3. In an incandescent electric lamp, the combination of an exhausted globe, a wire sealed therein, and coated with or embedded in a glass stem, a carbon stem united with the wire, a refractory conductor mounted on said stem, and a conducting tube or cylinder surrounding the wire and carbon stem, as and for the purpose set forth.

NIKOLA TESLA.

Witnesses:
ERNEST HOPKINSON,
PARKER W. PAGE.

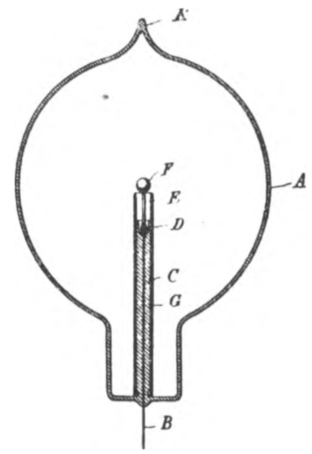
P-218

(No Model.)

N. TESLA.

INCANDESCENT ELECTRIC LIGHT.

No. 514,170. Patented Feb. 6, 1894.



Witnesses:
Raphaël Netter
[signature]

Inventor
Nikola Tesla
by
Duncan & Page
Attorneys

IV

HIGH FREQUENCY APPARATUS AND CIRCUIT CONTROLLERS

UNITED STATES PATENT OFFICE.

NIKOLA TESLA, OF NEW YORK, N. Y.

METHOD OF AND APPARATUS FOR ELECTRICAL CONVERSION AND DISTRIBUTION.

SPECIFICATION forming part of Letters Patent No. 462,418, dated November 3, 1891.

Application filed February 4, 1891. Serial No 380,182. (No model.)

To all whom, it may concern:

Be it known that I, NIKOLA TESLA, a subject of the Emperor of Austria, from Smiljan, Lika, border country of Austria-Hungary, residing at New York, in the county and State of New York, have invented certain new and useful Improvements in Methods of and Apparatus for Electrical Conversion and Distribution, of which the following is a specification, reference being had to the drawings accompanying and forming a part of the same.

This invention is an improvement in methods of and apparatus for electrical conversion, designed for the better and more economical distribution and application of electrical energy for general useful purposes.

My invention is based on certain electrical phenomena which have been observed by eminent scientists and recognized as due to laws which have been in a measure demonstrated, but which, so far as I am aware, have not hitherto been utilized or applied with any practically useful results. Stated briefly, these phenomena are as follows: First, if a condenser or conductor possessing capacity be charged from a suitable generator, and discharged through a circuit, the discharge under certain conditions will be of an intermittent or oscillatory character; second, if two points in an electric circuit through which a current rapidly rising and falling in strength is made to flow be connected with the plates or armatures of a condenser, a variation in the current's strength in the entire circuit or in a portion of the same only may be produced; third, the amount or character of such variation in the current's strength is dependent upon the condenser capacity, the self-induction and resistance of the circuit or its sections, and the period or time rate of change of the current. It may be observed, however, that these several factors—the capacity, the self-induction, resistance, and period—are all related in a manner well understood by electricians, but to render such conversion as may be effected by condensers practically available and useful it is desirable, chiefly on account of the increased output and efficiency and reduced cost of the apparatus, to produce current-impulses succeeding each other with very great rapidity, or, in other words, to render the duration of each impulse, alternation, or oscillation of the current extremely small. To the many difficulties in the way of effecting this mechanically, as by means of rotating switches or interrupters, is perhaps due the failure to realize practically, at least to any marked degree, the advantages of which such a system is capable. To obviate these difficulties, I have in my present invention taken advantage of the fact above referred to, and which has been long recognized, that if a condenser or a conductor possessing capacity be charged from a suitable source and be discharged through a circuit the discharge under certain conditions, dependent on the capacity of the condenser or conductor, the self-induction and resistance of the discharging circuit, and the rate of supply and decay of the electrical energy, may be effected intermittently or in the form of oscillations of extremely small period.

Briefly stated in general terms, the plan which I pursue in carrying out my invention is as follows:

I employ a generator, preferably, of very high tension and capable of yielding either direct or alternating currents. This generator I connect up with a condenser or conductor of some capacity and discharge the accumulated electrical energy disruptively through an air-space or otherwise into a working circuit containing translating devices and, when required, condensers. These discharges may be of the same direction or alternating and intermittent, succeeding each other more or less rapidly or oscillating to and fro with extreme rapidity. In the working circuit, by reason of the condenser action, the current impulses or discharges of high tension and small volume are converted into currents of lower tension and greater volume. The production and application of a current of such rapid oscillations or alternations (the number may be many millions per second) secures, among others, the following exceptional advantages: First, the capacity of the condensers for a given output is much diminished; second, the efficiency of the condensers is increased and the tendency to become heated reduced, and, third, the range of conversion is enlarged. I have thus succeeded in producing a system or method of conversion radically different from what has been done heretofore—first, with respect to the number of impulses, alternations or oscillations of current per unit of time, and, second, with respect to the manner in which the impulses are obtained. To express this result, I define the working current as one of an excessively small period or of an excessively large number of impulses or alternations or oscillations per unit of time, by which I mean not a thousand or even twenty or thirty thousand per second, but many times that number, and one which is made intermittent, alternating, or oscillating of itself without the employment of mechanical devices.

I now proceed to an explanation somewhat more in detail of the nature of my invention, referring to the accompanying drawings.

The two figures are diagrams, each representing a generating-circuit, a working circuit, means for producing an intermittent or oscillating discharge, and condensers arranged or combined as contemplated by my invention.

In Figure 1, A represents a generator of high tension; B B, the conductors which lead out from the same. To these conductors are connected the conductors C of a working circuit containing translating devices, such as incandescent lamps or motors G. In one or both conductors B is a break D, the two ends being separated by an air-space or a film of insulation, through which a disruptive discharge takes place. F is a condenser, the plates of which are connected to the generating-circuit. If this circuit possess itself sufficient capacity, the condenser F may be dispensed with.

In Fig. 2 the generating-circuit B B contains a condenser F and discharges through the air-gaps D into the working circuit C, to any two points of which is connected a condenser E. The condenser E is used to modify the current in any part of the working circuit, such as L.

It may conduce to a better understanding of the invention to consider more in detail the conditions existing in such a system as is illustrated in Fig. 1. Let it be assumed, therefore, that in the system there shown the rate of supply of the electrical energy, the capacity, self induction, and the resistance of the circuits are so related that a disruptive, intermittent, or oscillating discharge occurs at D. Assume that the first-named takes place. This will evidently occur when the rate of supply from the generator is not adequate to the capacity of the generator, conductors B B, and condenser F. Each time the condenser F is charged to such an extent that the potential or accumulated charge overcomes the dielectric strength of the insulating-space at D the condenser is discharged. It is then recharged from the generator A, and this process is repeated in more or less rapid succession. The discharges will follow each other the more rapidly the more nearly the rate of supply from the generator equals the rate at which the circuit including the generator is capable of taking up and getting rid of the energy. Since the resistance and self-induction of the working circuit C and the rapidity of the successive discharges may be varied at will, the current strength in the working and generating circuit may bear to one another any desired relation.

To understand the action of the local condenser E in Fig 2, let a single discharge be first considered. This discharge has two paths offered—one to the condenser E, the other through the part L of the working circuit C. The part L, however, by virtue of its self-induction, offers a strong opposition to such a sudden discharge, while the condenser, on the other band, offers no such opposition. The result is that practically no current passes at first through the branch L, but presumably opposite electricities rush to the condenser-coatings, this storing for the moment electrical energy in the condenser. Time is gained by this means, and the condenser then discharges through the branch L, this process being repeated for each discharge occurring at D. The amount of electrical energy stored in the condenser at each charge is dependent upon the capacity of the condenser and the potential of its plates. It is evident, therefore, that the quicker the discharges succeed each other the smaller for a given output need be the capacity of the condenser and the greater is also the efficiency of the condenser. This is confirmed by practical results.

The discharges occurring at D, as stated, may be of the same direction or may be alternating, and in the former case the devices contained in the working circuit may be traversed by currents of the same or alternately-opposite direction. It may be observed, however, that each intermittent discharge occurring at D may consist of a number of oscillations in the working circuit or branch L.

A periodically oscillating discharge will occur at D in Fig. 1 when the quantities concerned bear a certain relation expressed in well known formulae and ascertained by simple experiment. In this case it is demonstrated in theory and practice that the ratio of the strength of the current in the working to that in the generating circuits is the greater the greater the self-induction, and the smaller the resistance of the working circuit the smaller the period of oscillation.

I do not limit myself to the use of any specific forms of the apparatus described in connection with this invention nor to the precise arrangement of the system with respect to its details, herein shown. In the drawings return-wires are shown in the circuit; but it will be understood that in any case the ground may be conveniently used in lieu of the return wire.

What I claim is—

1. The method of electrical conversion herein described, which consists in charging a con-

denser or conductor possessing capacity and maintaining a succession of intermittent or oscillating disruptive discharges of said conductor into a working circuit containing translating devices.

2. In a system of electrical conversion, the combination of a generator or source of electricity and a line or generating circuit containing a condenser or possessing capacity, and a working circuit operatively connected with the generating-circuit through one or more air-gaps or breaks in the conducting medium, the electrical conditions being so adjusted that an intermittent or oscillating disruptive discharge from the generating into the working circuit will be maintained, as set forth.

NIKOLA TESLA

Witnesses:
ROBT. F. GAYLORD,
PARKER W. PAGE.

P-224

(No Model.)

N. TESLA

METHOD OF AND APPARATUS FOR ELECTRICAL CONVERSION AND DISTRIBUTION

No. 462,418 Patented Nov 3, 1891

Fig. 1

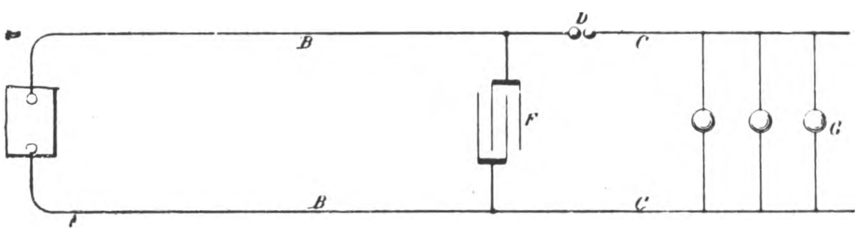
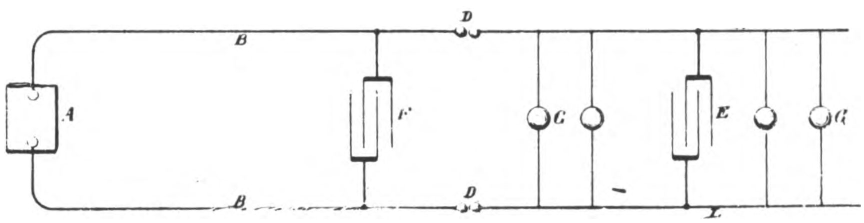


Fig. 2



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UNITED STATES PATENT OFFICE.

NIKOLA TESLA, OF NEW YORK, N.Y.

MEANS FOR GENERATING ELECTRIC CURRENTS.

SPECIFICATION forming part of Letters Patent No. 514,168, dated February 6, 1894.

Application filed August 2, 1893. Serial No. 432,194. (No model.)

To all whom it may concern:

Be it known that I, NIKOLA TESLA, a citizen of the United States, residing at New York, in the county and State of New York, have invented certain new and useful Improvements in Means for Generating Electric Currents, of which the following is a specification, reference being had to the drawings accompanying and forming a part of the same.

The invention, subject of my present application, is an improvement applicable more especially to the method or system of generating and utilizing electrical energy, heretofore discovered by me, and more fully set forth in Letters Patent No. 454,622, of June 23, 1891, and No. 462,418, of November 3, 1891, and which involves the maintenance of an intermittent or oscillatory discharge of a condenser or circuit, of suitable capacity into a working circuit containing translating devices. In systems of this character when the high frequency of the currents employed is due to the action of a disruptive or intermittent discharge across an air gap or break at some point of the circuit, I have found it to be of advantage not only to break up or destroy the least tendency to continuity of the arc or discharge, but also to control the period of the re-establishment of the same, and from investigations made by me with this object in view I have found that greatly improved results are secured by causing the discharge to take place in and through an insulating liquid, such as oil, and instead of allowing the terminal points of the break to remain at a uniform distance from each other, to vary such distance by bringing them periodically in actual contact or sufficiently near to establish the discharge and then separating them, or what is the equivalent of this, throwing in and out of the gap or break a conducting bridge at predetermined intervals. To obtain the best results, moreover, I find it essential to maintain at the point of discharge a flow of the insulating medium, or, in general, such a circulation of the same as will constantly operate to cut off or break up the discharge as fast as it is established. The accomplishment of this latter result involves the employment of some mechanism for maintaining the flow or circulation of the insulating medium past the points of discharge, and I take advantage of the presence of such mechanism to accomplish a further and beneficial result which is the maintenance of a flow or circulation of the insulating liquid in which I immerse the converter coils used for raising the potential of the current, and also the condenser plates when such are required and used. By this means the insulating liquid surrounding the said coils and plates may be prevented from heating, either by its circulation alone or by the application to it while in motion of a cooling medium, and its requisite qualities preserved for an indefinite time.

Broadly considered the plan contemplated is entirely independent of the special means for carrying it into execution, but in illustration of the preferred manner in which the invention is or may be carried out, I now refer to the drawings which are hereto annexed.

Figure 1 is a diagram of the system and devices employed by me. Fig. 2 is a sectional view of a detail of mechanism.

G represents an electric generator, as for instance, an ordinary alternator, in the circuit of which is the primary P of a transformer, of which S represents the secondary, which is usually of much longer and finer wire than the primary. To the secondary circuit, if it have not of itself sufficient capacity for the purpose herein contemplated, are connected the plates of a condenser C, and at any point in said circuit is a break or gap at which occurs the disruptive discharge. In a portion of the secondary circuit, preferably in series with the condenser, as shown in the drawings, is a primary coil P' with which is associated a secondary S', which latter constitutes the ultimate source of currents for a working circuit D in which or with which are connected translating devices E. Under the conditions assumed it will be understood that by the oscillation or change caused by the action of the discharge, the condenser is charged and discharged setting up in the primary P' an electrical disturbance of enormous frequency, as has been explained in my patent referred to, and as is now well understood. Instead of employing two terminals at a fixed distance, however, for the gap across which the discharge takes place, I vary the distance between them, or what is practically the same thing, I interpose between said terminals a conductor or a series of conductors successively by means of which the effective distance or length of the path of discharge is or may be varied at will. This I accomplish in the following manner:

A is a pipe or tube that leads into a tank B. To the end of this tube is secured an extension F, of insulating material and the two terminals G' G' are caused to project through the sides of the same, as indicated in Fig. 2. Within the extension I secure two cross-bars H which afford bearings for the spindle of a small metallic turbine I, the blades of which, as the turbine revolves, bridge the space between the two terminals, nearly or quite touching the terminals in their movement. If now the tank B. be filled with oil and the latter is drawn off or permitted to flow off through the tube A, the turbine will be rotated by the flow, the rate of rotation being dependent upon the rate of flow. By this means the arc or discharge is periodically established through a flow of oil, which secures in the most satisfactory manner the conditions best adapted for practical results.

The further objects of the invention are secured by placing the transformer P' S' in the body of oil in the tank B, and the condenser in a closed receptacle L. Then in order to maintain a circulation of the oil and to provide for the requisite flow which rotates the turbine, I connect the tank B with the condenser box L by means of the pipe A. I also run a pipe M from the box L to a small rotary pump N, and another pipe O from the latter back to the tank B.

When necessary or desirable I may insert in the pipe O a coil R, which is contained in a jacket T through which a cooling medium is passed.

The flow of oil is regulated by the speed at which the pump N is driven, and by this means the period of re-establishment of the arc is controlled.

Having now described my invention and the best means of which I am aware in which the same is or may be carried into effect, what I claim is—

1. In an electric system of the kind described, the combination with the points or terminals between which occurs the intermittent or oscillating discharge of means for maintaining between said points and in the path of the discharge a flow of insulating liquid, as set forth.

2. In an electrical system of the kind described, the combination with a transformer, and the points or terminals between which occurs the intermittent or oscillating discharge, of a body of insulating liquid surrounding the same, and means for maintaining a flow or circulation of the same, as set forth.

3. In an electrical system of the kind described, the combination with a transformer and the points or terminals between which occurs the intermittent or oscillating discharge, of receptacles inclosing the same and containing oil and means for maintaining a flow of the oil through said receptacles and around the devices therein, as set forth.

4. In an electrical system of the kind described, the combination with the points or terminals between which occurs the intermittent or oscillating discharge, of a means for maintaining a flow of insulating liquid between the discharge points, and means for varying the length of the path of discharge through such fluid, dependent for operation upon the flow of the same, as set forth.

5. The combination with discharge points immersed in oil, of means for periodically varying the length of the path of discharge between them, as described.

6. The combination with discharge points immersed in oil, of a conductor adapted to periodically bridge the space between such points, as set forth.

7. The combination with discharge points immersed in oil, means for causing a flow of the oil between said points and a metallic turbine mounted between the points and adapted by the rotation produced by the flowing oil to bridge with its vanes or blades the space between the said points.

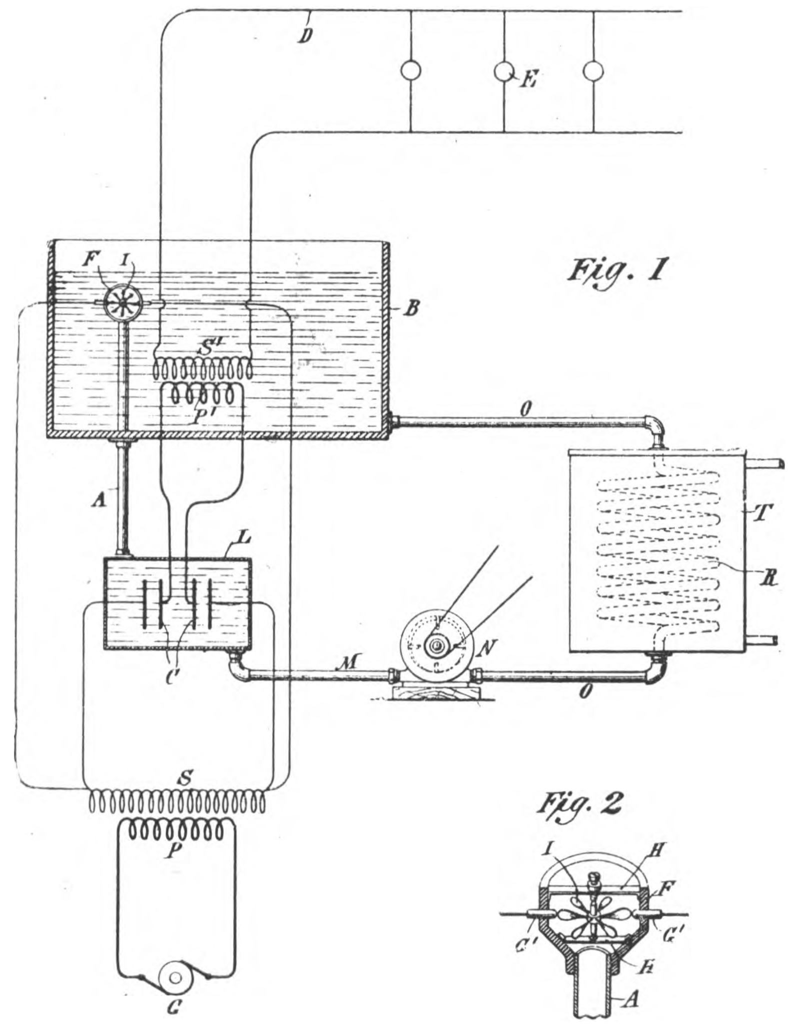
NIKOLA TESLA.

Witnesses:
ROBT. F. GAYLORD,
PARKER W. PAGE.

(No Model.)

N. TESLA.
MEANS FOR GENERATING ELECTRIC CURRENTS.

No. 514,168. Patented Feb. 6, 1894.



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UNITED STATES PATENT OFFICE.

NIKOLA TESLA, OF NEW YORK, N. Y.

METHOD OF REGULATING APPARATUS FOR PRODUCING CURRENTS OF HIGH FREQUENCY.

SPECIFICATION forming part of Letters Patent No. 568,178, dated September 22, 1896.

Application filed June 20, 1896. Serial No. 596,262. (No model.)

To all whom it may concern:

Be it known that I, NIKOLA TESLA, a citizen of the United States, residing at New York, in the county and State of New York, have invented certain new and useful Improvements in Methods of Regulating Apparatus for Producing Currents of High Frequency, of which the following is a specification, reference being had to the drawings accompanying and forming a part of the same.

In previous patents and applications I have shown and described a method of and apparatus for generating electric currents of high frequency suitable for the production of various novel phenomena, such as illumination by means of vacuum-tubes, the production of ozone, Roentgen shadows, and other purposes. The special apparatus of this character which I have devised for use with circuits carrying currents in the nature of those classed as direct, or such as are generally obtainable from the ordinary circuits used in municipal systems of incandescent lighting, is based upon the following principles:

The energy of the direct-current supply is periodically directed into and stored in a circuit of relatively high self-induction, and in such form is employed to charge a condenser or circuit of capacity, which, in turn, is caused to discharge through a circuit of low self-induction containing means whereby the intermittent current of discharge is raised to the potential necessary for producing any desired effect.

Considering the conditions necessary for the attainment of these results, there will be found, as the essential elements of the system, the supply-circuit, from which the periodic impulses are obtained, and what may be regarded as the local circuits, comprising the circuit of high self-induction for charging the condenser and the circuit of low self-induction into which the condenser discharges and which itself may constitute the working circuit, or that containing the devices for utilizing the current, or may be inductively related to a secondary circuit which constitutes the working circuit proper. These several circuits, it will be understood, may be more or less interconnected; but for purposes of illustration they may be regarded as practically distinct, with a circuit-controller for alternately connecting the condenser with the circuit by which it is charged and with that into which it discharges, and with a primary of a transformer in the latter circuit having its secondary in that which contains the devices operated by the current.

To this system or combination the invention, subject of my present application, pertains, and has for its object to provide a proper and economical means of regulation therefor.

It is well known that every electric circuit, provided its ohmic resistance does not exceed certain definite limits, has a period of vibration of its own analogous to the period of vibration of a weighted spring. In order to alternately charge a given circuit of this character by periodic impulses impressed upon it and to discharge it most effectively, the frequency of the impressed impulses should bear a definite relation to the frequency of vibration possessed by the circuit itself. Moreover, for like reasons the period or vibration of the discharge-circuits should bear a similar relation to the impressed impulses or the period of the charging-circuit. When the conditions are such that the general law of harmonic vibrations is followed, the circuits are said to be in resonance or in electromagnetic synchronism, and this condition I have found in my system to be highly advantageous. Hence in practice I adjust the electrical constants of the circuits so that in normal operation this condition of resonance is approximately attained. To accomplish this, the number of impulses of current directed into the charging-circuit per unit time is made equal to the period of the charging-circuit itself, or, generally, to a harmonic thereof, and the same relations are maintained between the charging and discharge circuit. Any departure from this condition will result in a decreased output, and this fact I take advantage of in regulating such output by varying the frequencies of the impulses or vibrations in the several circuits.

Inasmuch as the period of any given circuit depends upon the relations of its resistance, self-induction, and capacity, a variation of any one or more of these may result in a variation in its period. There are therefore various ways in which the frequencies of vibration of the several circuits in the system referred to may be varied, but the most practicable and efficient ways of accomplishing the desired result are the following: (*a*) varying the rate of the impressed impulses of current, or those which are directed from the source of supply into the charging-circuit, as by varying the speed of the commutator or other circuit-controller; (*b*) varying the self-induction of the charging-circuit; (*c*) varying the self-induction or capacity of the discharge-circuit.

To regulate the output of a single circuit which has no vibration of its own by merely varying its period would evidently require, for any extended range of regulation, a very wide range of variation of period; but in the system described a very wide range of regulation of the output may be obtained by a very slight change of the frequency of one of the circuits when the above-mentioned rules are observed.

In illustration of my invention I have shown by diagrams in the accompanying drawings some of the more practicable means for carrying out the same. The figures, as stated, are diagrammatic illustrations of the system in its typical form provided with regulating devices of different specific character. These diagrams will be described in detail in their order.

In each of the figures, A B designate the conductors of a supply-circuit of continuous current; C, a motor connected therewith in any of the usual ways and driving a current-controller D, which serves to alternately close the supply-circuit through the motor or through a self-induction coil E and to connect such motor-circuit with a condenser F, the circuit of which contains a primary coil G, in proximity to which is a secondary coil H, serving as the source of supply to the working circuit, or that in which are connected up the devices K K for utilizing the current.

The circuit-controller, it may be stated, is any device which will permit of a periodic charging of the condenser F by the energy of the supply-circuit and its discharging into a circuit of low self-induction supplying directly or indirectly the translating devices. Inasmuch as the source of supply is generally of low potential, it is undesirable to charge the condenser directly therefrom, as a condenser of large capacity will in such cases be required. I therefore employ a motor of high self-induction, or in place of or in addition to such motor a choking or self-induction coil E, to store up the energy of the supply current directed into it and to deliver it in the form of a high-potential discharge when its circuit is interrupted and connected to the terminals of the condenser.

In order to secure the greatest efficiency in a system of this kind, it is essential, as I have before stated, that the circuits, which, mainly as a matter of convenience, I have designated as the "charging" and the "discharge" circuits, should be approximately in resonance or electromagnetic synchronism. Moreover, in order to obtain the greatest output from a given apparatus of this kind, it is desirable to maintain as high a frequency as possible.

The electrical conditions, which are now well understood, having been adjusted to secure, as far as practical considerations will permit, these results, I effect, the regulation of the system by adjusting its elements so as to depart in a greater or less degree from the above conditions with a corresponding variation of output. For example, as in Figure 1, I may vary the speed of the motor, and consequently of the controller, in any suitable manner, as by means of a rheostat L in a shunt to such motor or by shifting the position of the brushes on the main commutator M of the motor or otherwise. A very slight variation in this respect, by disturbing the relations between the rate of impressed impulses and the vibration of the circuit of high self-induction into which they are directed, causes a marked departure from the condition of resonance and a corresponding reduction in the amount of energy delivered by the impressed impulses to the apparatus.

A similar result may be secured by modifying any of the constants of the local circuits, as above indicated. For example, in Fig. 2 the choking-coil E is shown as provided with an adjustable core N, by the movement of which into and out of the coil the self-induction, and consequently the period of the circuit containing such coil, may be varied.

As an example of the way in which the discharge-circuit, or that into which the condenser discharges, may be modified to produce the same result I have shown in Fig. 3 an adjustable self-induction coil R in the circuit with the condenser, by the adjustment of which the period of vibration of such circuit may be changed.

The same result would be secured by varying the capacity of the condenser; but if the condenser were of relatively large capacity this might be an objectionable plan, and a more practicable method is to employ a variable condenser in the secondary or working circuit, as shown in Fig. 4. As the potential in this circuit is raised to a high degree, a condenser of very small capacity may be employed, and if the two circuits, primary and secondary, are very intimately and closely connected the variation of capacity in the secondary is similar in its effects to the variation of the capacity of the condenser in the primary. I have illustrated as a means well adapted for this purpose two metallic plates S S, adjustable to and from each other and constituting the two armatures of the condenser.

I have confined the description herein to a source of supply of direct current, as to such the invention more particularly applies, but it will be understood that if the system be supplied by periodic impulses from any source which will effect the same results the regulation of the system may be effected by the method herein described, and this my claims are intended to include.

What I claim is—

1. The method of regulating the energy delivered by a system for the production of high-frequency currents and comprising a supply-circuit, a condenser, a circuit through which the same discharges and means for controlling the charging of the condenser by the supply-circuit and the discharging of the same, the said method consisting in varying the relations of the frequencies of the impulses in the circuits comprising the system, as set forth.

2. The method of regulating the energy delivered by a system for the production of high-frequency currents comprising a supply-circuit of direct currents, a condenser adapted to be charged by the supply-circuit and to discharge through another circuit, the said method consisting in varying the frequency of the impulses of current from the supply-circuit, as set forth.

3. The method of producing and regulating electric currents of high frequency which consists in directing impulses from a supply-circuit into a charging-circuit of high self-induction, charging a condenser by the accumulated energy of such charging-circuit, discharging the condenser through a circuit of low self-induction, raising the potential of the condenser discharge and varying the relations of the frequencies of the electrical impulses in the said circuits, as herein set forth.

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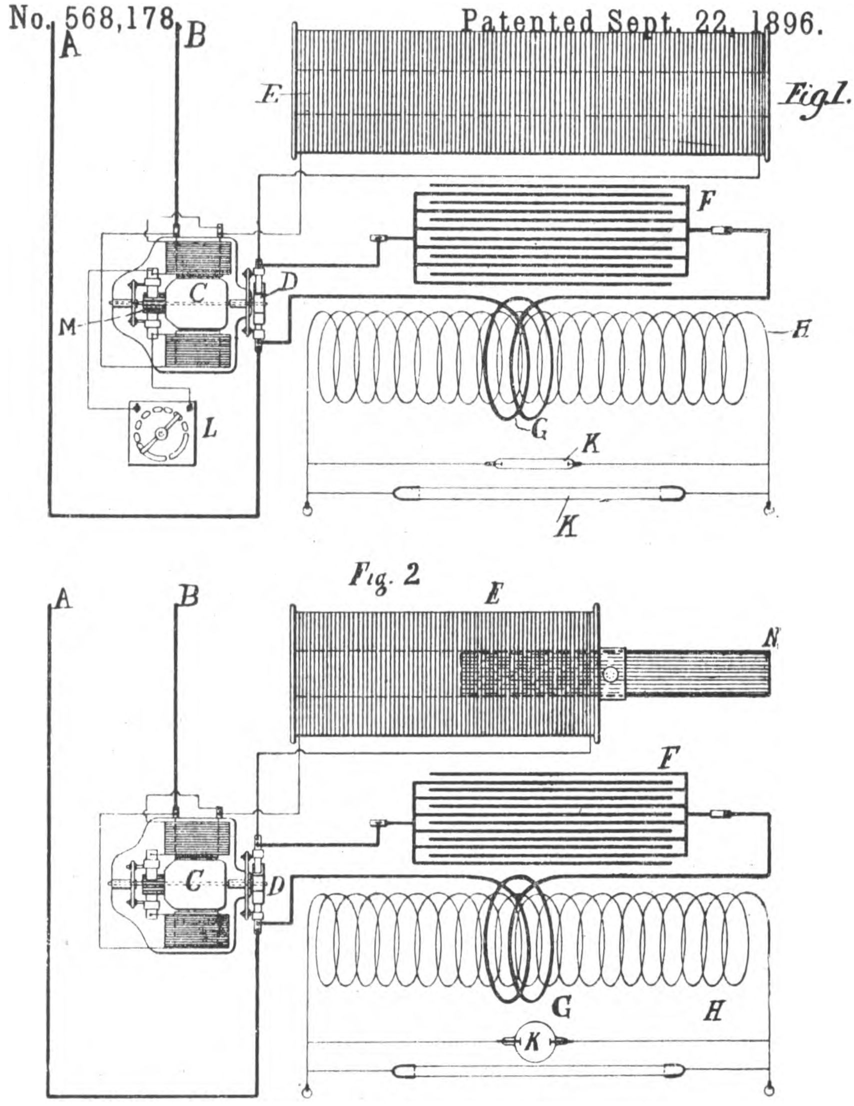
(No Model.) 2 Sheets—Sheet 1

N. TESLA.

METHOD OF REGULATING APPARATUS FOR PRODUCING CURRENTS OF HIGH FREQUENCY.

No. 568,178. Patented Sept. 22, 1896.



WITNESSES
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P-232

(No Model.) 2 Sheets—Sheet 2

N. TESLA.

METHOD OF REGULATING APPARATUS FOR PRODUCING CURRENTS OF HIGH FREQUENCY.

No. 568,178. Patented Sept. 22, 1896

Fig. 3.

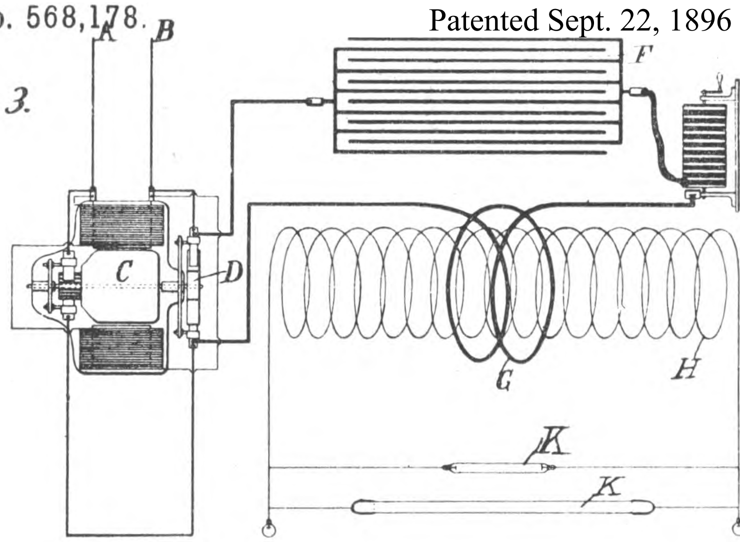
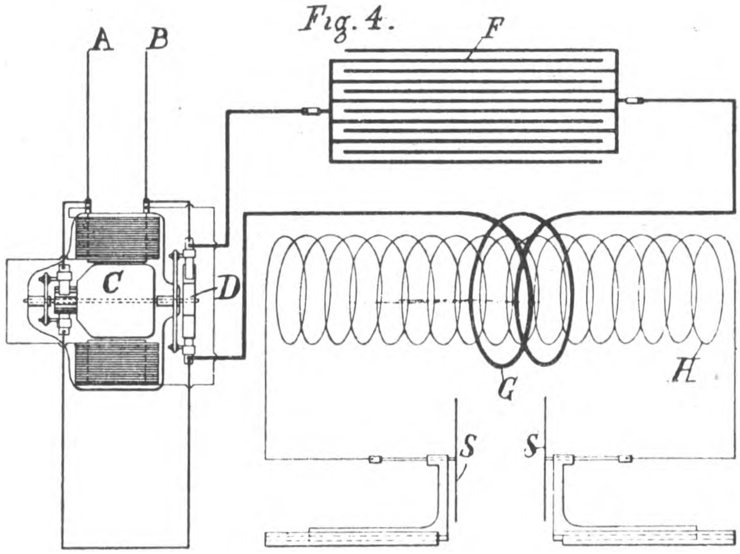


Fig. 4.



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UNITED STATES PATENT OFFICE.

NIKOLA TESLA, OF NEW YORK, N. Y.

APPARATUS FOR PRODUCING ELECTRIC CURRENTS OF HIGH FREQUENCY AND POTENTIAL.

SPECIFICATION forming part of Letters Patent No. 568,176, dated September 22, 1896.

Application filed April 22, 1896. Serial No. 588,534. (No model.)

To all whom it may concern:

Be it known that I, NIKOLA. TESLA, a citizen of the United States, residing at New York, in the county and State of New York, have invented certain new and useful Improvements in Apparatus for the Production of Electric Currents of High Frequency and Potential, of which the following is a specification, reference being had to the drawings accompanying and forming a part of the same.

The invention which forms the subject of my present application is embodied in an improvement on an electrical apparatus invented by me and described in prior Letters Patent, notably in United States Patents No. 462,418, dated November 3, 1891, and No. 454,622, dated June 23, 1891. This apparatus was devised for the purpose of converting and supplying electrical energy in a form suited for the production of certain novel electrical phenomena which require currents of higher frequency and potential than can readily or even possibly be developed by generators of the ordinary types or by such mechanical appliances as were theretofore known. The apparatus, as a whole, involves means for utilizing the intermittent or oscillating discharge of the accumulated electrical energy of a condenser or a circuit possessing capacity in what may be designated the "working" circuit, or that which contains the translating devices or those which are operated by such currents.

The object of my present improvements is to provide a simple, compact, and effective apparatus for producing these effects, but adapted more particularly for direct application to and use with existing circuits carrying direct currents, such as the ordinary municipal incandescent-lighting circuits. The way in which I accomplish this, so as to meet the requirements of practical and economical operation under the conditions present, will be understood from a general description of the apparatus which I have devised. In any given circuit, which for present purposes may be considered as conveying direct currents or those of substantially the character of direct or continuous currents and which for general purposes of illustration may be assumed to be a branch or derived circuit across the mains from any ordinary source, I interpose a device or devices in the nature of a choking-coil in order to give to the circuit a high self-induction. I also provide a circuit-controller of any proper character that may be operated to make and break said circuit. Around the break or point of interruption I place a condenser or condensers to store the energy of the discharge-current, and in a local circuit and in series with such condenser I place the primary of a transformer, the secondary of which then becomes the source of the currents of high frequency. It will be apparent from a consideration of the conditions involved that were the condenser to be directly charged by the current from the source and then discharged into the working circuit a very large capacity would ordinarily be required, but by the above arrangement the current of high electromotive force which is induced at each break of the main circuit furnishes the proper current for charging the condenser, which may therefore be small and inexpensive. Moreover, it will be observed that since the self-induction of the circuit through which the condenser discharges, as well as the capacity of the condenser itself, may be given practically any desired value, the frequency of the discharge-current may be adjusted at will.

The object sought in this invention may be realized by specifically different arrangements of apparatus, but in the drawings hereto annexed I have illustrated forms which are typical of the best and most practicable means for carrying out the invention of which I am at present aware.

Figure 1 is a diagrammatic illustration of the apparatus, and Fig. 2 a modification of the same.

Referring to Fig. 1, A designates any source of direct current. In any branch of the circuit from said source, such, for example, as would be formed by the conductors A" A" from the mains A' and the conductors K K, are placed self-induction or choking coils B B and a circuit-controller C. This latter may be an ordinary metallic disk or cylinder with teeth or separated segments D D E E, of which one or more pairs, as E E, diametrically opposite, are integral or in electrical contact with the body of the cylinder, so that when the controller is in the position in which the two brushes F F bear upon two of said segments E E the circuit through the choking-coils B will be closed. The segments D D are insulated, and while shown in the drawings as of substantially the same length of arc as the segments E E this latter relation may be varied at will to regulate the periods of charging and discharging.

The controller C is designed to be rotated by any proper device, such, for example, as an electromagnetic motor, as shown in Fig. 2, receiving current either from the main source or elsewhere. Around the controller C, or in general in parallel therewith, is a condenser H, and in series with the latter the primary K of a transformer, the secondary L of which constitutes the source of the currents of high frequency which may be applied to many useful purposes, as for electric illumination, the operation of Crooke's tubes, or the production of high vacua.

L' indicates the circuit from the secondary, which may be regarded as the working circuit.

A more convenient and simplified arrangement of the apparatus is shown in Fig. 2. In this case the small motor G, which drives the controller, has its field-coils in derivation to the main circuit, and the controller C and condenser H are in parallel in the field-circuit between the two coils. In such case the field-coils M take the place of the choking-coils B. In this arrangement, and in fact generally, it is preferable to use two condensers or a condenser in two parts and to arrange the primary coil of the transformer between them. The interruptions of the field-circuit of the motor should be so rapid as to permit only a partial demagnetization of the cores. These latter, however, should in this specific arrangement be laminated,

The apparatus, as will now be seen, comprises, as essential elements, choking-coils, a circuit-controller, means for rotating the same, a condenser, and a transformer. These elements may be mechanically associated in any convenient and compact form, but so far as their general arrangement and relations are concerned I prefer the relative disposition illustrated, mainly because, by reason of their symmetrical arrangement in the circuit, the liability of injury to the insulation of any of the devices is reduced to a minimum.

I do not mean to imply by the terms employed in describing my improvements that I limit myself to the use of the precise devices commonly designated by such terms For instance, the choking-coil as a distinctive device may be wholly dispensed with, provided the circuit in which it must otherwise be placed have a sufficiently high self-induction produced in other ways. So, too, the necessity of a condenser, strictly speaking, is avoided when the circuit itself possesses sufficient capacity to accomplish the desired result.

Having now described my invention and the manner in which the same is or may be carried into practical effect, what I claim is—

1. The apparatus herein described for converting direct currents into currents of high frequency, comprising in combination a circuit of high self-induction, a circuit-controller adapted to make and break such circuit, a condenser into which the said circuit discharges when interrupted, and a transformer through the primary of which the condenser discharges as set forth.

2. The combination of a source of direct current and a circuit therefrom, choking-coils In said circuit, means for making and breaking the circuit through said coils, a condenser around the point of interruption in the said circuit and a transformer having its primary in circuit with the condenser as set forth.

3. The combination with a circuit of high self-induction and means for making and breaking the same, of a condenser around the point of interruption in the said circuit, and a transformer the primary of which is in the condenser-circuit as described.

4. The combination with a circuit of direct current and having a high self-induction, of a circuit-controller for making and breaking said circuit, a motor for driving the controller, a condenser in a circuit connected with the first around the point of interruption therein, and a transformer the primary of which is in circuit with the condenser as set forth.

5. The combination with a circuit of direct current, a controller for making and breaking the same, a motor having its field-magnets in said circuit and driving the said controller, a condenser connected with the circuit around the point of interruption therein and a transformer the primary of which is in circuit with the condenser as set forth.

NIKOLA TESLA

Witnesses;
EDWIN B. HOPKINSON,
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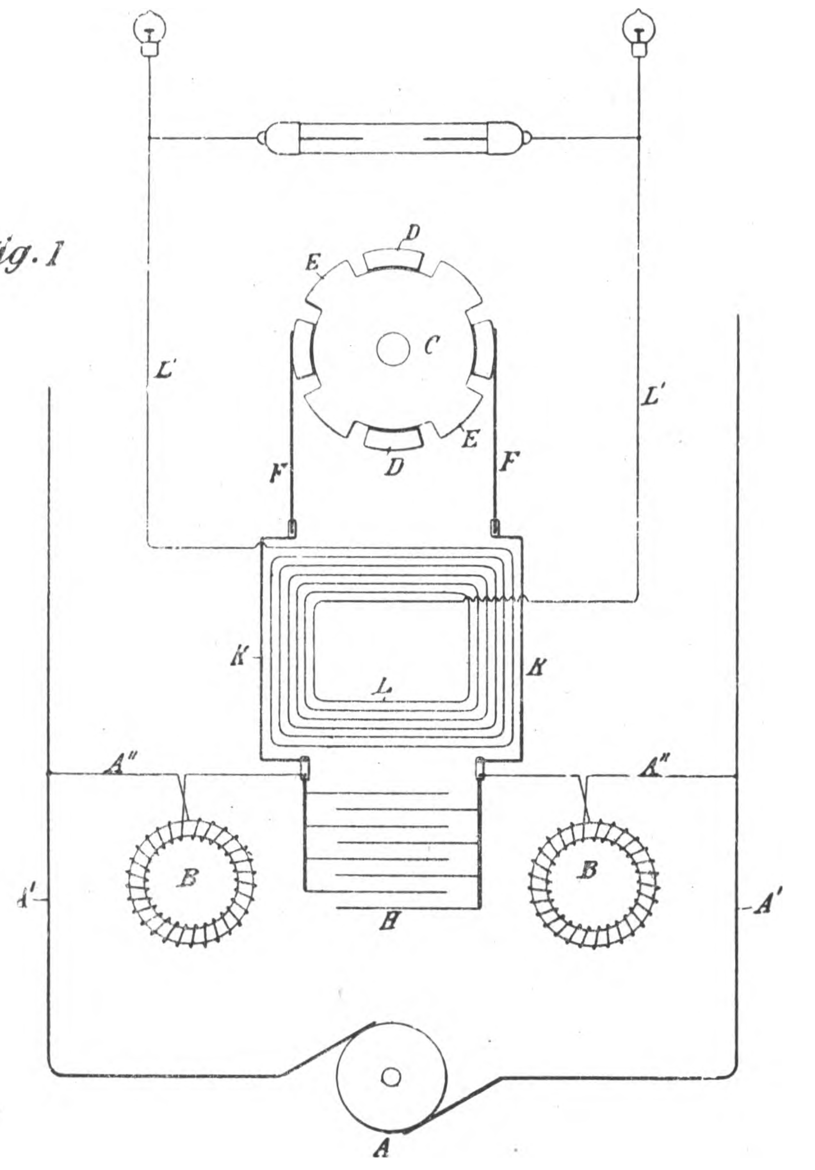
(No Model.) 2 Sheets—Sheet 1

N. TESLA

APPARATUS FOR PRODUCING ELECTRIC CURRENTS OF HIGH FREQUENCY AND POTENTIAL.

No. 568,176 Patented Sept. 22, 1896.

Fig. 1



Witnesses:
Raphaël Netter
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Nikola Tesla, Inventor
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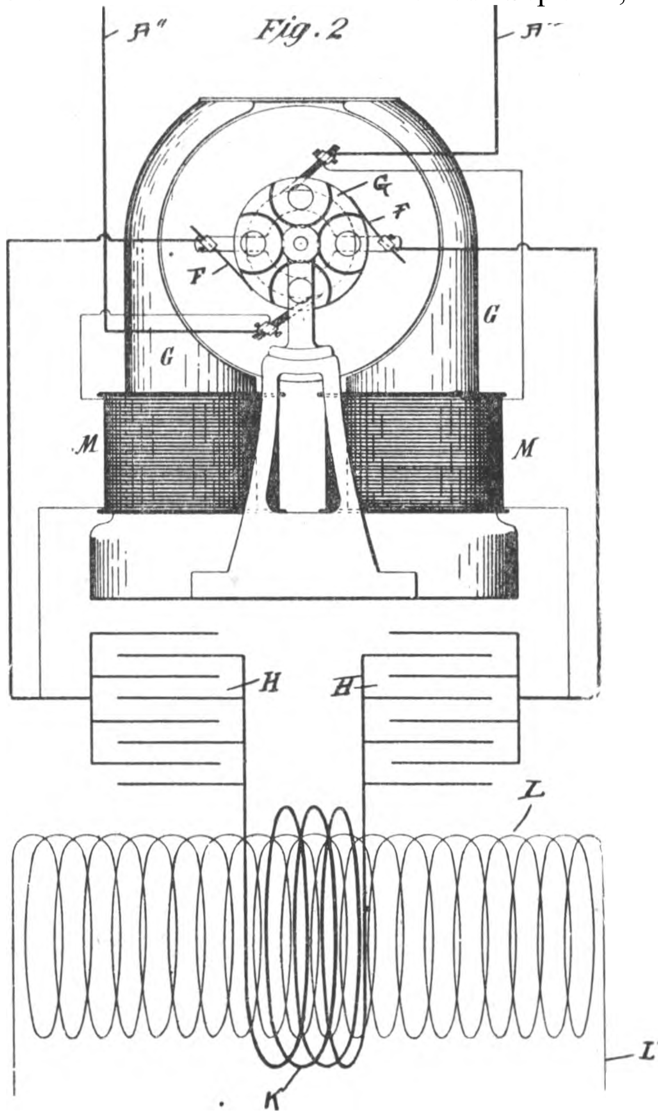
P-236

(No Model.) 2 Sheets—Sheet 2

N. TESLA.

APPARATUS FOR PRODUCING ELECTRIC CURRENTS OF HIGH FREQUENCY AND POTENTIAL.

No. 568,176. Patented Sept. 22, 1896.



WITNESSES:

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UNITED STATES PATENT OFFICE.

NIKOLA TESLA, OF NEW YORK, N. Y.

METHOD OF AND APPARATUS FOR PRODUCING CURRENTS OF HIGH FREQUENCY.

SPECIFICATION forming part of Letters Patent No. 568,179, dated September 22, 1896.
Application filed July 6, 1896. Serial No. 598,130. (No model.)

To all whom it may concern:

Be it known that I, NIKOLA TESLA, a citizen of the United States, residing at New York, in the county and State of New York, have invented certain new and useful Improvements in Methods of and Apparatus for Producing Currents of High Frequency, of which the following is a specification, reference being had to the drawings accompanying and forming a part of the same.

The apparatus for producing electrical currents of very high frequency in which is embodied the invention of my present application involves as its chief element means for the periodic charging of a condenser or circuit possessing capacity by the energy of a given source and the discharge of the same through a circuit of low self-induction, Whereby the rapid succession of impulses characteristic of a condenser discharge under such circumstances is made available for many practical and useful purposes.

The general arrangement of circuits and apparatus which I prefer for ordinary applications of this invention I have shown and described in an application filed by me April 22, 1896, Serial No. 588,534, as comprising a local circuit of high self-induction connected with a source of supply, a condenser, a discharge-circuit of low self-induction, and a circuit-controller operating to alternately effect the charging of the condenser by the energy-stored in the circuit of high self-induction and its discharge through that of low self-induction. I have shown, however, in the application referred to as the source of supply a continuous-current generator, or in general a source of direct currents, and while the principle of operation and the general character of the apparatus remain the same whether the current of the source be direct or alternating, yet the economical utilization of the latter involves certain special principles and appliances which it is my present object to illustrate as the basis for the claims of invention made herein.

When the potential of the source periodically rises and falls, whether with reversals or not is immaterial, it is essential to economical operation that the intervals of interruption of the charging-current should bear a definite time relation to the period of the current, in order that the effective potential of the impulses charging the condenser may be as high as possible. I therefore provide, in case an alternating or equivalent electromotive force be employed as the source of supply, a circuit-controller which will interrupt the charging-circuit at instants predetermined with reference to the variations of potential therein. The most practicable, means for accomplishing this of which I am. aware is to employ a synchronous motor connected with the source of supply and operating a circuit-controller which interrupts the charging-current at or about the instant of highest potential of each wave and permits the condenser to discharge the energy stored in it through its appropriate circuit. This apparatus, which may be considered as typical of the means employed for carrying out the invention, I have illustrated in the accompanying drawings.

The figures are diagrammatic illustrations of the system in slightly-modified forms, and will be described in detail in their order.

Referring to Figure 1, A designates any source of alternating or equivalent current, from which lead off mains A' A. At any point where it is desired to produce the high-frequency currents a branch circuit B is taken off from the mains, and in order to raise the potential of the current a transformer is employed, represented by the primary C and secondary D. The circuit of the secondary includes the energizing-coils of a synchronous motor E and a circuit-controller, which, in the present instance, in Fig. 1 is shown as composed of a metal disk F with insulated segments F' in its periphery and fixed to the shaft of the motor. An insulating-arm G, stationary with respect to the motor-shaft and adjustable with reference to the poles of the fixed magnets, carries two brushes H H, which bear upon the periphery of the disk. With the parts thus arranged the secondary circuit is completed through the coils of the motor whenever the two brushes rest upon the uninsulated segments of the disk and interrupted through the motor at other times. Such a motor, if properly constructed, in well-understood ways, maintains very exact synchronism with the alterations of the source, and the arm G may therefore be adjusted to interrupt the current at any determined point in its waves. It will be understood that by the proper relations of insulated and conducting segments and the motor-poles the current may be interrupted twice in each complete wave at or about, the points of highest potential. The self-induction of the circuit containing the motor and controller should be high, and the motor itself will usually be constructed in such manner that no other self-induction device will be needed. The energy stored in this circuit is utilized at each break therein to charge a condenser K. With this object the terminals of the condenser are connected to the two brushes H H or to points of the circuit adjacent thereto, so that when the circuit through the motor is interrupted the terminals of the motor-circuit will be connected with the condenser, whereby the latter will receive the high-potential inductive discharge from the motor or secondary circuit.

The condenser discharges into a circuit of low self-induction, one terminal of which is connected directly to a condenser-terminal and the other to the brush H opposite to that connected with the other condenser-terminal, so that the discharge-circuit of the condenser will be completed simultaneously with the motor-circuit and interrupted while the motor-circuit is broken and the condenser being charged.

The discharge-circuit contains a primary M of a few turns, and this induces in a secondary N impulses of high potential, which by reason of their great frequency are available for the operation of vacuum-tubes P, single terminal-lamps R, and other novel and useful purposes.

It is obvious that the supply-current need not be alternating, provided it be converted or transformed into an alternating current before reaching the controller. For example, the present improvements are applicable to various forms of rotary transformers, as is illustrated in Figs. 2 and 3.

E' designates a continuous-current motor, here represented as having four field-poles wound with coils E" in shunt to the armature. The line-wires B B connect with the brushes *b b*, bearing on the usual commutator.

On an extension of the motor-shaft is a circuit-controller composed of a cylinder the surface of which is divided into four conducting-segments *c* and four insulating-segments *d*, the former being diametrically connected in pairs, as shown in Fig. 3.

Through the shaft run two insulated conductors *e e* from any two commutator-segments ninety degrees apart, and these connect with the two pairs of segments *c*, respectively. With such arrangement it is evident that any two adjacent segments *c c* become the terminals of an alternating-current source, so that if two brushes H H be applied to the periphery of the cylinder they will take off current during such portion of the wave as the width of segment and position of the brushes may determine. By adjusting the position of the brushes relatively to the cylinder, therefore, the alternating current delivered to the segments *c c* may be interrupted at any point in its waves.

While the brushes H H are on the conducting-segments the current which they collect stores energy in a circuit of high self-induction formed by the wires *f f*, self-induction coils S S, the conductors B B, the brushes, and commutator. When this circuit is interrupted by the brushes H H passing on to the insulating-segments of the controller, the high-potential discharge of this circuit charges the condensers K K, which then discharge through the circuit of low self-induction containing the primary M. The secondary circuit N contains any devices, as P R, for utilizing the current.

The mechanical construction of the circuit-controller may be greatly varied, and in other respects the details shown and described are merely given as typical illustrations of the nature and purpose of the invention.

What I claim is—

1. The method herein described of producing electric currents of high frequency, which consists in generating an alternating current, charging a condenser thereby during determinate intervals of each wave of said current, and discharging the condenser through a circuit of low self-induction, as herein set forth.

2. The combination with a source of alternating current, a condenser, a circuit-controller adapted to direct the current during determinate intervals of each wave into the condenser for charging the same, and a circuit of low self-induction into which the condenser discharges, as set forth.

3. The combination with a source of alternating current, a synchronous motor operated thereby, a circuit-controller operated by the motor and adapted to interrupt the circuit through the motor at determinate points in each wave, a condenser connected with the motor-circuit and adapted on the interruption of the same to receive the energy stored therein, and a circuit into which the condenser discharges, as set forth.

4. The combination with a source of alternating current, a charging-circuit in which the energy of said current is stored, a circuit-controller adapted to interrupt the charging-circuit at determinate points in each wave, a condenser for receiving, on the interruption of the charging-circuit, the energy accumulated therein, and a circuit into which the condenser discharges when connected therewith by the circuit-controller, as set forth.

NIKOLA TESLA

Witnesses:
M. LAWSON DYER,
DRURY W. COOPER.

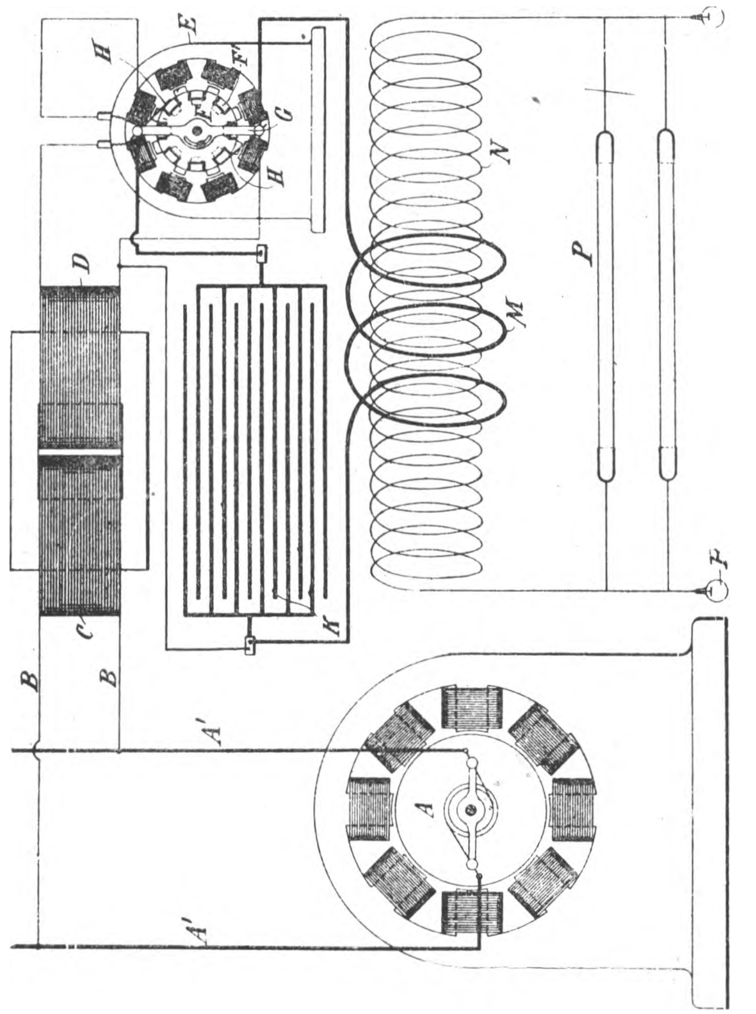
(No Model.) 2 Sheets—Sheet 1

N. TESLA.

METHOD OF AND APPARATUS FOR PRODUCING CURRENTS OF HIGH FREQUENCY.

No. 568,179. Patented Sept. 22, 1896.

Fig. 1



WITNESSES
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P-240

(No Model.) 2 Sheets—Sheet 2

N. TESLA.

METHOD OF AND APPARATUS, FOR PRODUCING CURRENTS OF HIGH FREQUENCY.

No. 568,179. Patented Sept. 22, 1896.

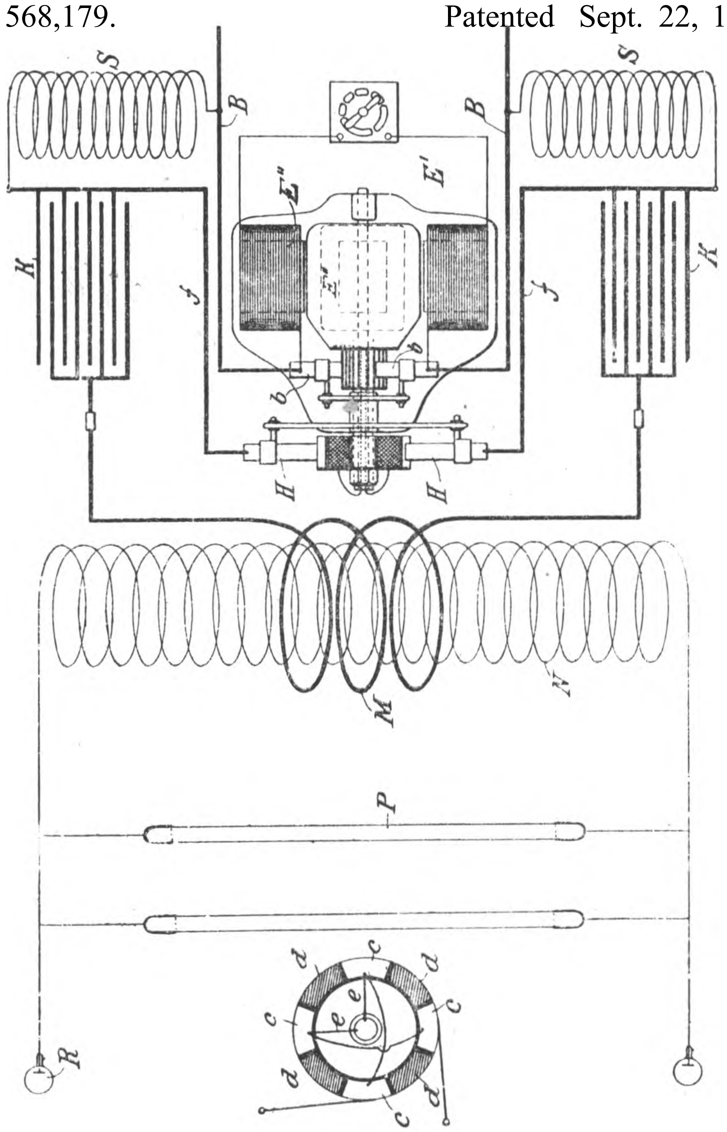

Fig. 2

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NIKOLA TESLA, OF NEW YORK, N. Y.

APPARATUS FOR PRODUCING ELECTRICAL CURRENTS OF HIGH FREQUENCY.

SPECIFICATION forming part of Letters Patent No. 568,180, dated September 22, 1896.

Application filed July 9, 1896. Serial No. 598,552. (No model.)

To all whom it may concern:

Be it known that I, NIKOLA TESLA, a citizen of the United States, residing at New York, in the county and State of New York, have invented certain new and useful Improvements in Apparatus for Producing Electrical Currents of High Frequency, of which the following is a specification, reference being had to the drawings accompanying and forming a part of the same.

This invention is an improvement in apparatus for producing electrical currents of high frequency in accordance with the general plan heretofore invented and practiced by me and based upon the principle of charging a condenser or circuit possessing capacity and discharging the same through a circuit of low self-induction, so that rapid electrical oscillations are obtained. To secure this result, I employ some means for intermittently charging the condenser and for discharging it through the circuit of low self-induction; and among the means which I have heretofore employed for this purpose was a mechanical contact device which controlled both the charging and the discharge-circuit in such manner that the condenser was alternately charged by the former and discharged into the latter.

My present improvement consists in an apparatus for effecting the same result by the use of a circuit-controller of special character in which the continuity of the paths for the current is established at intervals by the passage of sparks across a dielectric.

In carrying out my present improvement I employ a circuit-controller containing two terminals or sets of terminals movable with respect to each other into and out of proximity, and I provide means whereby the intervals between the periods of close approximation, during which the spark passes, may be adjusted so that when used in a system supplied by a source of alternating current the periods of make and break may be timed with reference to a phase of the current wave or impulse.

Referring to the drawings, which illustrate in its preferred form the improvement above referred to, Figure 1 is a view, partly in elevation and partly in section, of a generator arranged to give an alternating current with the circuit-controller mounted on its shaft. Fig. 2 is a section of the controller of Fig. 1 on line *x x* of said figure. Fig. 3 is a diagram illustrating the system or apparatus as a whole. Figs. 4 and 5 are sectional views of a modified form of circuit-controller.

A designates in Fig. 1 a generator having a commutator A' and brushes A'' bearing thereon, and also collecting-rings B B, from which an alternating current is taken by brushes B' in the well-understood manner.

The circuit-controller is mounted in part on an extension of the shaft C of the generator, and in part on the frame of the same, or on a stationary sleeve surrounding the shaft. Its construction in detail is as follows: D is a metal plate with a central hub D', which is keyed or clamped to the shaft C. The plate is formed with segmental extensions corresponding in number to the waves of current which the generator delivers. These segments are preferably cut away, leaving only rims or frames, to one of the radial sides of which are secured bent metal plates E, which serve as vanes to maintain a circulation of air when the device is in operation. The segmental disk and vanes are contained within a close insulated box or case F, mounted on the bearing of the generator, or in any other proper way, but so as to be capable of angular adjustment around the shaft. To facilitate such adjustment, a screw-rod F', provided with a knob or handle, is shown as passing through the wall of the box. The latter may be adjusted by this rod, and when in proper position may be held therein by screwing the rod down into a depression in the sleeve or bearing, as shown in Fig. 1. Air-passages G G are provided at opposite ends of the box, through which air is maintained in circulation by the action of the vanes. Through the sides of the box F and through insulating-gaskets H, when the material of the box is not a sufficiently good insulator, extend metallic terminal plugs K K, with their ends in the plane of the conducting segmental disk D and adjustable radially toward and from the edges of the segments. This or similar devices are employed to carry out the invention above referred to in the manner illustrated in Fig. 3. A in this figure represents any source of alternating current the potential of which is raised by a transformer, of which *a* is the primary and *b* the secondary. The ends of the secondary circuit S are connected to the terminal plugs K K of an apparatus similar to that of Figs. 1 and 2 and having segments rotating in synchronism with the alternations of the current source, preferably, as above described, by being mounted on the shaft of the generator when the conditions so permit. The plugs K K are then adjusted radially, so as to approach more or less the path of the outer edges of the segmental disk, and so that during the passage of each segment in front of a plug a spark will pass between them, which completes the secondary circuit S. The box or the support for the plugs K is adjusted angularly, so as to bring the plugs and segments into proximity at the desired instants with reference to any phase of the current-wave in the secondary circuit and fixed in position in any proper manner. To the plugs K K are also connected the terminals of a condenser or condensers L, so that at the instant of the rupture of the secondary circuit S by the cessation of the sparks the energy accumulated in such circuit will rush into and charge the condenser. A path of low self-induction and resistance, including a primary M of a few turns, is provided to receive the discharge of the condenser, when the circuit S is again completed by the passage of sparks, the discharge being manifested as a succession of extremely rapid impulses. The potential of these impulses may be raised by a secondary T, which constitutes the source of current for the working circuit or that containing the devices R for utilizing the current.

By means of this apparatus effects of a novel and useful character are obtainable, but to still further increase the efficiency of the discharge or working current I have in some instances provided a means for further breaking up the individual sparks themselves. A device for this purpose is shown in Figs. 4 and 5. The box or case F in these figures is fixedly secured to the frame or bearing of the generator or motor which rotates the circuit-controller in synchronism with the alternating source. Within said box is a disk D, fixed to the shaft C, with projections *d′* extending from its edge parallel with the axis of the shaft. A similar disk D" on a spindle *d*, in face of the first, is mounted in a bearing in the end of the box F with a capability of rotary adjustment. The ends of the projections *d′* are deeply serrated or several pins or narrow projections placed side by side, as shown in Fig. 4, so that as those of the opposite disks pass each other a rapid succession of sparks will pass from the projections of one disk to those of the other.

What I claim as my invention is—

1. The combination with a source of current, of a condenser adapted to be charged thereby, a circuit into which the condenser discharges in a series of rapid impulses, and a circuit-controller for effecting the charging and discharge of said condenser, composed of conductors movable into and out of proximity with each other, whereby a spark may be maintained between them and the circuit closed thereby during determined intervals, as set forth.

2. The combination with a source of alternating current, of a condenser adapted to be charged thereby, a circuit into which the condenser discharges in a series of rapid impulses, and a circuit-controller for effecting the charging and discharge of said condenser, composed of conductors movable into and out of proximity with each other in synchronism with the alternations of the source, as set forth.

3. A circuit-controller for systems of the kind described, comprising in combination a pair of angularly-adjustable terminals and two or more rotating conductors mounted to pass in proximity to the said terminals, as set forth.

4. A circuit-controller far systems of the kind described, comprising in combination two sets of conductors, one capable of rotation and the other of angular adjustment whereby they may be brought into and out of proximity to each other, at determinate points, and one or both being subdivided so as to present a group of conducting-points, as set forth.

NIKOLA TESLA.

Witnesses:
M. LAWSON DYER,
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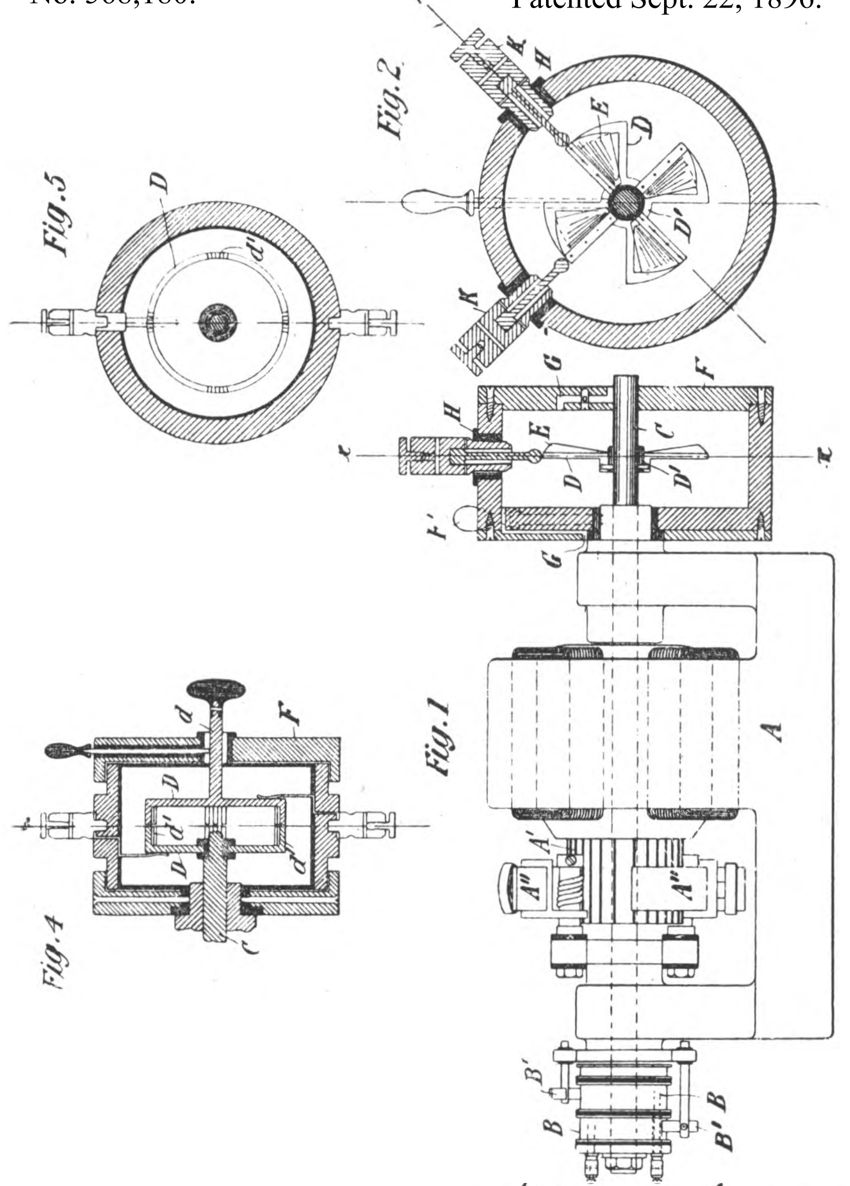
P-243

(No Model.) 2 Sheets—Sheet 1

N TESLA.

APPARATUS FOR PRODUCING ELECTRICAL CURRENTS OF HIGH FREQUENCY.

No. 568,180. Patented Sept. 22, 1896.



WITNESSES:

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P-244

(No Model.) 2 Sheets—Sheet 2

N. TESLA

APPARATUS FOR PRODUCING ELECTRICAL CURRENTS OF HIGH FREQUENCY.

No. 568,180. Patented Sept. 22, 1890.

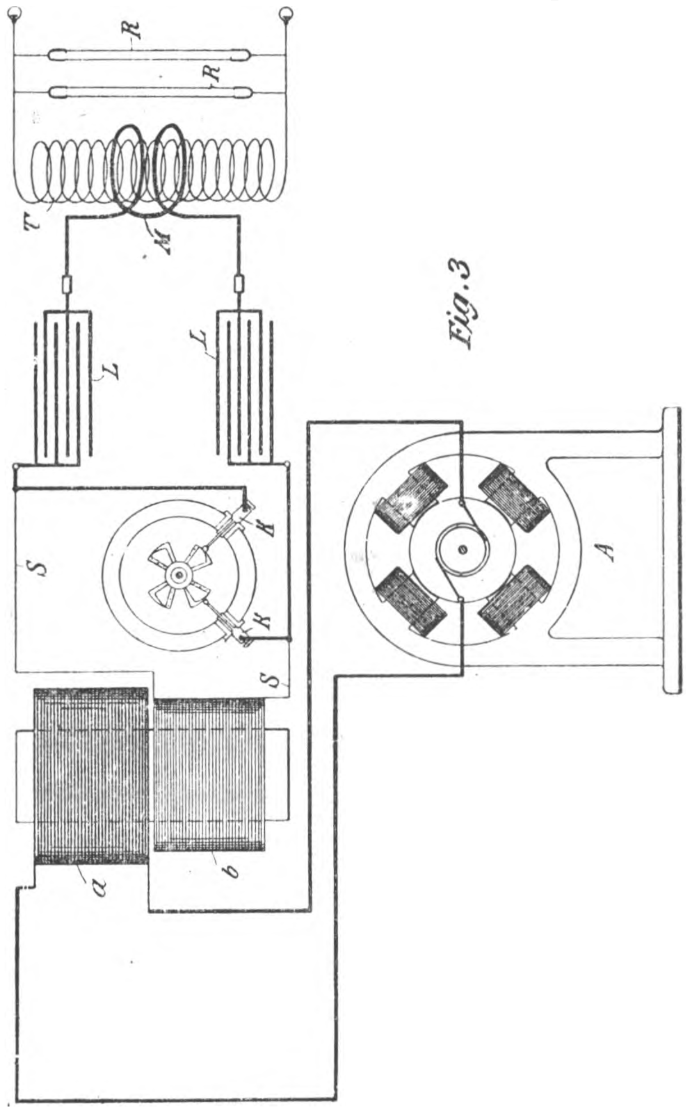

Fig. 3

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APPARATUS FOR PRODUCING ELECTRIC CURRENTS OF HIGH FREQUENCY.

SPECIFICATION forming part of Letters Patent No. 577,670, dated February 23, 1897.

Application filed September 3. 1896. Serial No. 604,723. (No model.)

To all whom it may concern:

Be it known that I, NIKOLA TESLA, a citizen of the United States, residing at New York, in the county and State of New York, have invented certain new and useful Improvements in Apparatus for Producing Electric Currents of High Frequency, of which the following is a specification, reference being had to the drawings accompanying and forming a part of the same.

The apparatus for converting electric currents of ordinary character into those of high frequency, which I have heretofore shown and described in applications for Letters Patent, has usually comprised a condenser and a circuit-controller operated by a suitable motive device and acting to alternately charge the condenser from a suitable source of supply and discharge it through a circuit of such character as to render the discharge one of very high frequency. For many purposes it has been found advantageous to construct the circuit-controller with insulating and conducting segments of equal length, so that the condenser is connected with its discharge-circuit during one-half of the time only. It follows from this that the working circuit, or that in which the high-frequency currents are developed in form for practical application, receives such currents during only one-half the time.

For certain purposes it is. desirable for economical operation that there should be no cessation of the flow of such currents, and my present improvements have been devised with the object of increasing the output of a given apparatus by providing means by which, without material additions to or complication of such apparatus, high-frequency currents may be produced thereby continuously or without periods of rest.

Broadly stated, the improvement consists in the combination of two condensers with a circuit-controller of such character and so operated by a single motive device as to charge and discharge said condensers alternately, whereby one will be discharging while the other is being charged, and conversely.

In the drawings hereto annexed, Figure 1 is a diagrammatic illustration of the arrangement and circuit connections of the invention. Fig. 2 is a sectional view of a part of the commutator employed; and Fig. 3 is a diagram similar to that of Fig. 1, illustrative of a modified embodiment of the invention.

Let A B designate the two conductors of any circuit from which the energy is derived that is to be converted into a current of high frequency.

C is a circuit controller or commutator, a portion only for convenience being shown in the figures. It is designed to be rotated by any suitable motive device, of which, however, the shaft D only is shown, and its plan of construction is as follows:

The letters *c c'* designate two metal heads or castings with projecting portions *d d'*, which, when the two heads are brought together and secured to a hub or shaft, intermesh, as shown in the drawings.

The spaces between two adjacent projections or bars *d d'* are equal in arc to the width of one of said bars and are filled in with blocks *e,* preferably of metal, insulated from the other conducting portions of the device. By the interposition of mica or other suitable insulating material the two heads or castings *c c'* are insulated from each other. Upon the periphery of this commutator bear three brushes G G' H, the two former resting upon the continuous metallic portions of the two heads, respectively, the latter being in position to bear upon the projections *d d'* and blocks *e* alternately.

In order that the brushes may be capable of carrying any current which the operation of the apparatus may demand, they are made of large cross-section, the brush H being approximately equal in width to one of the projections or segments *d d'*, or to the space between adjacent segments, so that in passing from one it comes into contact with the next.

The brush H is connected to the main B through a primary coil K of low self-induction in inductive relation to a secondary L, which constitutes the ultimate source of the current of high frequency which the apparatus is designed to develop and which feeds a circuit containing vacuum-tubes M, single terminal lamps M', or other suitable devices. The brushes G G' are connected with the main B through condensers N N', respectively, and to the main A through self-induction or choking coils O O', these latter being used in order that the inductive discharge of the accumulated energy therein may be taken advantage of in charging the condensers.

The operation of the apparatus thus described is as follows: By the rotation of the commutator C the brush H is caused to pass over the projections *d,* closing the circuits through the primary K and the two condensers alternately. These two circuits are so adjusted as to have the same capacity, self-induction, and resistance. When said brush is in electrical connection with any projection *d'* from the part *c'*, the circuit is closed between mains A and B through coil O', brush G', brush H, and coil K. Energy is therefore accumulated in the coil O'. At the same time the condenser N' is short-circuited through the brush G', brush H, and coil K, and discharges through this circuit the energy stored in it, the discharge being in the form of a series of impulses which induce in the secondary L corresponding impulses of high potential. When brush H breaks the circuit through coil O', the high-potential discharge or "kick" from the latter rushes into and recharges the condenser N', but as soon as the brush H has passed over the intervening block e and reached the next segment *d* it closes the circuit through coil O and short-circuits the condenser N, so that high-frequency currents from either one or the other of the two condensers are flowing through the primary K practically without interruption. Thus without increasing the size or power of the motive device or complicating in any material degree the commutator these devices are made to perform double duty and the output of the apparatus as a whole greatly increased.

In Fig. 3 I have illustrated a modified form of commutator for this apparatus, which comprises a disk E, of metal, but insulated from its shaft. The periphery of this disk is divided into conducting and insulated segments by the insertion therein of insulated metal blocks *f.* The circumferential width of these blocks is three limes that of the conducting-segments *f'*. A brush F bears upon a continuous metallic portion of the disk or upon a continuous ring in electrical connection with the segments *f'* and is connected with one terminal of the primary K. Brushes F' F'' bear upon the periphery of the disk E and are connected to the main B through the two condensers, respectively. These brushes are Capable of angular adjustment, so that they may be set to bear upon the disk at any two desired points.

From the explanation of the operation already given it is evident that when the two brushes F' F'' are set so that one leaves a segment *f'* at the instant that the other comes in contact with a segment *f'* the effect in charging and discharging the condensers is the same as in the previous instance. The capability of varying the relations of the brushes, however, which this form possesses has the advantage of permitting not only an alternate charging and discharge of the condensers, but their simultaneous charging and discharge in multiple arc, whereby the frequency of the current of discharge is reduced.

It is also evident that all phase differences in the charging and discharging of the condensers may in like manner be secured and the frequency varied within wide limits. Of course the same motor and circuit-controller might be made to charge more than two condensers in succession and to discharge them in the same order.

What I claim is—

1. The combination with a source of electric energy, of a plurality of condensers and a discharge-circuit therefor, a motive device and a circuit-controller operated thereby and adapted to direct the energy of the source into the condensers and connect them with the discharge-circuit successively and in alternation, as set forth.

2. The combination with a source of electric energy, of a motive device, two condensers, a circuit-controller adapted to direct the energy of the source alternately into the said condensers, and a discharge-circuit through which, by the operation of said circuit-controller one condenser discharges while the other is being charged, as set forth.

NIKOLA TESLA.

Witnesses:

M. LAWSON DYER,

DRURY W. COOPER.

(No Model.) 2 Sheets—Sheet 1

N. TESLA.

APPARATUS FOR PRODUCING ELECTRIC CURRENTS OF HIGH FREQUENCY

No. 577.670. Patented Feb. 23, 1897.

Fig. 1

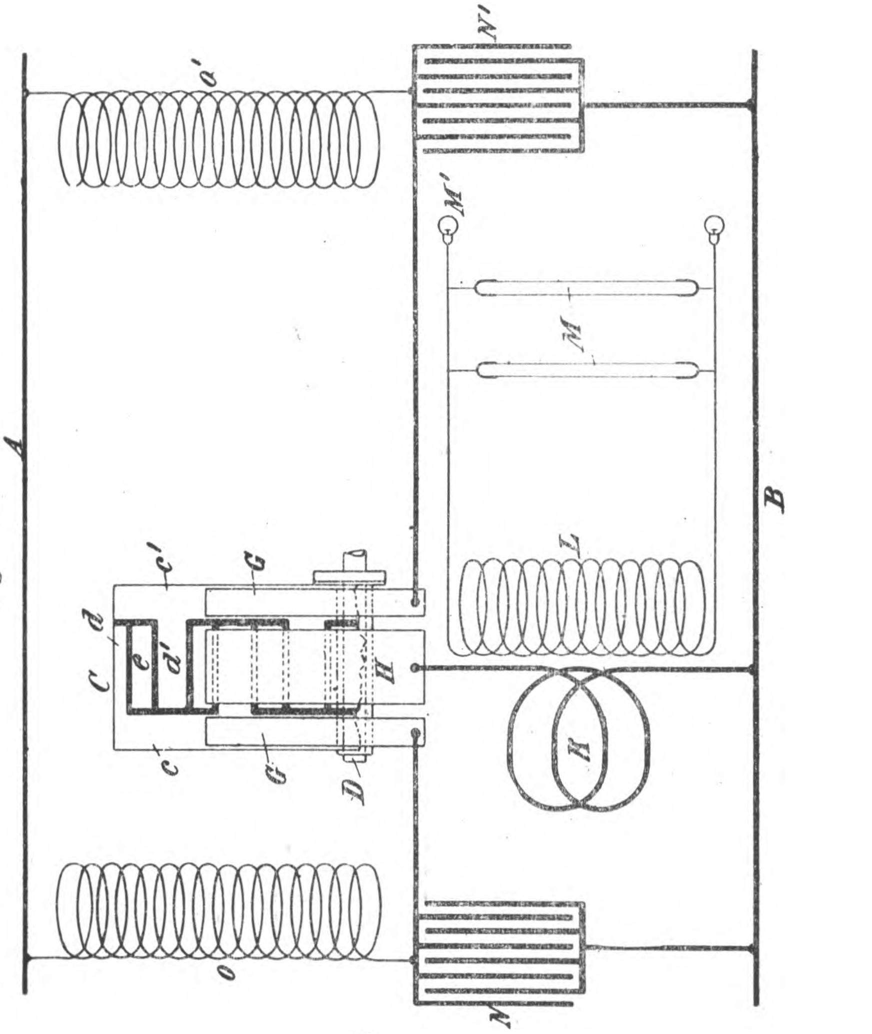
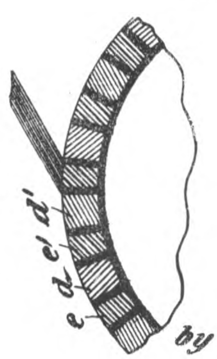


Fig. 2.



Witnesses:
Edwin B. Hopkinson,
M. Lawson Dyer

Nikola Tesla
Inventor
by Ken. Curtis & Page.
Att'ys.

P-248

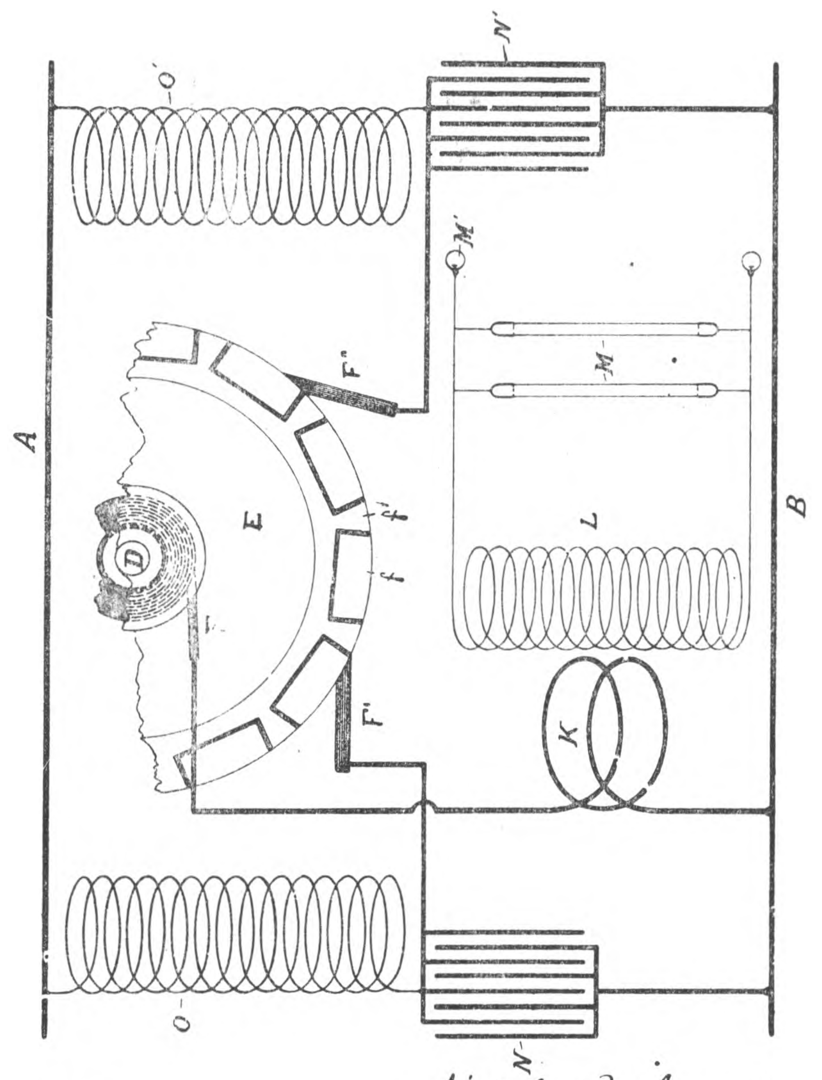
(No Model.)

2 Sheets—Sheet 2

N. TESLA

APPARATUS FOR PRODUCING ELECTRIC CURRENTS OF HIGH FREQUENCE

No. 577,670. Patented Feb. 23, 1897.



WITNESSES

M. Lawson Dyer

Edwin B. Hopkinson.

Nikola Tesla INVENTOR

BY

Kerr, Curtis & Page ATTORNEYS

UNITED STATES PATENT OFFICE.

NIKOLA TESLA, OF NEW YORK, N. Y.

APPARATUS FOR PRODUCING CURRENTS OF HIGH FREQUENCY.

SPECIFICATION forming part of Letters Patent No. 583,953, dated June 8, 1897

Application filed October 19, 1896. Serial No. 609,292. (No model.)

To all whom it may concern:

Be it known that I, NIKOLA TESLA, a citizen of the United States, residing at New York, in the county and State of New York, have invented certain new and useful Improvements in Apparatus for Producing Currents of High Frequency, of which the following is specification, reference being had to the drawings accompanying and forming a part of the same.

The invention upon which my present application is based is an improvement in apparatus for the conversion of electrical currents of ordinary character—such, for instance, as are obtainable from the mains of municipal electric light and power systems and either continuous or alternating—into currents of very high frequency and potential.

The improvement is applicable generally to apparatus of the kind heretofore invented by me and more particularly described in United States Letters Patent granted to me on September 22, 1896, No. 568,176; but in the description of the invention which follows the illustration is confined to a form of apparatus designed for converting a continuous or direct current into one of high frequency. In the several forms of apparatus for this purpose which I have devised and heretofore described I have employed a circuit of high self-induction connected with the mains from a suitable source of current and containing some form of circuit-controller for periodically interrupting it. Around the break or point of interruption I have arranged a condenser, into which the circuit discharges when interrupted, and this condenser is in turn made to discharge through a circuit containing the primary of a transformer, and of such character that the condenser-discharge will be in the form of an extremely rapid succession of impulses.

Now in order to secure in an apparatus of this kind as high frequency as possible and the advantages resulting therefrom I subdivide the condenser necessary for storing the energy required into integral parts or provide independent condensers, and employ moans for charging said condensers in multiple and discharging them in series through the primary of the transformer. To secure this result without unduly complicating the apparatus is a matter of very considerable difficulty, but I have accomplished it by means of the apparatus which I shall now proceed to describe by reference to the drawings.

Figure 1 is a side elevation of the apparatus which I employ, and Fig. 2 is a diagram of the circuit connections.

Referring to Fig. 1, A is a box or case containing the condensers, of which the terminals are *a a b b*, respectively. On this case is mounted a small electromagnetic motor B, by the shaft of which is operated the circuit-controller C. Upon the said controller bear brushes, as shown at D D' D'' D'''.

F F are self-induction coils placed beside the motor. Above these is the transformer, composed, essentially, of a primary G and a secondary H. These devices are intended to be inclosed in a suitable box or case, and may be very greatly modified in construction and relative arrangement. The circuit-controller, however, should conform in general principle of construction to that hereinafter described in so far as may be necessary to secure the operation pointed out.

Referring now to Fig. 2, L L designate the mains from a suitable source of supply, between which a circuit is formed, including the self-induction coils F F and the circuit-controller C. A switch *d* may be employed to bring either or both of the coils F F into this circuit, as may be desired.

The circuit-controller is built up of insulated plates or segments, upon which the positive and negative brushes bear, and these plates may be considered as belonging to three sets or classes, first, the plates *m* for what may be considered as the positive brushes D D' in one row, electrically connected together, and the corresponding plates *n* for what may similarly be considered as the negative brushes E E' in the other row; second, the plates *o,* which lie in both rows, and hence are conveniently made in single pieces extending across the controller, and, third, the idle or spacing plates *p,* which are interposed in each row between the other two sets. The angle between adjacent plates of the same set is equal to the angle of displacement between adjacent, brushes of the same sign, and obviously there may be two or more of each. The brush D of one set is connected with one main through the coils F, and each one of the brushes of the same set is connected to one of the terminals of the condensers M N, respectively. Similarly the brush E of the other set of brushes is connected to the opposite main and each of the brushes of said set to the opposite condenser terminals through the primary or strands of a primary G. In the diagram, Fig. 2, I have shown but two brushes in each set and two condensers, but more than this number may be used, the same plan of connections shown and described being followed out.

In the position of the parts shown in Fig. 2, in which two positive and two negative brushes are shown, the brushes are bearing on plates *m m* and *n n*. Consequently the circuit through the coils F F is through the condensers in multiple, and, assuming that energy has been stored in said coils, the condensers will thus be charged. If now by the movement of the controller plates or brushes the latter are shifted across the idle or spacing plates *p* onto the long or cross-connected plates o two results follow: The mains are short-circuited through the coils F F, which therefore store energy, while the condensers are connected in series through the primary coil or coils G. These actions are repeated by the further movement of the controller, the condensers being charged in parallel when the brushes are on plates *m n* and discharged in series when the brushes pass onto plates *o*. The motor may be run by an independent source or by current derived from the mains, and the apparatus may be employed to supply current for any suitable devices S T, connected with the secondary coil H.

As stated above, the specific construction of the circuit-controller may be very greatly varied without departure from the invention. In the drawings the plates are assumed to be associated in the form of a cylinder which revolves with respect to brushes bearing on its periphery; but it will be understood that this is merely a typical illustration of any form of terminals or contacts and conductors, whether rotary or reciprocating, which constitute a circuit-controller capable of effecting the same result.

The advantages resulting from the subdivision of the condenser or the employment of a plurality of condensers are mainly that a high frequency is obtainable in apparatus of any size; that the current of discharge through the sliding contacts is greatly reduced and injury to such contacts thereby avoided and a great saving in wire in the secondary effected.

What I claim is—

1. In an apparatus of the kind described, the combination with a set of contacts, one of which is adapted for connection with one of the mains from a source of current, and each of which is connected to one of the terminals of a series of condensers, and a second set of contacts similarly connected to the opposite main and condenser terminals, respectively, of electrically-connected plates or segments upon which the contacts of the first set bear, similarly-connected plates upon which the contacts of the second set bear, and isolated plates common to the two sets of contacts, the said plates being arranged in the manner described, whereby the condensers will be alternately charged in multiple and discharged in series, as set forth.

2. In an apparatus of the kind described, the combination with a set of positive brushes, one of which is adapted for connection with one of the mains from a source of current, and each of which is connected to one of the terminals of a series of condensers, and negative brushes similarly connected to the opposite main and condenser terminals, respectively, of a cylinder composed of electrically-connected segments upon which the positive brushes only bear, similarly-connected segments upon which the negative brushes only bear, and isolated plates upon which both sets of brushes simultaneously bear, the said plates being arranged in the manner described, whereby the condensers will be alternately charged in multiple and discharged in series, as set forth.

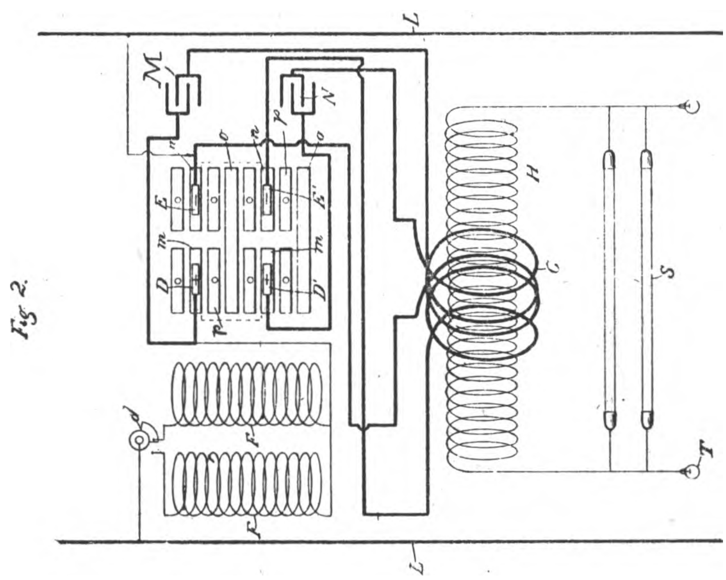
NIKOLA TESLA

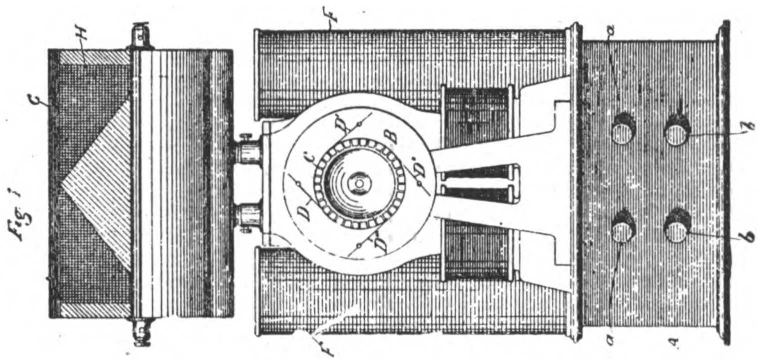
Witnesses:
M. LAWSON DYER,
DRURY W. COOPER

(No Model.)

N. TESLA
APPARATUS FOR PRODUCING CURRENTS OF HIGH FREQUENCY.

No. 583,953 Patented June 8, 1897.





WITNESSES

G. B. Lewis

Edwin B Hopkinson

INVENTOR

Nikola Tesla

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ATTORNEYS.

UNITED STATES PATENT OFFICE.

NIKOLA TESLA, OF NEW YORK, N. Y.

ELECTRICAL TRANSFORMER.

SPECIFICATION forming part of Letters Patent No. 593,138, dated November 2, 1897.

Application filed March 20, 1897. Serial No. 628,453. (No model.)

To all whom it may concern:

Be it known that I, NIKOLA TESLA, a citizen of the United States, residing at New York, in the county and State of New York, have invented certain new and useful Improvements in Electrical Transformers, of which the following is a specification, reference being had to the drawings accompanying and forming a part of the same.

The present application is based upon an apparatus which I have devised and employed for the purpose of developing electrical currents of high potential, which transformers or induction-coils constructed on the principles heretofore followed in the manufacture of such instruments are wholly incapable of producing or practically utilizing, at least without serious liability of the destruction of the apparatus itself and danger to persons approaching or handling it.

The improvement involves a novel form of transformer or induction-coil and a system for the transmission of electrical energy by means of the same in which the energy of the source is raised to a much higher potential for transmission over the line than has ever been practically employed heretofore, and the apparatus is constructed with reference to the production of such a potential and so as to be not only free from the danger of injury from the destruction of insulation, but safe to handle. To this end I construct an induction-coil or transformer in which the primary and secondary coils are, wound or arranged in such manner that the convolutions of the conductor of the latter will be farther removed from the primary as the liability of injury from the effects of potential increases, the terminal or point of highest potential being the most remote, and so that between adjacent convolutions there shall be the least possible difference of potential.

The type of coil in which the last-named features are present is the flat spiral, and this form I generally employ, winding the primary on the outside of the secondary and taking off the current from the latter at the center or inner end of the spiral. I may depart from or vary this form, however, in the particulars hereinafter specified.

In constructing my improved transformers I employ a length of secondary which is approximately one-quarter of the wave length of the electrical disturbance in the circuit including the secondary coil, based on the velocity of propagation of electrical disturbances through such circuit, or, in general, of such length that the potential at the terminal of the secondary which is the more remote from the primary shall be at its maximum. In using these coils I connect one end of the secondary, or that in proximity to the primary, to earth, and in order to more effectually provide against injury to persons or to the apparatus I also connect it with the primary.

In the accompanying drawings, Figure 1 is a diagram illustrating the plan of winding and connection which I employ in constructing my improved coils and the manner of using them for the transmission of energy over long distances. Fig. 2 is a side elevation, and Fig. 3 a side elevation and part section, of modified forms of induction-coil made in accordance with my invention.

A designates a core, which may be magnetic when so desired.

B is the secondary coil, wound upon said core in generally spiral form.

C is the primary, which is wound around in proximity to the secondary. One terminal of the latter will be at the center of the spiral coil, and from this the current is taken to line or for other purposes. The other terminal of the secondary is connected to earth and preferably also to the primary.

When two coils are used in a transmission system in which the currents are raised to a high potential and then reconverted to a lower potential, the receiving-transformer will be constructed and connected in the same manner as the first—that is to say, the inner or center end of what corresponds to the secondary of the first will be connected to line and the other end to earth and to the local circuit or that which corresponds to the primary of the first. In such case also the line-wire should be supported in such manner as to avoid loss by the current jumping from line to objects in its vicinity and in contact with earth—as, for example, by means of long insulators, mounted, preferably, on metal poles, so that in case of leakage from the line it will pass harmlessly to earth. In Fig. 1, where such a system is illustrated, a dynamo G is conveniently represented as supplying the primary of the sending or "step-up" transformer, and lamps H and motors K are shown as connected with the corresponding circuit of the receiving or "step-down" transformer.

Instead of winding the coils in the form of a flat spiral the secondary may be wound on a support in the shape of a frustum of a cone and the primary wound around its base, as shown in Fig. 2.

In practice for apparatus designed for ordinary usage the coil is preferably constructed on the plan illustrated in Fig. 3. In this figure L L are spools of insulating material upon which the secondary is wound—in the present case, however, in two sections, so as to constitute really two secondaries. The primary C is a spirally-wound flat strip surrounding both secondaries B.

The inner terminals of the secondaries are led out through tubes of insulating material M, while the other or outside terminals are connected with the primary.

The length of the secondary coil B or of each secondary coil when two are used, as in Fig. 3, is, as before stated, approximately one-quarter of the wave length of the electrical disturbance in the secondary circuit, based on the velocity of propagation of the electrical disturbance through the coil itself and the circuit with which it is designed to be used—that is to say, if the rate at which a current traverses the circuit, including the coil, be one hundred and eighty-five thousand miles per second, then a frequency of nine hundred and twenty-five per second would maintain nine hundred and twenty-five stationary waves in a circuit one hundred and eighty-five thousand miles long, and each wave length would be two hundred miles in length. For such a frequency I should use a a wire of fifty miles in length, so that at one terminal the potential would be zero and at the other maximum.

Coils of the character herein described have several important advantages. As the potential increases with the number of turns the difference of potential between adjacent turns is comparatively small, and hence a very high potential, impracticable with ordinary coils, may be successfully maintained.

As the secondary is electrically connected with the primary the latter will be at substantially the same potential as the adjacent portions of the secondary, so that there will be no tendency for sparks to jump from one to the other and destroy the insulation. Moreover, as both primary and secondary are grounded and the line-terminal of the coil carried and protected to a point remote from the apparatus the danger of a discharge through the body of a person handling or approaching the apparatus is reduced to a minimum.

I am aware that an induction-coil in the form of a flat spiral is not in itself new, and this I do not claim; but

What I claim as my invention is—

1. A transformer for developing or converting currents of high potential, comprising a primary and secondary coil, one terminal of the secondary being electrically connected with the primary; and with earth when the transformer is in use, as set forth.

2. A transformer for developing or converting currents of high potential, comprising a primary and secondary wound in the form of a flat spiral, the end of the secondary adjacent to the primary being electrically connected therewith and with earth when the transformer is in use, as set forth.

3. A transformer for developing or converting currents of high potential comprising a primary and secondary wound in the form of a spiral, the secondary being inside of, and surrounded by, the convolutions of the primary and having its adjacent terminal electrically connected therewith and with earth when the transformer is in use, as set forth.

4. In a system for the conversion and transmission of electrical energy, the combination of two transformers, one for raising, the other for lowering, the potential of the currents, the said transformers having one terminal of the longer or fine-wire coils connected to line, and the other terminals adjacent to the shorter coils electrically connected therewith and to the earth, as set forth.

NIKOLA TESLA.

Witnesses:
M. LAWSON DYER
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P-254

(No Model.) 2 Sheets—Sheet 1.

N. TESLA.
ELECTRICAL TRANSFORMER.

No. 593,138. Patented Nov. 2, 1897.

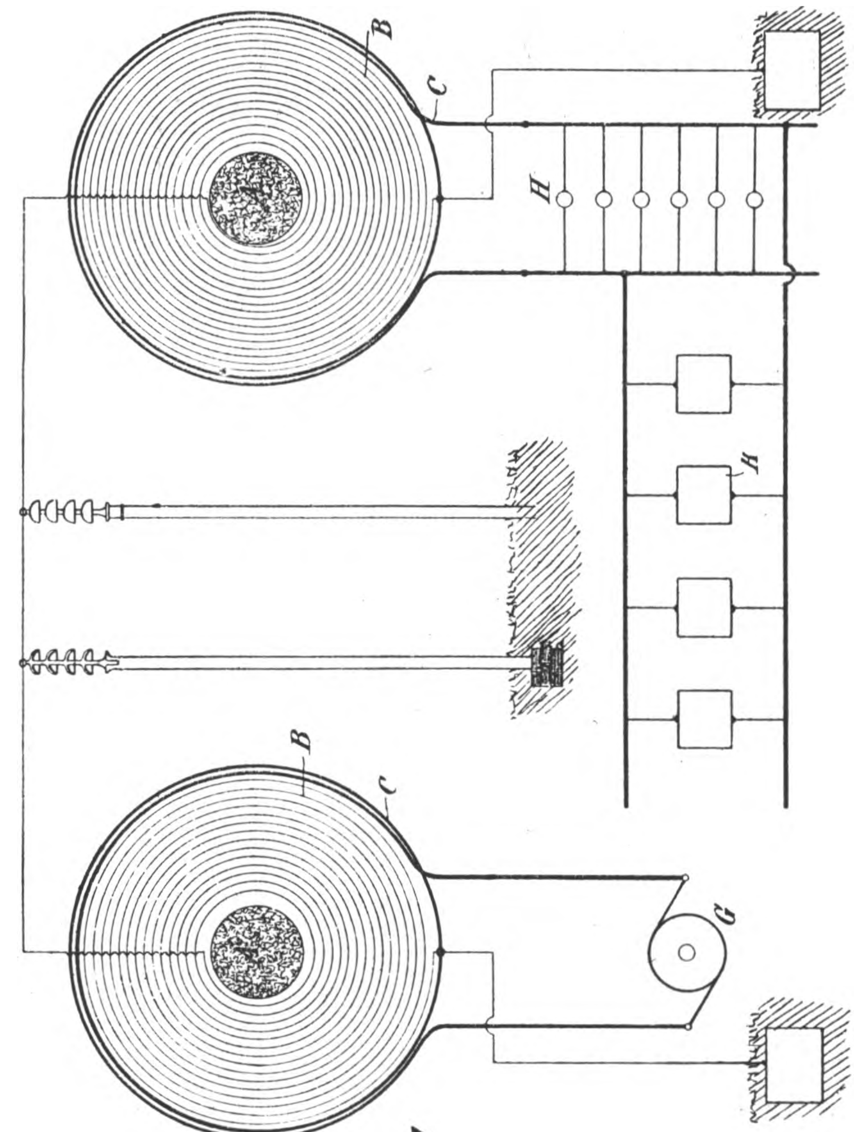

Fig.1

WITNESSES

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(No Model.) 2 Sheets—Sheet 2

N. TESLA.

ELECTRICAL TRANSFORMER.

No. 593,128. Patented Nov. 2, 1897.

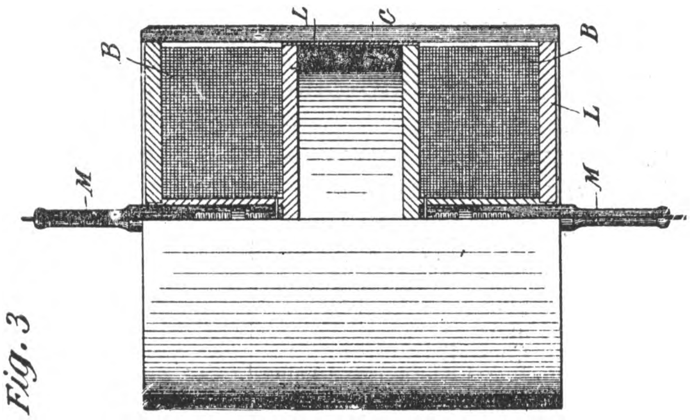

Fig. 3

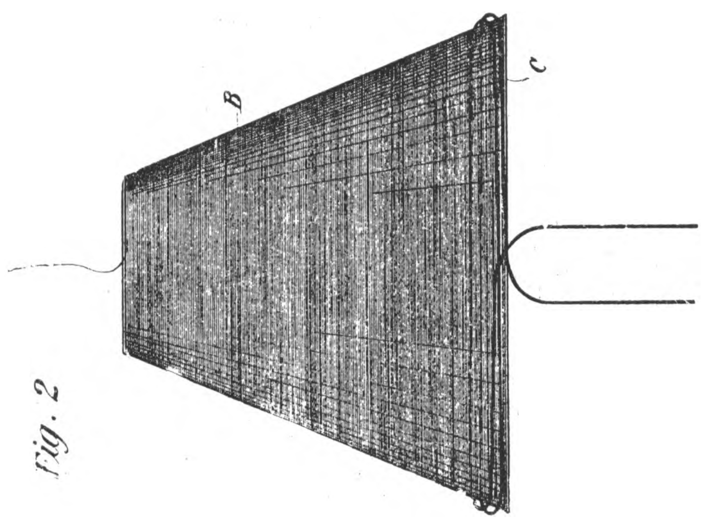

Fig. 2

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Edwin B. Hopkinson

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UNITED STATES PATENT OFFICE.

NIKOLA TESLA, OF NEW YORK, N. Y.

ELECTRIC-CIRCUIT CONTROLLER.

SPECIFICATION forming part of Letters Patent No. 609,251, dated August 16, 1898.

Application filed June 3, 1897. Renewed June 15, 1898. Serial No. 683,525. (No model.)

To all whom it may concern:

Be it known that I, NIKOLA TESLA, a citizen of the United States, residing at New York, in the county and State of New York, have invented certain new and useful Improvements in Electric-Circuit Controllers, of which the following is a specification, reference being had to the drawings accompanying and forming a part of the same.

In previous patents granted to me I have shown and described methods and apparatus for the conversion and utilization of electrical currents of very high frequency based upon the principle of charging a condenser or a circuit possessing capacity and discharging the same generally through the primary of a transformer, the secondary of which constituted the source of working current and under such conditions as to yield a vibrating or rapidly-intermittent current.

In some of the forms of apparatus which I have heretofore devised for carrying out this invention I have employed a mechanism for making and breaking an electric circuit or branch thereof for the purpose of charging and discharging the condenser, and my present application is based upon a novel and improved form of device for this purpose, which may be generally styled a "circuit-controller."

In order that the full advantages of my system may be realized and the best practical results secured, the said circuit-controller should be capable of fulfilling certain requirements, the most important among which is the capability of effecting an extremely-rapid interruption and completion of the circuit. It is also of importance that such makes and breaks, and more especially the former, should be positive and abrupt, and from considerations of economy and practicability it is essential that the apparatus should be cheaply constructed, not liable to derangement, and capable of prolonged use without attention or adjustment. With the object of attaining these results, which have never heretofore been fully attained in any form of mechanical circuit-controller of which I am aware, I devised and developed the circuit-controller which forms the subject of my present application and which may in general terms be described as follows:

The device in its typical embodiment comprises as essential elements two terminals—one with peripheral contacts alternating with insulating-spaces, such as is exemplified in a stelliform disk and which is capable of rotation, and the other a rotatable receptacle containing a fluid in which more or less of the first-named terminal is immersed.

In the preferred construction of the apparatus the receptacle contains both a conducting and a non-conducting fluid, the former being the heavier, and I maintain the terminals in such relations that the electrical connection between them is made and broken by the successive immersion of the contact-points into and their withdrawal from the conducting through the non-conducting fluid. These relations are best maintained by such construction of the receptacle that the distribution of the two fluids necessary for the proper operation of the device may be preserved by centrifugal action and the rotation of the other terminal effected by the movement of the fluid or fluids relatively thereto.

To secure the conditions necessary for the accomplishment of the objects of the invention, various mechanical expedients may be resorted to; but the best and most practicable device for the purpose of which I am aware is a hollow wheel or drum mounted so as to be rotated at any desired speed and containing a conducting fluid, such as mercury or an electrolyte, which by the rotation of the drum is thrown by centrifugal force outward to the inner periphery of the same, and a sufficient quantity of a lighter non-conducting or poorly-conductive fluid, such as water or oil, which by the centrifugal action is maintained on the surface of the heavier conducting fluid and tends to prevent the occurrence of arcs between the contact-points and the conducting fluid.

A central opening is formed in one side of the drum, through which enters an arm carrying a disk with peripheral projections or vanes which when the drum is rotated project to a sufficient extent toward or into the conducting fluid to effect the makes and breaks of the circuit.

The motion of the fluid within the drum causes the disk to rotate and its projections or vanes to make and break the circuit with a rapidity which may be very great. In fact, when the drum is rotated at a high rate of speed the fluid conductor may become in its effect similar to a solid body, upon which the conducting-disk rolls, so that, the conducting fluid might, be dispensed with, although I find it preferable to use it.

In order to insure the proper immersion of the projections into the fluid to compensate for wear and at the same time to secure a yielding pressure between the fluid and the disk, it is desirable to employ for the disk some form of spring connection or support which will exert a force tending to force it in contact with the fluid.

I have also devised certain details of construction which add to the efficiency and practicability of the apparatus which will be more conveniently described by reference to the accompanying drawings.

Figure 1 is a side elevation of a complete apparatus for producing currents of high frequency and to which my present invention is applied. Fig. 2 is a central vertical section of the improved circuit-controller of Fig. 1; Fig. 3, an end view of the same; Fig. 4, a modified form of the circuit-controller, showing it in connection with the remaining parts of the apparatus illustrated diagrammatically; and Fig. 5, a side view of the same with the receptacle in section.

As the apparatus as a whole is now well known, a brief description of the same will suffice for an understanding of its character.

The various parts or devices are preferably mounted on a base B, which contains the condenser, and comprise a transformer A with primary and secondary coils, one or more self-induction coils C, a small electromagnetic motor D, and the circuit-controller, which is driven by the motor. The circuit connections will be described in connection with Fig. 5.

In general plan of construction and arrangement the apparatus is essentially the same as that described and shown in a patent granted to me September 22, 1896, No. 568,176.

The shaft of the motor D extends through a stationary disk E, and to its end is keyed a hollow wheel or drum F, which rotates with it. Two standards G are secured to the disk E and connected by a cross-bar H, from which extends an arm K into the interior of the drum F through a central opening in its side.

To the end of the arm K is secured an arm L, carrying at its free end a disk M with peripheral teeth or projections N, as shown in Fig. 3. The disk is mounted on any suitable bearings in the arm L, so as to be capable of free rotation.

It is desirable that the disk should admit of adjustment with respect to the inner peripheral surface of the drum, and for this purpose I secure the arm K to a rod O, which passes through supports in the cross-bar H and is adjustable therein by means of threaded nuts P.

The interior of the drum F is formed by preference in substantially the manner shown in Fig. 2—that is to say, it is tapered or contracted toward the periphery so as to form a narrow trough in which the fluid is confined when the drum is rotated.

R designates the conducting fluid, and S the lighter non-conducting fluid, which are used in the drum. If the proper quantities and proportions of these fluids be introduced into the drum and the latter set in rapid rotation, the two fluids will distribute themselves under the action of centrifugal force around the drum in the manner indicated in Fig. 2. The arm K is adjusted so that the teeth or projections on the disk M will just enter the conducting fluid, and by the action of either or both the disk will be rapidly rotated. Its teeth are so arranged that no two are simultaneously in contact with the conducting fluid, but come into the same successively. If, therefore, one part of the circuit be connected to the drum, as by a contact strip or brush T, and the other part to the disk M, or to any part, as the standards G, which are insulated from the frame of the apparatus and in metallic connection with the disk M, the circuit will be made and broken with a rapidity which may obviously be made enormously high. The presence of the non-conducting fluid on the surface of the other operates to prevent the occurrence of sparks as the teeth N leave the latter and also to prevent the current from leaping across the space between the teeth and the conductor as the two approach.

In illustration of the modifications of which the improvement is susceptible I now refer to Figs. 4 and 5, in which also certain novel and useful details of construction applicable generally to the invention are shown.

In the modification shown in Figs. 4 and 5 two rigid arms L and L', each carrying a disk M, are shown, and this number may be increased, if so desired. The rotating disks in this case are mounted on spindles at right angles to the axis of rotation of the drum F, and the contact points or projections are formed as vanes, with faces inclined to the plane of rotation, so as to be rotated by the movement of the fluid in the manner of turbine wheels.

In order to provide a means for automatically adjusting the disks to compensate for any wear and keep the ends of the vanes or points properly immersed in the fluids, each disk-carrying arm is impelled by a spring or weight in the direction of the periphery of the drum. A convenient way to accomplish this is to form racks on the arms L L' and to provide a pinion *b* in engagement therewith. From the shaft of the pinion extends an arm *c*, the end of which is connected to an adjustable stop *d* by a spiral spring *e*, the tendency of which is to turn the pinion and force both arms L and L' toward the periphery of the drum.

In some applications of the invention it is practicable to prevent the occurrence of arcs still more effectively or even entirely by using in addition to the non-conducting fluid a somewhat heavier fluid W, which is a comparatively poor conductor and which takes up a position between the conducting and non-conducting fluids.

When two or more disks or equivalent devices are used, they may be connected either in series or multiple. In the present illustration they are shown as in series, and as the arms L and L' are insulated from each other and each connected with a terminal of the source of current the circuit is completed only when a vane of each disk is immersed in the conducting fluid and interrupted at all other times.

The diagram of circuit connections will serve to illustrate the purpose and mode of operation of the device. Let *f f* be the conductors from a source of current, each including a self induction coil C C' and connected with the arms L and L' and with two conductors B' B", respectively. Then during the periods when the circuit is completed between the two arms L L' the coils C C' store energy, which on the interruption of said circuit rushes into and charges the condensers. These latter during the periods when the circuit is closed between arms L and L' discharge through the primary A' and induce by such discharge currents in the secondary A", which are utilized for any purpose for which they may be suited, as in operating vacuum-tubes X or suitable lamps Y.

It will be understood that the rotating drum may be mounted in a horizontal or other plane and from the nature and objects of the results which are attained by the particular apparatus described the construction of this apparatus may be very greatly varied without departure from my invention.

Without therefore limiting myself to the details of construction and arrangement shown herein in illustration of the manner in which my invention is or may be carried out, what I claim is—

1. A circuit-controller comprising, in combination, a receptacle containing a fluid, means for rotating the receptacle, and a terminal supported independently of the receptacle and adapted to make and break electric connection with the receptacle through the fluid, as set forth.

2. A circuit controller comprising in combination a receptacle containing a conducting fluid and a non-conducting fluid, means for rotating the receptacle and a terminal adapted to make and break electrical connection with the conducting fluid within or under the non-conducting fluid, as set forth.

3. A circuit-controller comprising in combination a terminal capable of rotation and formed or provided with peripheral contacts, a receptacle comprising the opposite terminal and containing a fluid into which the said contacts extend, and means for rotating the receptacle, as set forth.

4. A circuit-controller, comprising, in combination, a terminal capable of rotation and formed or provided with peripheral projections, a receptacle containing a fluid conductor into which the points or projections of the said conductor extend, and means for rotating the said receptacle, as set forth.

5. A circuit-controller comprising, in combination, a terminal capable of rotation and formed or provided with peripheral projections, a centrifugal drum or wheel containing a fluid conductor into which the points or projections of the said conductor extend, and means for rotating the said drum, as set forth.

6. A circuit-controller comprising, in combination, a terminal capable of rotation and formed or provided with peripheral projections, a centrifugal drum or wheel containing a fluid conductor into which the points of the said terminal extend, and means for adjusting the latter with relation to the surface of the fluid, as set forth.

7. A circuit-controller comprising, in combination, a terminal having peripheral projections and capable of rotation, a centrifugal drum or receptacle containing a conducting and a lighter non-conducting fluid, the said terminal being arranged so that its points or projections extend through the non-conducting into the conducting fluid, when the fluids are distributed in the drum under the action of centrifugal force, as set forth.

8. The combination with a hollow centrifugal drum or wheel containing a conducting fluid, a motor for rotating the same, a support extending through an opening into the drum, and a rotatable terminal having peripheral projections, mounted on said support in position in which its projections extend into the fluid when displaced by centrifugal action, as set forth.

9. The combination with a receptacle containing a fluid and means for rotating the same, a terminal with peripheral projections capable of rotation, and a spring connection or support for said terminal tending to force it toward the periphery of the receptacle, as set forth.

10. The combination with a hollow centrifugal drum or wheel containing a conducting fluid and a lighter non-conducting fluid, means for rotating the said drum, a support extending through an opening into the drum, and a rotatable terminal having peripheral projections, mounted on said support in position in which the projections extend through the non-conducting into the conducting fluid when the fluids are displaced by centrifugal action, as set forth.

11. The combination with a centrifugal drum containing a conducting and a non-conducting fluid, means for rotating the drum, a terminal capable of rotation and having peripheral projections, mounted within the drum on a stationary support, and a spring or its equivalent acting on the said terminal

and tending to force its projections toward the inner periphery of said drum, as set forth.

12. The combination with a receptacle containing a conducting fluid, a lighter fluid of low conductivity and a non-conducting fluid lighter than the others, and means for rotating the receptacle, of a terminal adapted to make and break the circuit by movements between the conducting and non-conducting fluid through the intermediate fluid of low conductivity, as set forth.

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Witnesses:
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P-260

No. 609,251. Patented Aug. 16, 1898.

N. TESLA.

ELECTRIC CIRCUIT CONTROLLER.

(Application filed June 3. 1807. Renewed June 15, 1898.

(No Model.) 2 Sheets—Sheet 1.

Fig. 3

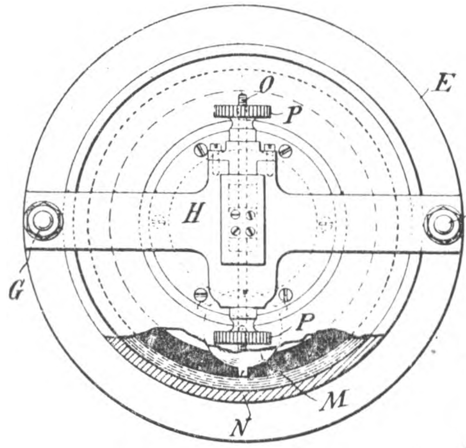


Fig. 2

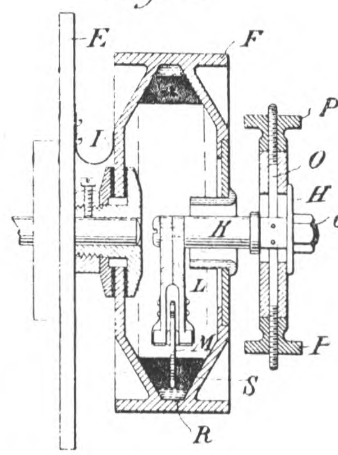
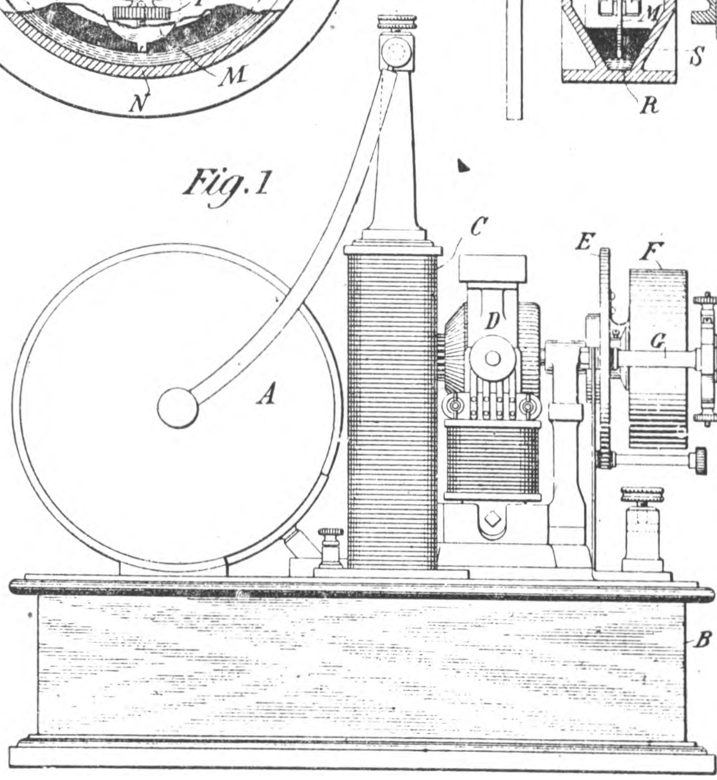


Fig. 1



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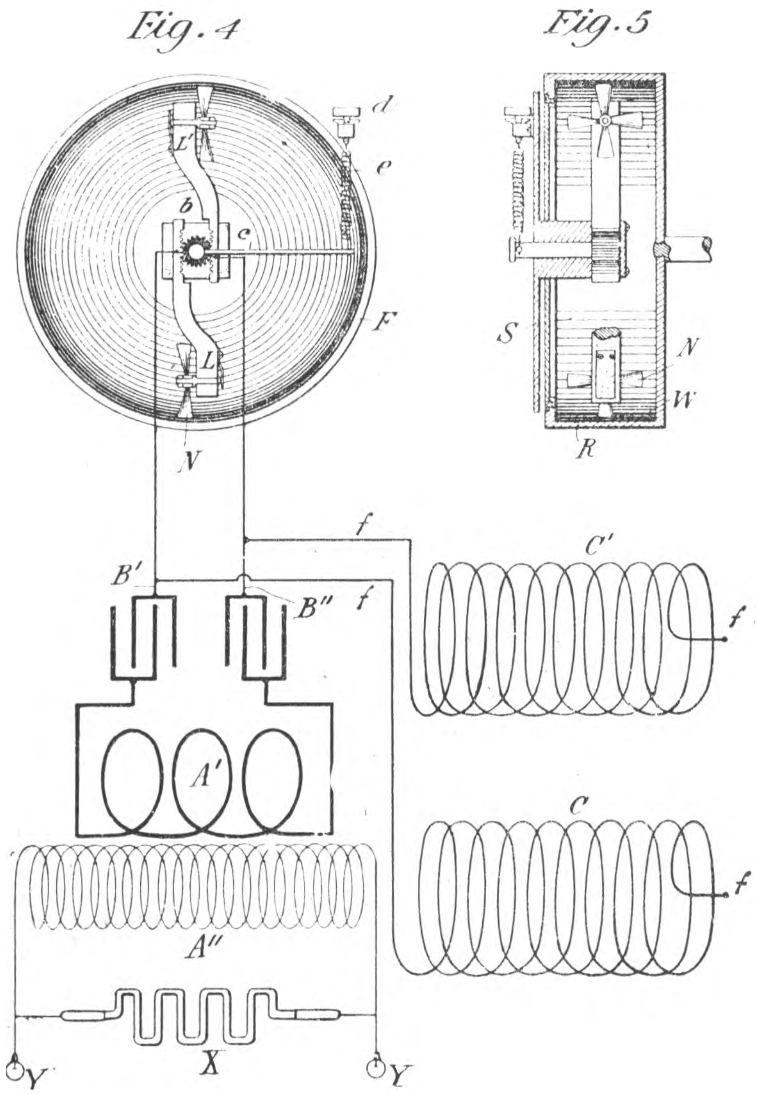
ELECTRIC CIRCUIT CONTROLLER

(Application filed June 3, 1897. Renewed June 15, 1898)

2 Sheets—Sheet 2



WITNESSES

Edwin B. Hopkinson,
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NIKOLA TESLA, OF NEW YORK, N. Y.

ELECTRICAL-CIRCUIT CONTROLLER.

SPECIFICATION forming part of Letters Patent No. 609,245, dated August 16, 1898.

Application filed December 3, 1897. Serial No. 660,518. (No model.)

To all whom it may concern:

Be it known that I, NIKOLA TESLA, residing at New York, in the county and State of New York, have invented certain new and useful Improvements in Electrical-Circuit Controllers, of which the following is a specification, reference being had to the drawings accompanying and forming a part of the same.

In every form of electrical apparatus involving a means for making and breaking, more or less abruptly, a circuit a waste of energy occurs during the periods of make or break, or both, due to the passage of the current through an arc formed between the receding or approaching terminals or contacts, or, more generally, through a path of high resistance. The tendency of the current to persist after the actual disjunction or to precede the conjunction of the terminals exists in varying degrees in different forms of apparatus, according to the special conditions present. For example, in the case of an ordinary induction-coil the tendency to the formation of an arc at the break is, as a rule, the greater, while in certain forms of apparatus I have invented in which the discharge of a condenser is utilized this tendency is greatest at the instant immediately preceding the conjunction of the contacts of the circuit-controller which effects the discharge of the condenser.

The loss of energy occasioned by the causes mentioned may be very considerable and is generally such as to greatly restrict the use of the circuit-controller and render impossible a practical and economical conversion of considerable amounts of electrical energy by its means, particularly in cases in which a high frequency of the makes and breaks is required.

Extended experiment and investigation conducted with the aim of discovering a means for avoiding the loss incident to the use of ordinary forms of circuit-controllers have led me to recognize certain laws governing the waste of energy and making it dependent chiefly on the velocity with which the terminals approach and recede from one another and also more or loss on the form of the current-wave. Briefly stated, from both theoretical considerations and practical experiment it appears that the loss of energy in any device for making and breaking a circuit, other conditions being the same, is inversely proportional rather to the square than to the first power of the speed or relative velocity of the terminals in approaching and receding from one another in an instance in which the current-curve is not so steep as to materially depart from one which may be represented by a sine function of the time; but such a case seldom obtains in practice. On the contrary, the current-curve resulting from a make and break is generally very steep and particularly so when, as in my system, the circuit-controller effects the charging and discharging of a condenser, and consequently the loss of energy is still more rapidly reduced by increased velocity of approach and separation. The demonstration of these facts and the recognition of the impossibility of attaining the desired results by using ordinary forms of circuit-controllers led me to invent new and essentially different means for making and breaking a circuit in which I have utilized a conducting fluid, such as mercury, as the material for one or both of the terminals and devised novel means for effecting a rapidly-intermittent contact between the fluid and a conductor or series of conductors forming the other terminal.

With a view, however, to securing a more practical and efficient circuit-controller in which not only the relative speed of the terminals but also the frequency of the makes and breaks should be very high I devised the the form of instrument described in an application filed by me June 3, 1897, Serial No. 639,227, in which a receptacle is rotated to impart a rapid movement to a body of conducting fluid contained therein, which is brought in rapidly-intermittent contact with a conductor having peripheral projections extending into the fluid, the movement of the latter being conveniently utilized to rotate the conductor. Such a device, though meeting fully many requirements in practice, is nevertheless subject to certain limitations in the matter of attaining a high relative speed of approach and separation of the terminals, since the path of movement of the conducting projections is not directly away from and toward the fluid, but more or less tangential to the surface of the latter, the velocity of approach and separation being of course the smaller the greater the diameter of the rotated conductor or terminal.

With the object of securing a greater relative speed of the terminals and a consequently more efficient form of circuit-controller of this type I devised the modified form of apparatus which constitutes the subject of my present application.

In this apparatus one of the members or terminals is a conducting fluid which is caused to issue from an orifice against a series of spaced conductors in rapid succession. For this purpose the series of conductors, or it may be a single conductor, is moved transversely through the stream or jet of fluid, or the jet is moved so as to impinge upon the conductors, or both jet and conductors are moved. This is preferably accomplished by mounting the conductors and the tube or duct from which the fluid issues concentrically and revolving one or both.

The chief feature of novelty which distinguishes the apparatus and in which my improvement resides is the plan adopted for maintaining the stream or jet of conducting fluid. This consists in utilizing the same power that actuates or drives the circuit-controller in effecting the necessary relative movement of its terminals to maintain the proper circulation of the conducting fluid by combining the two mechanisms (the controller and the means for maintaining a circulation of the conducting fluid) in one. This feature is of great practical advantage and may be effected in many ways. A typical arrangement for this purpose is to provide a tube or duct having an orifice at one end directed toward the spaced conductors and its other end in a position to take up a portion of the rapidly-rotating body of conducting fluid, divert it through the duet, and discharge it against the conductors. With this object when a closed receptacle is used a holder for the tube is employed, mounted within the receptacle and concentrically therewith, and this holder, when the receptacle is revolved, is held or influenced by any suitable means, as by magnetic attraction exerted from the outside or otherwise, in such manner as to keep it either in a fixed position or impress upon it a velocity different from that of the rotated fluid.

Such other improvements in details as I have devised and applied to the construction and operation of my improved circuit-controller will be more fully hereinafter described; but from the above general statement of the nature of the device it will be observed that by means of the same the velocity of relative movement of the two parts or elements may be enormously increased and the duration of the arc or discharge between them at the periods of make and break thereby greatly reduced without material increase in the power required to effect it and without impairing the quality of contact or deteriorating the terminals.

In the drawings hereto annexed, Figure 1 is a diagram illustrating the system for which the improvement was more especially designed. Fig. 2 is a top plan view of the circuit-controller. Fig. 3 is a view showing the induction-coil of Fig. 1 with its condenser-case in side elevation and the circuit-controller in vertical central section.

The general scheme of the system for use with which my improved circuit-controller is more especially designed will be understood by a brief reference to Fig. 1. In said figure, A A represent the terminals of a source of current. A' is a self-induction or choking coil included in one branch of the circuit and permanently connected to one side of a condenser A''. The opposite terminal of this condenser is connected to the other terminal of the source through the primary B of a transformer, the secondary B' of which supplies the working circuit containing any suitable translating devices, as B''.

The circuit-controller C, which is represented conventionally, operates to make and break a bridge from one terminal of the source to a point between the choking-coil A' and the condenser A'', from which it will result that when the circuit is completed through the controller the choking-coil A' is short-circuited and stores energy which is discharged into the condenser when the controller-circuit is broken, to be in turn discharged from the condenser through the primary B when these two are short-circuited by the subsequent completion of the controller-circuit.

I refer now to Figs. 2 and 3 for an illustration of the more important and typical features of my improved circuit-controller. The parts marked *a* compose a closed receptacle of cylindrical form having a dome or extension of smaller diameter. The receptacle is secured to the end of a spindle *c*, which is mounted vertically in bearings of any character suitable for the purpose. As it is intended to impart a rapid rotation to the receptacle *a*, I have shown a convenient device for this purpose comprising a field-magnet *d*, secured to the base or frame *e*, and an annular armature *f*, secured to the receptacle *a*. The coils of the armature are connected with the plates *g* of a commutator secured to the receptacle *a* and made in cylindrical form, so as to surround the socket in which the spindle *c* is stepped. A body of magnetic material *h*, which serves as an armature, is mounted on antifriction-bearings on an extension of the spindle *c*, so that the receptacle and the body *h* may have freely independent movements of rotation. Surrounding the dome *b*, in which the armature *h* is contained, is a core with pole-pieces *o*, which are magnetized by coils *p*, wound on the core. The said core is stationary, being

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supported by arms *r*, Fig. 2, independently of the receptacle, so that when the receptacle is rotated and the core energized the attractive force exerted by the poles *o* upon the armature *h* within the receptacle *a* holds the said armature against rotation. To prevent loss from currents set up in the shell of the dome *b*, the latter should be made of German silver or other similar precaution taken. An arm *i* is secured to the armature *h* within the receptacle *a* and carries at its end a short tube *k*, bent, as shown in Fig. 2, so that one open end is tangential to the receptacle-wall and the other directed toward the center of the same. Secured to the top plate of the receptacle *a* are a series of conducting-plates *l*. The part of the top plate *s* from which said conducting-plates *l* depend is insulated from the receptacle proper by insulating packing-rings *t*, but is electrically connected with the dome *h*, and in order to maintain electrical connection from an external circuit to the conductors *l* a mercury-cup *w* is set in the top of the dome, into which cup extends a stationary terminal plug *n*. A small quantity of a conducting fluid, such as mercury, is put into the receptacle *a*, and when the latter is rotated the mercury by centrifugal action is forced out toward its periphery and rises up along its inner wall. When it reaches the level of the open-mouthed tube *k*, a portion is taken up by the latter, which is stationary, and forced by its momentum through the tube and discharged against the conductors *l* as the latter pass in rapid succession by the orifice of said tube. In this way the circuit between the receptacle and the conductors *l* is completed during the periods in which the stream or jet of mercury impinges upon any of the conductors Zand broken whenever the stream is discharged through the spaces between the conductors.

From the nature of the construction and mode of operation of the above-described apparatus it is evident that the relative speed of separation and approach of the two elements or terminals (the jet and the conductors *l*) may be extremely high, while such increased speed affects in no material respect the quality of contact.

A circuit-controller of the kind described is applicable and useful in many other systems and apparatus than that particularly described herein, and may be greatly modified in construction without departure from the invention.

I am aware that a jet or stream of conducting fluid has heretofore been employed as a means for completing an electric circuit, and I do not claim, broadly, the employment of a conducting fluid in such form as a contact or terminal; but so far as I am aware both the purpose for which I employ such form of contact or terminal and the manner in which I apply it are wholly of my invention, neither having been heretofore proposed.

What I claim is—

1. The combination with a receptacle of a conductor or series of spaced conductors, a nozzle or tube for directing a jet or stream of fluid against the same, the nozzle and conductor being capable of movement relatively to each other, and means for maintaining a circulation of conducting fluid, contained in the receptacle, through the said nozzle, and dependent for operation upon such relative movement, as set forth.

2. The combination with a closed receptacle of a conductor or series of spaced conductors, a nozzle or tube for directing a jet or stream of fluid against the same, and means for forcing a conducting fluid contained in the receptacle through the said nozzle, these parts being associated within the receptacle and adapted to be operated by the application of a single actuating power, as set forth.

3. The combination with a receptacle containing a series of spaced conductors, a duct within the receptacle having one of its ends directed toward the said conductors, means for maintaining a rapid movement of relative rotation between the said end and the conductors and means for maintaining a circulation of a conducting fluid contained in the receptacle through the duct against the conductors, the said conductors and jot constituting respectively the terminals or elements of an electric-circuit controller.

4. The combination with a receptacle capable of rotation and containing a series of spaced conductors, a duct within the receptacle having an orifice directed toward the said conductors, and an open end in position to take up a conducting fluid from a body of the same contained in the receptacle, when the latter is rotated, and direct it against the conductors, the said conductors and the fluid constituting the terminals or elements of an electric-circuit controller.

5. The combination with a receptacle for containing a conducting fluid and a series of spaced conductors thereon, of a duct having an orifice directed toward the said conductors and forming a conduit through which the fluid when the receptacle is rotated is forced and thrown upon the conductors.

6. The combination with a receptacle capable of rotation, and a series of conductors mounted therein, of a duct having an orifice directed toward the conductors, a holder for said duct mounted on bearings within the receptacle which permit of a free relative rotation of said receptacle and holder, and means for opposing the rotation of the said holder in the direction of the movement of the fluid while the receptacle is rotated, whereby the conducting fluid within the receptacle will be caused to flow through the duct against the conductors.

7. The combination with a receptacle and a motor for rotating the same, of a magnetic body mounted in the receptacle, a magnet exterior to the receptacle for maintaining the body stationary while the receptacle rotates,

a series of conductors in the receptacle and a duct carried by the said magnetic body and adapted to take up at one end a conducting fluid in the receptacle when the latter rotates and to direct such fluid from its opposite end against the series of conductors.

8. The combination with a receptacle for containing a conducting fluid, a series of spaced conductors within the same, and a motor, the armature of which is connected with the receptacle so as to impart rotation thereto, a magnetic body capable of turning freely within the receptacle about an axis concentric with that of the latter, a duct carried by the said body having one end in position to take up the conducting fluid and the other in position to discharge it against the spaced conductors, and a magnet exterior to the receptacle for holding the magnetic body stationary when the receptacle is rotated.

NIKOLA TESLA.

Witnesses:

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G. W. MARTLING.

P-266

No. 609,245

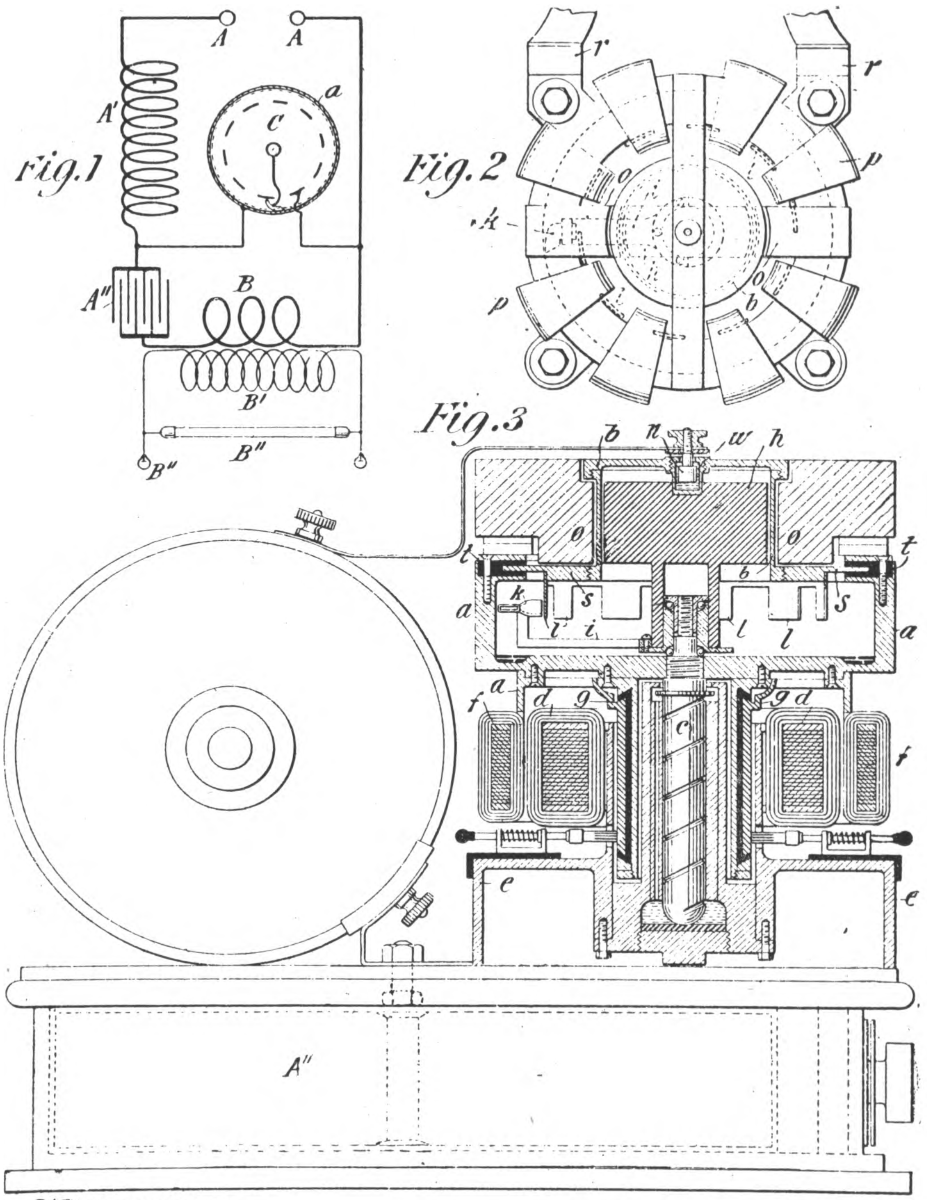
Patented Aug. 16. 1898.

N. TESLA

ELECTRICAL CIRCUIT CONTROLLER.

(Application filed Dec. 2, 1807.)

(No Model.)



Witnesses:
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M Lawson Dyer.

Nikola Tesla, Inventor
by Kerr, Curtis & Page Attys.

UNITED STATES PATENT OFFICE

NIKOLA TESLA OF NEW YORK. N. Y.

ELECTRICAL-CIRCUIT CONTROLLER.

SPECIFICATION forming part of Letters Patent No. 611,719, dated October 4, 1898.

Application filed December 10, 1897. Serial No. 661,403. (No model.)

To all whom it may concern:

Be it known that I, NIKOLA TESLA, residing at New York, in the county and State of New York, have invented certain new and useful Improvements in Electrical - Circuit Controllers, of which the following is a specification, reference being had to the drawings accompanying and forming part of the same.

In order to secure a more efficient working of circuit-controllers, particularly in their use in connection with my system of electrical-energy conversion by means of condenser discharges, I have devised certain novel forms of such appliances, comprising as essential elements a body of conducting fluid constituting one of the terminals, a conductor or series of conductors forming the other terminal, and means for bringing the two into rapidly-intermittent contact with each other. These devices possess many desirable qualities, particularly that of being eminently adapted for making and breaking at a very rapid rate an electric circuit and thus reducing to a minimum the time of passage of the current through an arc or path of high resistance and diminishing thereby the losses incident to the closure and interruption of the circuit. Continued experimentation with these appliances has led me to make further important improvements by causing the make-and-break to be effected in an inert medium of very high insulating power.

It is a fact, which was fully demonstrated by Poggendorff and utilized by him to improve the operation of induction-coils, that when the contact-points of a circuit-breaker are inclosed in a vessel and the latter exhausted to a high degree the interruption, of the current is rendered more sudden, as if a condenser were connected around the break. Furthermore, my own investigations have shown that under such conditions the closure also is more sudden, and this to even a greater degree than the break, which result I attribute to the high insulating quality of the vacuous space, in consequence of which the electrodes may be brought in very close proximity before an arc can be formed between them. Obviously these facts may be utilized in connection with my novel circuit-controllers; but inasmuch as only a very moderate improvement is secured in this manner and as the high vacuum required is quickly destroyed and cannot be maintained, unless by a continuous process of rarefaction and other inconvenient measures, I have found it desirable to employ more effective and practical means to increase the efficiency of the devices in question. The measures I have adopted for this purpose have resulted from my recognition of certain ideal qualifications of the medium wherein to effect a make-and-break. These may be summed up as follows: First, the medium by which the contact-points are surrounded should have as high an insulating quality as possible, so that the terminals may be approached to an extremely short distance before the current leaps across the intervening space; second, the closing up or repair of the injured dielectric, or, in other words, the restoration of the insulating power, should be instantaneous in order to reduce to a minimum the time during which the waste principally occurs; third, the medium should be chemically inert, so as to diminish as much as possible the deterioration of the electrodes and to prevent chemical processes which might result in the development of heat or, in general, in loss of energy; fourth, the giving way of the medium under the application of electrical pressure should not be of a yielding nature, but should be very sudden and in the nature of a crack, similar to that of a solid, such as a piece of glass when squeezed in a vise, and, fifth, most important, the medium ought to be such that the arc when formed is restricted to the smallest possible linear dimensions and is not allowed to spread or expand. As a step in the direction of these theoretical requirements I have employed in some of my circuit-controlling devices a fluid of high insulating qualities, such as liquid hydrocarbon, and caused the same to be forced, preferably with great speed, between the approaching and receding contact-points of the circuit-controller. By the use of such liquid insulator a very marked advantage was secured; but while some of the above requirements are attained in this manner certain defects still exist, notably that due to the fact that the insulating liquid, in common with a vacuous space, though in a less degree, permits the arc to expand in length and thickness, and thus pass through all degrees of resistance and causing a more or less considerable waste of energy. To overcome this defect and to still more nearly attain the theoretical conditions required for most efficient working of the circuit-controlling devices, I have been finally led to use a fluid insulating medium subjected to great pressure.

The application of great pressure to the medium in which the make-and-break is made secures a number of specific advantages. One of these may be obviously inferred from well-established experimental facts, which demonstrate that the striking distance of an are is approximately inversely proportional to the pressure of gaseous medium in which it occurs; but in view of the fact that in most cases occurring in practice the striking distance is very small, since the difference of potential between the electrodes is usually not more than a few hundred volts, the economical advantages resulting from the reduction of the striking distance, particularly on approach of the terminals, are not of very great practical consequence. By far the more important gain I have found to result from an effect which I have observed to follow from the action of such a medium when under pressure upon the arc—namely, that the cross-section of the latter is reduced approximately in an inverse ratio to the pressure. As under conditions in other respects the same the waste of energy in an arc is proportional to its cross-section, a very important gain in economy generally results. A feature of great practical value lies also in the fact that the insulating power of the compressed medium is not materially impaired even by considerable increase in temperature, and, furthermore, that variations of pressure between wide limits do not interfere notably with the operation of the circuit-controller, whereas such conditions are fatal drawbacks when, for instance, Poggendorff's method of insulating the terminals is used. In many other respects, however, a gas under great compression nearly fulfils the ideal requirements above mentioned, as in the sudden breaking down and quick restoration of the insulating power, and also in chemical inertness, which by proper selection of the gas is easily secured.

In carrying out my invention the medium under pressure may be produced or maintained in any proper manner, the improvement not being limited in this particular to any special means for the purpose. I prefer, however, to secure the desired result by inclosing the circuit-controller, or at least so much of the same as shall include the terminals, in a chamber or receptacle with which communicates a small reservoir containing a liquefied gas. For purpose of illustration this particular manner of carrying out the invention is described herein.

While the improvement is applicable generally to circuit-controllers, the best results will be secured by the use of devices in which a high relative speed between the terminals is obtainable, and with this special object in view I have devised a novel circuit-controller which, though belonging to the class of which I have shown a typical form in my application for patent filed December 2, 1897, Serial No. 660,518, differs in certain particulars of construction, which will be understood from the following comparison: In the previously-described form of said circuit-controllers a rotary receptacle, carrying within it a series of spaced conductors, is driven at a high speed by a suitable motor. Mounted within and concentrically with the receptacle, but capable of free independent rotation with respect thereto, is a body which during the rotation of the receptacle is retarded or restrained against rotation by the application of a suitable force. This body carries a tube or duct which takes up at one end a fluid conductor contained in the receptacle and rotating with the same and discharges it from the other end against the rotating spaced conductors.

While an apparatus thus constructed is very efficient and performs the work required of it in a highly-satisfactory manner, it is nevertheless subject to certain limitations, arising mainly from the amount of work which the conducting fluid is required to perform and which increases with the speed. With the object of overcoming objections that might lie to this form of circuit-controller in the particular referred to, I devised the form of instrument shown herein. The features which more particularly distinguish this form are the following: I employ a closed stationary receptacle within which is mounted a body that is capable of being rotated in any way—as, for example, by the drag or pull upon it of an external field of force or a magnet rotated bodily. The rotary body imparts rotation to a series of spaced conductors within the receptacle and also operates as a pump to maintain a flow of conducting fluid through one or more stationary ducts and from the same against the rotating conductors.

The details of this apparatus will be described by reference to the accompanying drawing, which is a vertical central section of the circuit-controller complete.

A is a receptacle, of iron, steel, or other proper material, with a head B, secured by a gas-tight insulating-joint. Within this receptacle is contained the circuit-controller, which, in so far as the main feature of my present invention is concerned, may be of any desired construction, but which, for the reason stated above, is of the special character shown. A spindle C is screwed or otherwise secured centrally in the head B, and on this is mounted on antifriction-bearings a body to which rotary motion may be imparted. The construction of the device in this particular and the means for imparting rotation to the said body may be greatly varied; but a convenient means for accomplishing this is to secure to the rotary sleeve D a laminated magnetic core E and place around the portion of the head B which contains it a core F, provided with coils and constituting the primary element of a motor capable of producing a rotary field of force which will produce a rapid rotation of the secondary element or core E. To the depending end of the sleeve D is secured a conductor G, usually in the form of a disk with downwardly-extending teeth or peripheral projections H. To the sleeve or the disk G is also attached, but insulated therefrom, a shaft T, having a spiral blade and extending down into a well or cylindrical recess in the bottom of the receptacle. One or more ducts or passages J lead from the bottom of this well to points near the path of the conducting-teeth H, so that by the rotation of the screw I a conducting fluid, which runs into the well from the receptacle, will be forced up through the duct or ducts, from which it issues in a jet or jets against the rotating conductor. To facilitate this operation, the well is surrounded by a flange K, containing passages L, which permit the conducting fluid to flow from the receptacle into the well, and having beveled sides which serve as a shield to deflect the fluid expelled from the ducts through the spaces in the conductor to the bottom of the receptacle.

M is any suitable reservoir communicating with the interior of the main receptacle and containing a liquefied gas, such as ammonia, which maintains a practically inert atmosphere under pressure in the receptacle.

Preferably, though mainly as a matter of convenience, the receptacle M is a metal cup with a hollow central stem N, the opening for the passage of gas being controlled by a screw-valve in the top of the cup. The said cup is screwed onto the end of the spindle C, through which is a passage O, leading into the interior of the receptacle A.

The receptacle A and the conducting fluid, which is generally mercury, being normally insulated from the head B and the parts attached and supported thereby, are connected to one part of the circuit to be controlled. The other circuit connection is made by a conductor P to any part of the head, so that when the core E and conductor G are rotated the circuit will be completed between the two insulated parts of the receptacle through the jet or jets of conducting fluid whenever they impinge upon the said conductor.

To insure a good electrical connection between the sleeve D and the spindle C, I provide in the former a small chamber R, which contains mercury, and into this the end of the spindle C extends.

The special advantages of this particular form of circuit-controller heretofore referred to will now more readily appear. The mass and weight of the rotating parts are greatly reduced and a very high speed of rotation obtained with small expenditure of energy. The power required to maintain the jets of conducting fluid is, moreover, very small.

Having now described my invention, what I claim is—

1. The combination with a closed receptacle, of a circuit-controller contained therein and surrounded by an inert insulating medium under pressure.

2. The combination with a closed receptacle, of a circuit-controller contained therein and means for maintaining within said receptacle an inert atmosphere under pressure.

3. The combination with a closed receptacle, of a circuit-controller contained therein, and a vessel containing a liquefied inert gas, and communicating with the interior of the receptacle.

4. The combination with a circuit-controlling mechanism, one part or terminal of which is a conducting fluid, such as mercury, of a receptacle inclosing the same and means for maintaining an inert gas under pressure in the receptacle.

5. The combination with a conductor or series of conductors constituting one terminal of a circuit-controller, means for maintaining a stream or jet of conducting fluid as the other terminal with which the conductor makes intermittent contact, a close receptacle containing the terminals, and means for maintaining an inert atmosphere under pressure in the receptacle.

6. A device for making and breaking an electric circuit comprising, in combination, means for maintaining a jet or stream of conducting fluid which constitutes one terminal, a conductor or conductors making intermittent contact with the jet and constituting the other terminal and a receptacle inclosing and excluding oxygen from the said terminals.

7. The combination with a receptacle, of a conductor or series of spaced conductors mounted therein, a motive device for rotating said conductors, one or more nozzles for directing a stream or jet of fluid against the conductor, and a force-pump in direct connection with the conductor for maintaining a circulation of conducting fluid contained in the receptacle through the nozzle or nozzles, the conductor and the fluid constituting respectively the terminals of a circuit-controller.

8. The combination of a casing, a conductor or series of spaced conductors mounted therein, a motor for rotating the same, one or more ducts or channels from a receptacle containing a conducting fluid and directed toward the conductors, and a screw operated by the motor for forcing the conducting fluid through the duct or ducts against the conductors, the conductors and the fluid constituting the terminals of an electric-circuit controller.

9. The combination with a receptacle containing a conducting fluid, of a conductor mounted within the receptacle, means for rotating the same, a screw rotating with the conductor and extending into a well in which

the fluid collects, and a duct or ducts leading from the well to points from which the fluid will be directed against the rotating conductor.

10. The combination with the receptacle, of a spindle secured to its head or cover, a magnetic core mounted on the spindle within the receptacle, means for rotating said core, a conductor rotated by the core, and a pumping device, such as a screw rotated by the core and operating to maintain a jet or jets of conducting fluid, against the conductor, when in rotation.

NIKOLA TESLA.

Witnesses:
M. LAWSON DYER,
G. W. MARTLING.

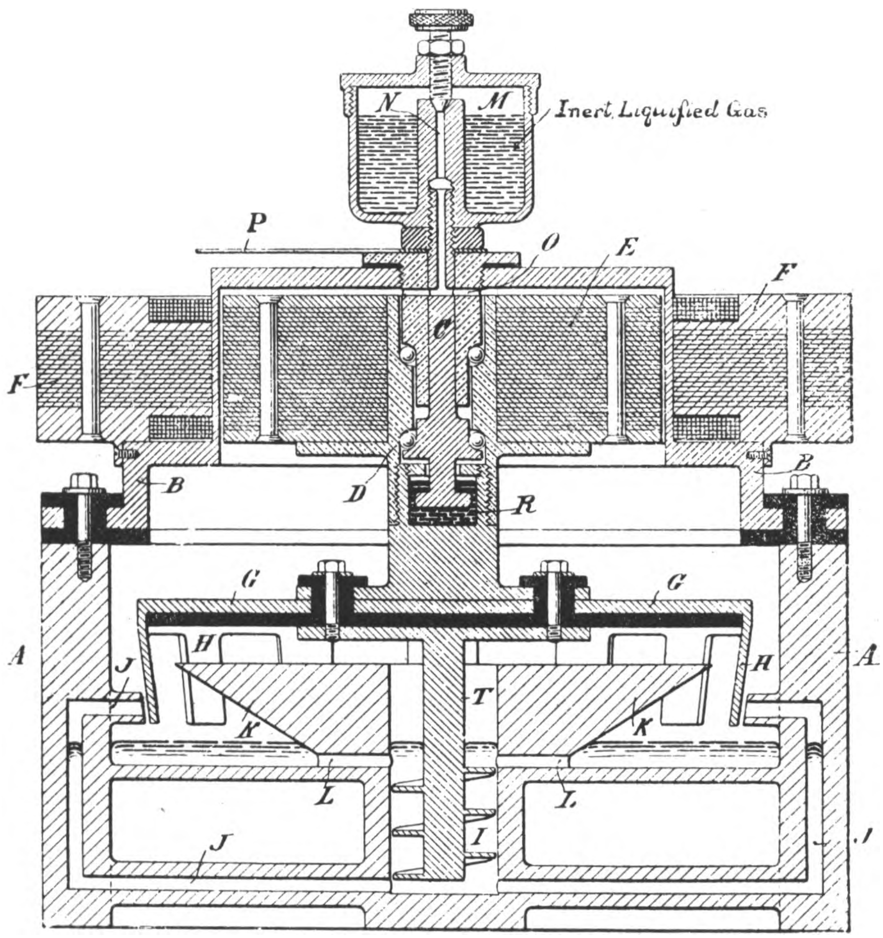
No. 611,719. Patented Oct 4, 1898.

N. TESLA

ELECTRICAL CIRCUIT CONTROLLER

(Application filed Dec. 10, 1897

(No Model.)



Witnesses:

Raphaël Netter

Edwin B. Hopkinson.

Nikola Tesla, Inventor

by Kerr, Curtis & Page Att'ys

UNITED STATES PATENT OFFICE.

NIKOLA TESLA OF NEW YORK, N. Y.

ELECTRIC-CIRCUIT CONTROLLER

SPECIFICATION forming part of Letters Patent No. 609,240, dated August 10, 1898

Application filed February 28, 1898. Serial No. 671,897 (No model.)

To all whom it may concern:

Be it known that I, NIKOLA TESLA, a citizen of the United States, residing in the borough of Manhattan, in the city, county, and State of New York, have invented certain new and useful Improvements in Electric-Circuit Controllers, of which the following is a specification, reference being had to the drawing accompanying and forming a part of the same.

The invention which forms the subject of my present application is an improvement in a novel class of circuit-controlling appliances heretofore invented by mo and more especially designed to be used with my now well-known apparatus for the production of electric currents of high frequency by means of condenser-discharges, but applicable generally as a means for making and breaking an electric circuit.

In the circuit-controllers of the particular class or type to which my present improvement pertains I have utilized a conducting liquid as one of the terminals and have employed as the other terminal a solid conductor and provided various means for bringing the two into rapidly-intermittent contact.

The distinguishing feature of my present improvement lies chiefly in the use of a conducting liquid for both the terminals under conditions which permit of a rapidly-intermittent contact between them, as will be herein set forth.

The accompanying drawing illustrates an apparatus embodying the principle of my said improvement.

The figure is a central vertical section of the circuit-controller.

In the drawing is shown a receptacle composed of two cylindrical metallic portions A A', secured together by bolts B and nuts C, but insulated from each other. The receptacle is journaled, by means of trunnions formed on or secured to its ends, in standards D D, and any suitable means is employed to impart rotation to it. This is conveniently effected by constructing or organizing the receptacle in such manner that it may serve as the rotating element of an electromagnetic motor in conjunction with a surrounding stationary element E E. The abutting ends of the two parts of the receptacle are formed with inwardly-extending flanges F, which divide the peripheral portions of the receptacle into two compartments G G'. Into one of these compartments, as G, extends a spindle H, having its bearing in the end of the part A and the trunnion secured to or extending therefrom. Into the other compartment G' extends a spindle H, similarly journaled in the end of part A' and its trunnion. Each spindle carries or is formed with a weighted arm K, which, remaining in a vertical position, holds its spindle stationary when the receptacle is revolved.

To the weighted arm of spindle H is secured a standard L, carrying a tube L', with one open end in close proximity to the inner peripheral wall of the compartment G and the other directed toward the axis, but inclined toward the opposite compartment. To the weighted arm of spindle H' is similarly secured a standard M, which is hollow and constitutes a portion of a duct or passage which extends through a part of the spindle and opens through a nozzle M' into a circular chamber N in the wall of the part A'. From this chamber run passages N' to nozzles O, in position to discharge jets or streams of liquid in such directions as to intersect, when the nozzles are rotated, a stream issuing from the end of tube L'.

In each portion or compartment of the receptacle is placed a quantity of a conducting liquid, such as mercury, and the ends of the tubes L' and M are provided with openings which take up the mercury when on the rotation of the receptacle it is carried by centrifugal force against the peripheral wall. The mercury when taken up by the tube L' issues in a stream or jet from the inner end of said tube and is projected into the compartment G'. The mercury taken up by the tube M runs into the circular chamber N, from which it is forced through the passages N' to the nozzles O, from which it issues in jets or streams directed into the compartment G. As the nozzles O revolve with the receptacle the streams which issue from them will therefore be carried across the path of the stream which issues from the tube L' and which is stationary, and the circuit between the two compartments will be completed by the streams whenever they intersect and interrupted at all other times.

The continuity of the jets or streams is not preserved ordinarily to any great distance beyond the orifices from which they issue, and hence they do not serve as conductors to electrically connect the two sides of the receptacle beyond their point of intersection with each other.

It will be understood that so far as the broad feature of maintaining the terminal jots is concerned widely different means may be employed for the purpose and that the spindles mounted in free bearings concentrically with the axis of rotation of the receptacle and held against rotation by the weighted arms constitute but one specific way of accomplishing this result. This particular plan, however, has certain advantages and may be applied to circuit-controllers of this class generally whenever it is necessary to maintain a stationary or nearly stationary body within a rotating receptacle. It is further evident from the nature of the case that it is not essential that the jet or jets in one compartment or portion of the instrument should be stationary and the others rotating, but only that there should be such relative movement between them as to cause the two sets to come into rapidly-intermittent contact in the operation of the device.

The number of jets, whether stationary or rotating, is purely arbitrary; but since the conducting fluid is directed from one compartment into the other the aggregate amount normally discharged from the compartments should be approximately equal. However, since there always exists a tendency to project a greater quantity of the fluid from that compartment which contains the greater into that which contains the lesser amount no difficulty will be found in this respect in maintaining the proper conditions for the satisfactory operation of the instrument.

A practical advantage, especially important when a great number of breaks per unit of time is desired, is secured by making the number of jets in one compartment even and in the other odd and placing each jet symmetrically with respect to the center of rotation. Preferably the difference between the number of jets should be one. By such means the distances between the jets of each set are made the greatest possible and hurtful short-circuits are avoided.

For the sake of illustration let the number of jets or nozzles L' in one compartment be nine and the number of those marked O in the other compartment ten. Then by one revolution of the receptacle there will be ninety makes and breaks. To attain the same result with only one jet, as L', it would be necessary to employ ninety jets O in the other compartment, and this would be objectionable, not only because of the close proximity of the jets, but also of the great quantity of fluid required to maintain them.

In the use of the instrument as a circuit-controller it is merely necessary to connect the two insulated parts of the receptacle to the two parts of the circuit, respectively, as by causing brushes X Y, connected with circuit-wires, to bear at any suitable points on the said two parts A A'.

In instruments of this character in which both terminals are formed by a liquid element there is no wear or deterioration of the terminals and the contact between them is more perfect. The durability and efficiency of the devices are thus very greatly increased.

Having now described my invention, what I claim is—

1. A circuit-controller comprising in combination means for producing streams or jets of conducting liquid forming the terminals, and means for bringing the jets or streams of the respective terminals into intermittent contact with each other, as set forth.

2. In a circuit-controller, the combination with two sets of orifices adapted to discharge jets in different directions, means for maintaining jets of conducting liquid through said orifices, and means for moving said orifices relatively to each other so that the jets from those of one set will intermittently intersect those from the other, as set forth.

3. The combination in a circuit-controller of ducts and means for discharging therefrom streams or jets of conducting fluid in electrical contact with the two parts of the circuit respectively, the orifices of said ducts being capable of movement relatively to each other, whereby the streams discharged therefrom will intersect at intervals during their relative movement, and make and break the electric circuit, as set forth.

4. In a circuit-controller the combination with one or more stationary nozzles and means for causing a conducting fluid forming one terminal to issue therefrom, of one or more rotating tubes or nozzles, means for causing a conducting liquid forming the other terminal to issue therefrom, the said rotating nozzles being movable through such a path as to cause the liquid issuing therefrom to intersect that from the stationary nozzles as set forth.

5. The combination with a rotating receptacle divided into two insulated compartments, a spindle in one compartment with its axis concentric with that of the receptacle, means for opposing the rotation of said spindle, and a tube or duct carried by the spindle and adapted to take up a conducting fluid at one end from the inner periphery of the compartment when the receptacle is rotated and direct it from the other end into the other compartment, of a similar spindle in the other compartment and means for opposing its rotation, a tube carried by the spindle and having an opening at one end near the inner periphery of the compartment and discharging into a chamber from which lead one or more passages to nozzles fixed to the rotating re-

ceptacle and adapted to discharge across the path of the jet from the stationary nozzle, as set forth.

6. In a circuit-controller the combination with a rotating receptacle of a body mounted therein and formed or provided with a weighted portion eccentric to its axis which opposes its rotation and a tube or duct carried by said body and adapted to take up a conducting fluid from the rotating receptacle as set forth.

7. In a circuit-controller the combination of two sets of nozzles and means for projecting from the same, jets of conducting fluid which constitute respectively the terminals of the controller, means for moving the nozzles relatively to each other so that the jets of the two sets are brought successively into contact, the nozzles of each set being arranged symmetrically about an axis of rotation, there being one more nozzle in one set than in the other.

NIKOLA TESLA.

Witnesses:

M. LAWSON DYER,

G. W. MARTLING.

P-275

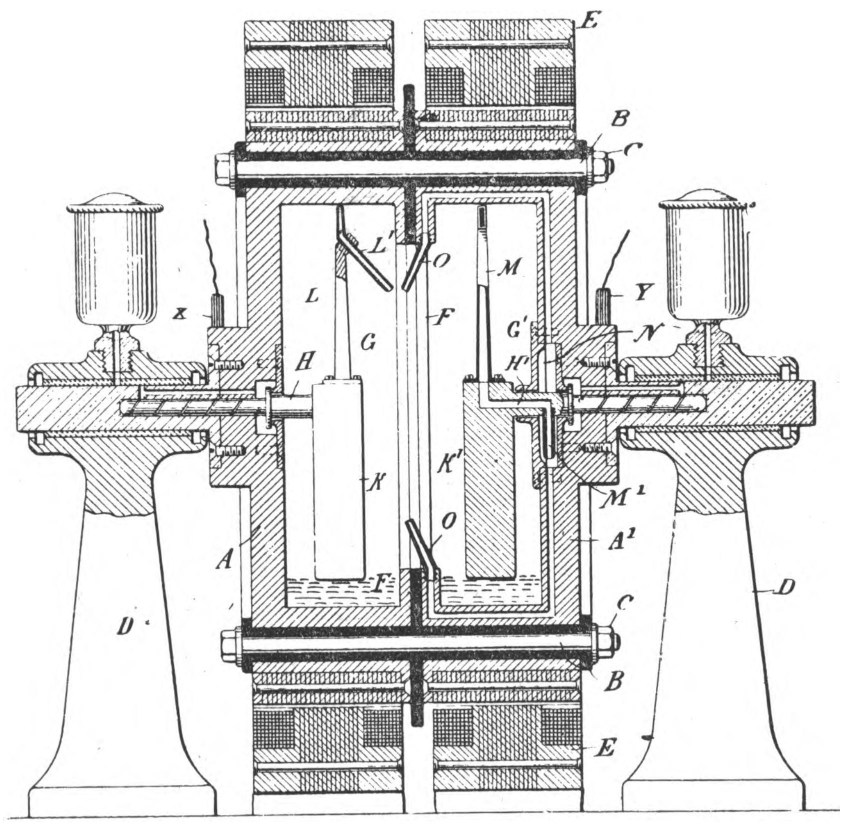
No 609,246 Patented Aug. 16, 1898.

N. TESLA.

ELECTRIC CIRCUIT CONTROLLER

(Application filed Feb. 28. 1898

(No Model)



Witnesses:
Benjamin Miller
Augustine Fenton

Inventor
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UNITED STATES PATENT OFFICE.

NIKOLA TESLA OF NEW YORK, N. Y.

ELECTRIC-CIRCUIT CONTROLLER.

SPECIFICATION forming part of letters Patent No. 609,247, dated August 10, 1898.

Application filed March 12, 1898. Serial No. 673,558 (No model.)

To all whom it may concern:

Be it known that I, NIKOLA TESLA, of the borough of Manhattan, in the city, county, and State of New York, have invented certain new and useful Improvements in Circuit-Controllers, of which the following is a specification, reference being had to the drawings accompanying and forming a part of the same.

In an application filed by me on June 3, 1897, Serial No. 639,227, I have shown and described a device for making and breaking an electric circuit comprising a rotary receptacle containing a conducting fluid and a terminal mounted within but independently of the receptacle and caused by the rotation of the latter to make and break electrical contact with the fluid.

The invention on which my present application is based is an improvement in devices of this particular class, and has primarily as its object the production of a circuit-controller in which an independently-mounted terminal operated in a similar manner by a rotating body of conducting fluid may be inclosed within a gas-tight receptacle.

The invention comprises features of construction by which this object is practically secured and certain improvements applicable to this and other analogous devices, as will be more fully hereinafter set forth.

In the accompanying drawings, Figure 1 is vertical central section of the improved circuit-controller, and Fig. 2 a top plan view of the same with the top or cover of the receptacle removed.

The operative portions of the circuit-controlling mechanism are contained in a closed cylindrical receptacle A, of iron or steel, mounted on a spindle B in a suitable socket or support C to permit it to be freely and rapidly rotated. The socket C is secured to or forms a part of a base or stand D.

As a means of producing the proper rotation of the receptacle A, I have shown a field-magnet E, mounted on or secured to the base D, and an armature F, supported by a bracket G from the under side of the receptacle A. The same bracket also carries a series of commutator - segments H, upon which bear brushes I, these parts being arranged to constitute an electromagnetic motor with stationary field and rotating armature. It may be stated that any other suitable means may be employed to rotate the receptacle and the fluid.

In the spindle B and concentric with its axis is a spindle J in bearings specially constructed to reduce friction in order that the spindle J may be as little as possible influenced by the rotation of the main spindle and receptacle carried thereby. A suitable provision is made to oppose or prevent the rotation of the spindle J during the rotation of the receptacle. I have devised for this purpose the following:

The spindle B is held by its bearings at an angle to the vertical, and a weight K is secured eccentrically to the spindle J and lends to hold the said spindle always in one position. The inclination of the axes of rotation necessary for this result may be substantially that, shown and should not be materially greater, for the reason that it is especially advantageous to preserve the spindles and bearings as nearly as practicable vertical on account of lesser friction and easier lubrication.

Attached to the spindle J or weight K is an insulated bracket L, carrying a standard or socket M, in which is mounted on antifriction-bearings a spindle N. Secured to this latter is a plate with radial arms O, from which depend vanes or blades P, with projections Q extending radially therefrom. A shield or screen R incloses the vanes, except on the side adjacent to the inner periphery of the receptacle A.

A small quantity of a conducting fluid S is placed in the receptacle, and in order to secure a good electrical connection between the vanes P and a terminal on the outside of the receptacle a small mercury-cup T, in metallic contact with the vanes through the bracket L and socket M, is secured to the weight K. A metal stud V, set in an insulated bolt W, projects into the cup T through a packed opening in its cover. One terminal of the circuit-controlling mechanism will thus be any part of the metal receptacle and the other the insulated bolt W. The apparatus may be connected up in circuit by connecting the wires of the circuit to a brush X, bearing on the bolt W, and to a binding-post Y in contact with the base D.

To operate the apparatus, the receptacle is set in rotation, and as its speed increases the mercury or other conducting fluid which it contains is carried by centrifugal force up the sides of the inner wall, over which it spreads in a layer. When this layer rises sufficiently to encounter the projections Q on the blades or vanes P, the latter are set in rapid rotation, and the electrical connection between the terminal of the apparatus is thereby made and broken, it may be, with very great rapidity.

The projections Q are preferably placed at different heights on the vanes P, so as to secure greater certainty of good contact with the mercury film when in rapid rotation.

As to the forms of the circuit-controller heretofore referred to and upon which my present invention is an improvement the blades or vanes P may be regarded in a broad sense as typical of any device—such, for example, as a stelliform disk—which will be set and maintained in rotation by that of the receptacle. So, also, having regard to the feature of my invention which provides for maintaining such a device in operation in a receptacle which may be hermetically sealed, so as to be capable of containing an inert medium under pressure in which the makes and breaks occur and which medium is practically essential to a long-continued and economical operation of the device, I may employ other and widely different means for opposing or preventing the rotation of the part carrying such vanes in the direction of the rotation of the receptacle and fluid.

Having now described my invention, what I claim is—

1. A circuit-controller comprising, in combination, a closed receptacle containing a fluid, means for rotating the receptacle, a support mounted within the receptacle, moans for opposing or preventing its movement in the direction of rotation of the receptacle, and a conductor carried by said support and adapted to make and break electric connection with the receptacle through the fluid, as set forth.

2. A circuit-controller comprising, in combination, a terminal capable of rotation and formed or provided with radiating contacts, a closed receptacle containing a fluid which constitutes the opposite terminal, means for rotating the receptacle, a support therein for the rotating terminal, and means for opposing or preventing the rotation of the support in the direction of the rotation of the receptacle, as set forth.

3. In a circuit-controller, the combination with a receptacle capable of rotation about an axis inclined to the vertical and containing a fluid which constitutes one terminal, a second terminal mounted within the receptacle, on a support capable of free rotation relatively to the receptacle, and a weight eccentric to the axis of rotation of the support for said terminal for opposing or preventing its movement in the direction of the rotation of the said receptacle, as set forth.

4. The combination with a receptacle mounted to revolve about an axis inclined to the vertical, of a spindle within the receptacle and concentric with its axis, a weight eccentric to the spindle, and a terminal carried by the said spindle, and adapted to be rotated by a body of conducting fluid contained in the receptacle when the latter is rotated, as set forth.

5. The combination with a receptacle mounted to rotate about an axis inclined to the vertical, a spindle within the receptacle and concentric with its axis, a weighted arm attached to said spindle, a bracket or arm also secured to said spindle, a rotary terminal with radiating contact arms or vanes mounted on said bracket in position to be rotated by a body of conducting fluid contained in said receptacle when said fluid is displaced by centrifugal action, as set forth.

NIKOLA TESLA.

Witnesses:
M. LAWSON DYER,
G. W. MARTLING

P-278

No. 609,247. Patented Aug. 16, 1898.

N. TESLA.
ELECTRIC CIRCUIT CONTROLLER.

(Application filed Mar. 12, 1898.)

(No Model.)

Fig. 1

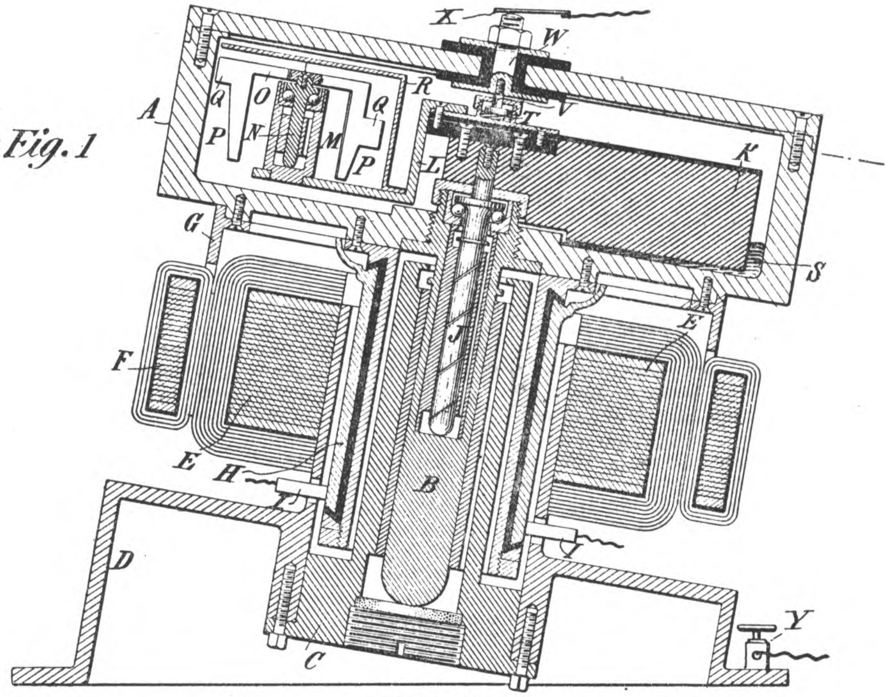
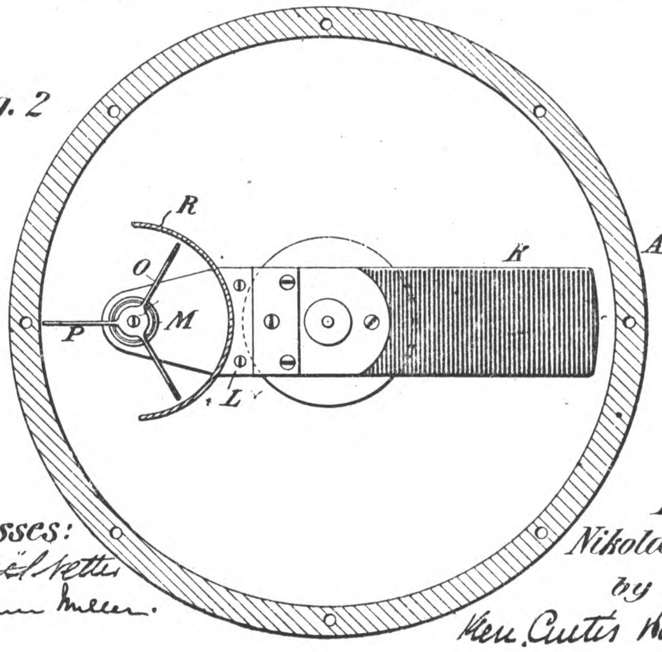


Fig. 2



Witnesses:
Raphaël Netter
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Inventor
Nikola Tesla
by
Ken. Curtis Page Att'ys

UNITED STATES PATENT OFFICE

NIKOLA TESLA, OF NEW YORK, N. Y.

ELECTRIC-CIRCUIT CONTROLLER.

SPECIFICATION forming part of Letters Patent No. 609,248, dated August 16, 1898.

Application filed March 12, 1898. Serial No. 673,559. (No model.)

To all whom it may concern.

Be it known that I, NIKOLA TESLA, of the borough of Manhattan, in the city, county, and State of New York, have invented certain new and useful Improvements in Circuit-Controllers, of which the following is a specification, reference being had to the drawing accompanying and forming a part of the same.

In previous applications filed by me, notably in Serial No. 660,518, filed December 2, 1897, and others, I have shown and described various forms of electric-circuit controllers in which a conducting fluid is used for one or both of the terminals. These contrivances, while applicable generally as a means of making and breaking an electric circuit with great rapidity, were devised by me more especially for use in my now well-known system of electrical conversion by means of condenser-discharges and for this reason have been designed with especial reference to the peculiar and exceptional conditions which obtain in such systems. My present invention is an improvement in circuit - controllers of this kind, and in order that the object and nature of the improvement may be more readily understood and appreciated I may refer briefly to the more essential characteristics of the devices described before upon which the present improvement is based. As it was primarily essential that these controllers be capable of making and breaking the circuit at a very rapid rate and as such a result could not be secured practically or economically by any of the ordinary devices employing rigid contacts or terminals I was led to invent apparatus in which the circuit connections were established and broken between a rigid terminal and a fluid conductor or between two fluid conductors in the form of jets or streams. In the forms of apparatus employing a rigid or solid conductor as one terminal and a fluid as the other the makes and breaks of course occur always between a solid and a fluid terminal, and although the operative parts of my improved circuit-controllers were usually contained in air or gas tight receptacles and in an inert medium, both for the purpose of improving their action and preventing deterioration of the terminals, there is still a liability to wear of the rigid or solid terminal.

Under certain conditions, as when the circuit-controller is operated from a source of direct current, the deterioration of the solid terminal may be materially reduced by connecting it to the negative pole of the generator. Nevertheless, there will be always a slow wearing away of the metal, which to overcome entirely in a novel manner is the object of my present improvement. To do this, I effect the closure of the circuit through two parts of conducting fluid; but instead of breaking the circuit by the movement of these two parts or terminals, as before, I separate them periodically by the interposition of an insulator which is preferably solid and refractory. For example, I provide a plate or disk with teeth or projections—preferably of glass, lava, or the like—which are caused by the rotation of the disk to pass through the fluid conductor, jet, or whatever it may be, and thus effect a make and break of the circuit.

By means of such a device the breaks always occur between fluid terminals, and hence deterioration and consequent impairment of the qualities of the apparatus are avoided.

A preferred form of my improved circuit-controller is illustrated in the accompanying drawing, which shows a central vertical section of the same.

The two terminals are contained in an air-tight receptacle A, of iron or steel, which is mounted on a spindle B in a suitable socket or support C, so as to rotate freely. The socket C is secured to or forms part of a base or stand D. Any suitable means may be employed for effecting the rotation of the receptacle, and in illustration of a convenient and practicable means for this purpose I have shown an armature E, secured to a cylindrical extension of the receptacle that surrounds the socket C, and a field-magnet F, which is supported independently and is stationary. The armature-coils are connected with the segments S of a commutator on which bear brushes G.

In the spindle B and concentric with its axis is a spindle H, supported on ball-bearings or otherwise arranged to have a free movement of rotation relatively to the spindle B, so as to be as little as possible influenced by the rotation of the latter.

Any convenient means is provided to oppose or prevent the rotation of the spindle H during the rotation of the receptacle. In the particular arrangement here shown for this purpose a weight or weighted arm J is secured to the spindle H and eccentrically to the axis of the latter, and as the bearing for the spindle B holds the same at an angle to the vertical this weight acts by gravity to hold the spindle II stationary.

Secured to the top or cover of the receptacle A by a stud K, which passes through an insulating-bushing in said cover and is held by a nut L, is a circular disk M, of conducting material, preferably iron or steel, having its edge turned downwardly and then inwardly to provide a peripheral trough on the under side of the disk.

To the under side of the disk M is secured a second disk N, having downwardly-inclined peripheral projections O O, of insulating and preferably refractory material, in a circle concentric with the disk M.

A tube or duct P is mounted on the spindle H or the weight J and is so arranged that the orifice at one end is directed outwardly toward the trough of the disk M, while the other lies close to the inner peripheral wall of the receptacle, so that if a quantity of mercury or other conducting fluid be placed in the receptacle and the latter rotated the tube or duct P, being held stationary, will take up the fluid which is carried by centrifugal action up the side of the receptacle and deliver it in a stream or jet against the trough or flange of the disk M or against the inner surfaces of the projections O of disk N, as the case may be.

Obviously, since the two disks M and N rotate with respect to the jet or stream of fluid issuing from the duct P, the electrical connection between the receptacle and the disk M through the fluid will be completed by the jet when the latter passes to the disk M between the projections O and will be interrupted whenever the jet is intercepted by the said projections.

The rapidity and the relative duration of the makes and breaks is determined by the speed of rotation of the receptacle and the number and width of the intercepting projections O.

By forming that portion of the disk M with which the jet makes contact as a trough, which will retain when in rotation a portion of the fluid directed against it, a very useful feature is secured. The fluid under the action of centrifugal force accumulates in and is distributed along the trough and forms a layer over the surface upon which the jet impinges. By this means a very perfect contact is always secured and all deterioration of the terminal surfaces avoided.

The principle of interrupting the circuit by intermittently passing an insulator through a fluid conductor may be carried out by many specifically different forms of apparatus, and in this respect I do not limit myself to the particular form herein shown.

What I claim is—

1. In an electrical-circuit controller, the combination with a conductor forming one of the terminals, of means for maintaining a jet or stream of conducting fluid forming the other terminal, and directing it against said conductor, and a body adapted to be intermittently moved through and to intercept the jet or stream, as set forth.

2. In an electrical-circuit controller, the combination with a rigid terminal, of means for directing against such terminal a jet or stream of conducting fluid in electrical connection with the other terminal, and a body adapted to be intermittently moved through and to intercept the jet or stream, as set forth.

3. In an electrical-circuit controller, the combination with a rigid terminal, of means for directing against such terminal a jet or stream of conducting fluid in electrical connection with the other terminal, a body having a series of radial projections and means for rotating the same so that the said projections will intermittently intercept the stream or jet, as set forth.

4. In a circuit-controller, the combination with a rotary conductor forming one terminal, means for directing against such terminal a jet or stream of conducting fluid in electrical connection with the other terminal, and a body with spaced projections mounted to rotate in a path that intercepts the jet or stream of fluid, as set forth.

5. In a circuit-controller, the combination with a rotary conductor forming one terminal, and means for directing intermittently against such terminal a jet or stream of fluid in electrical connection with the other terminal, the part of said rotary conductor upon which the jet or stream impinges being formed so as to retain, by centrifugal force, a portion of the fluid directed against it, as set forth.

6. The combination of the receptacle, the conducting-disk secured within it, the insulated disk with peripheral projections and the stationary tube or duct for directing a stream or jet of conducting fluid toward the conducting-disk and across the path of the projections O, as set forth.

7. The combination of the receptacle, the conducting-disk with a peripheral trough-shaped flange, the insulated disk with peripheral projections O, and the stationary tube or duct for directing a stream or jet of conducting fluid into the trough-shaped flange of the conducting-disk and across the path of the projections O, as set forth.

NIKOLA TESLA.

Witnesses:
M. LAWSON DYER,
G. W. MARTLING.

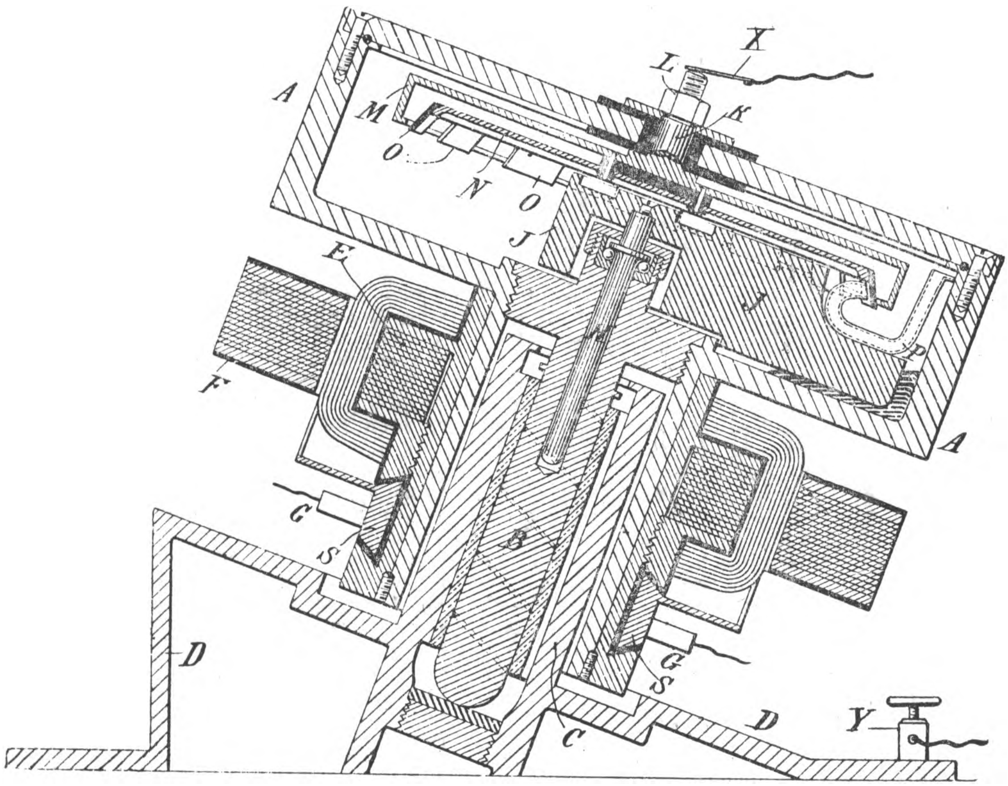
No. 609,248. Patented Aug. 16, 1898.

N. TESLA.

ELECTRIC CIRCUIT CONTROLLER.

(Application filed Mar. 12, 1898.)

(No Model.)



Witnesses:
Raphaël Netter
Benjamin Miller

Nikola Tesla, Inventor

by Kerr, Curtis & Page Att'ys.

UNITED STATES PATENT OFFICE.

NIKOLA TESLA, OF NEW YORK, N. Y.

ELECTRIC-CIRCUIT CONTROLLER.

SPECIFICATION forming part of Letters Patent No. 609,249, dated August 16, 1898.

Application filed March 12, 1898. Serial No. 673,560. (No model.)

To all whom it may concern:

Be it known that I, NIKOLA TESLA, of the borough of Manhattan, in the city, county, and State of New York, have invented certain new and useful Improvements in Electrical-Circuit Controllers, of which the following is a specification, reference being had to the drawing accompanying and forming part of the same.

The present application is based upon improvements in electrical-circuit controllers of the kind heretofore invented by me and described in previous applications, notably in an application filed December 2, 1897, Serial No. 660,518. The chief distinguishing features of these devices are the use of a conducting fluid for one or both of the terminals under conditions which permit of a very rapid succession of makes and breaks and a construction or arrangement which allows the inclosing of the terminals in an air-tight receptacle in which an inert medium may be maintained. My efforts to meet the practical requirements of apparatus of this kind have led me to adopt expedients and to invent mechanisms entirely novel in such devices. For example, in order to effect a rapidly-intermittent contact between two terminals by the use of a jet or jets in a closed receptacle it is obviously necessary to employ special means which will operate to hold one part of the apparatus stationary while the other rotates or to rotate both the essential parts or terminals in opposite directions or, as the case may be, in the same direction at different speeds.

The present invention is embodied in a device for securing the proper relative movement of the two parts or terminals of the circuit-controller and involves two salient features of novelty, one that it provides for maintaining in a rotating receptacle a stationary jet or jets which by impinging on a rigid conductor maintain the latter in rotation, thereby securing the requisite rapidly-intermittent contact between the two, and the other that it utilizes the rotation of such rigid conductor as a means for opposing or preventing the movement of its own supports in the direction of rotation of the receptacle, thereby securing, among other things, an approximately constant relative movement between the parts, a feature which in devices of this kind is often very desirable.

In the drawing hereto annexed I have illustrated the preferred form of apparatus which I have devised for carrying out these improvements. The figure is a central vertical cross-section of a circuit-controller.

A designates a receptacle, usually of iron or steel and mounted in any suitable manner, as by trunnions B B, having bearings in standards C C, so as to be capable of rapid rotation about a horizontal axis.

In the particular form of device under consideration the receptacle is divided into two parts insulated by a washer D and held together by insulated bolts E with nuts F. These two parts are electrically connected, respectively, with the two terminals of the apparatus, as hereinafter described and by means of brushes X Y, bearing at any suitable points on the two parts of the receptacle, the circuit-controller is connected with the wires of a circuit.

Any convenient means may be employed to rotate the receptacle; but a simple way to effect this is to surround the same with a field-magnet G and to make the receptacle itself the armature of an electric motor or else to secure to it armature-cores, as H.

A body I is supported by trunnions J, having bearings in the ends of the receptacle and concentric with the axis of rotation of the same. The weight of the body I being eccentric to this axis tends to oppose its turning about the axis when the receptacle is rotated.

Upon the body or support I, but insulated therefrom, is secured a vertical standard K, in which there is a freely-rotatable spindle L, carrying a disk M, with radial arms inclined to the plane of the disk, so as to form vanes N. Arms O P are also secured to the body I and are formed with or carry at their ends ducts or tubes Q, with one end directed toward and opening upon the vanes N and the other end close to the inner wall of the receptacle and opening in the direction opposite to that of the rotation of the receptacle.

A suitable quantity of mercury R is placed in the receptacle before the latter is sealed or, closed.

The operation of the device is as follows:

The receptacle is started in rotation, and as it acquires a high velocity the mercury or other conducting fluid R is caused by centrifugal action to distribute itself in a layer over the inner peripheral surface of the receptacle. As the tubes or ducts Q do not take part in the rotation of the fluid, being held at the start by the weighted body I, they take up the mercury as soon as it is carried to the points where the ducts open and discharge it upon the vanes of the disk M. By this means the disk is set in rapid rotation, establishing the contact between the two sides of the receptacle which constitute the two terminals of the circuit-controller whenever the two streams or jets of fluid are simultaneously in contact with the vanes, but breaking the contact whenever the jets discharge through the spaces between the vanes. The chief object of employing more than one insulated jet is to secure a higher velocity of approach and separation, and in respect to the number of jets thus employed the device may be obviously modified as desired without departure from the invention. The disk M, having acquired a very rapid rotation, operates to prevent by gyrostatic action any tendency of the body I to rotate or oscillate, as such movement would change the plane of rotation of the disk. The movement of the parts, therefore, and. the operation of the device as a whole are very steady and uniform, and a material practical advantage is thereby secured. The speed of the disk will be chiefly dependent on the velocity of the streams and pitch of the blades, and it is of course necessary in order to produce a constant speed of rotation of the disk that the velocity of the streams be constant. This is accomplished by rotating the receptacle with a constant speed; but when this is impracticable and the uniformity of motion of the disk very desirable I resort to special means to secure this result, as by providing overflowing-reservoirs V V, as indicated by dotted lines, from which the fluid issues upon the vanes with constant velocity, though the speed of the receptacle may vary between wide limits.

It may be stated that the jets can be produced in any other known ways and that they may be utilized in any desired manner to produce rotation of the disk.

Having now described my invention, what I claim is—

1. The combination in a circuit-controller with a closed rotary receptacle, of a rigid conductor mounted within the same and through which the circuit is intermittently established, and means for directing a jet or stream of a fluid which is contained in the receptacle, against the said body so as to effect its rotation independently of the receptacle, as set forth.

2. In an electric-circuit controller, the combination of a closed rotary receptacle, a conducting body therein adapted to be rotated independently of the receptacle by the impingement thereon of a jet or stream of conducting fluid, and means for maintaining such a jet and directing it upon the said conductor, as set forth.

3. In a circuit-controller, the combination with a rotary receptacle of a body or part mounted within the receptacle and concentrically therewith, a conducting-terminal supported by said body and capable of rotation in a plane at an angle to the plane of rotation of the receptacle so as to oppose, by gyrostatic action, the rotation of the support, and means for directing a jet of conducting fluid against the said terminal, as set forth.

4. In a circuit-controller, the combination with a rotary receptacle of a support for a conductor mounted thereon concentrically with the receptacle and a gyrostatic disk carried by the support and adapted, when rotating, to oppose its movement in the direction of rotation of the receptacle, as set forth.

5. In a circuit-controller, the combination with a rotary receptacle containing a conducting fluid, a support mounted within the receptacle, means for opposing or preventing its movement in the direction of rotation of the receptacle, one or more tubes or ducts carried thereby and adapted to take up the fluid from the rotating receptacle and discharge the same in jets or streams, and a conductor mounted on the support and adapted to be rotated by the impingement thereon of said jet or jets, as set forth.

6. The combination in a circuit-controller of a rotary receptacle, one or more tubes or ducts and a support therefor capable of rotation independently of the receptacle, a conductor mounted on said support in a plane at an angle to that of rotation of the receptacle, and adapted to be maintained in rotation by a jet of fluid taken up from the receptacle by and discharged upon it from the said tube or duct, when the receptacle is rotated.

7. The combination with a rotary receptacle of one or more tubes or ducts, a holder or support therefor mounted on bearings within the receptacle, which permit of a free relative rotation of said receptacle and holder, a disk with a bearing on the said holder and having its plane of rotation at an angle to that of the receptacle, the disk being formed or provided with conducting-vanes, upon which a jet of conducting fluid, taken up by the tube or duct from the receptacle when in rotation, is directed.

NIKOLA TESLA

Witnesses:
M. LAWSON DYER,
G. W. MARTLING.

P-284

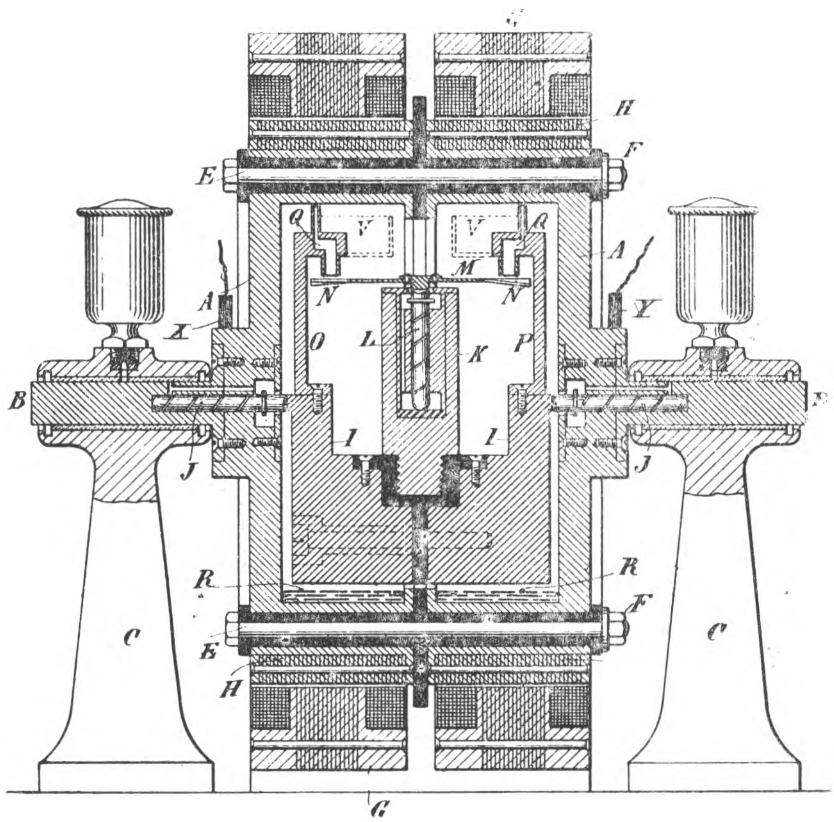
No. 609,249. Patented Aug. 16, 1898.

N. TESLA.

ELECTRIC CIRCUIT CONTROLLER.

(Application filed Mar 13, 1898)

(No Model)



Witnesses:
Raphaël Netter
Benjamin Miller

Nikola Tesla, Inventor
by Kerr, Curtis & Page Att'ys

UNITED STATES PATENT OFFICE.

NIKOLA TESLA, OF NEW YORK, N. Y.

ELECTRIC-CIRCUIT CONTROLLER.

SPECIFICATION forming part of Letters Patent No. 613,735, dated November 8, 1888.

Application filed April 19, 1898. Serial No. 678,127. (No model.)

To all whom it may concern:

Be it known that I, NIKOLA TESLA, residing at New York, in the county and State of New York, have invented certain new and useful Improvements in Electrical-Circuit Controllers, of which the following is a specification, reference being had to the drawings accompanying and forming a part of the same.

In the electrical system or combination of apparatus for the conversion of electrical energy by means of the discharges of a condenser invented and heretofore described by me the means employed for making and breaking the electric circuit, though performing a subordinate function, may from the peculiar conditions which exist become a highly important consideration, not only as regards their practicability and durability, but also the economy in the operation of the system or apparatus. Of such importance is this consideration that for the most efficient and reliable operation of my said system I have found it necessary to devise special appliances for making and breaking the circuit which differ materially in construction and mode of operation from any previously-existing devices of this character of which I am aware. In the forms of such apparatus which I have produced at least one of the terminals is a conducting fluid, while the other is usually a solid conductor or series of conductors, both being preferably inclosed in a gas-tight receptacle and brought by rotary movement into rapidly intermittent contact. I have shown and described typical forms of such circuit-controllers in applications Serial No. 660,518, filed December 2, 1897; Serial No. 639,227, filed June 3, 1897, and Serial No. 671,897, filed February 28, 1898.

The invention, subject of my present application, pertains to apparatus of this class and involves certain improvements in the construction and mode of operation of the same which have primarily for their object to secure a greater relative speed between the two terminals, whereby the periods of make-and-break, during which occurs the chief loss of energy, may be materially shortened and also a higher frequency of current impulses secured. A brief consideration of the forms of circuit-controller of this general kind which I have heretofore shown and described will conduce to a better understanding of the principles followed in the construction of the apparatus upon which my present application is based and of the primary object which I have in view—to increase the relative speed of the two terminals in approaching and receding from each other.

In some forms of the circuit-controllers heretofore described by me I employ a closed receptacle capable of being maintained in rapid rotation. Within this receptacle is mounted a body the rotation of which is retarded or prevented and which carries a tube or duct which takes up a conducting fluid from the receptacle when the latter is rotated and directs the said fluid against a conductor or series of spaced conductors carried by the rotating receptacle. This apparatus, while effective to a high degree and possessing many advantages over previously-existing forms, is nevertheless subject to certain limitations as to efficiency, having regard to the speed at which the receptacle is rotated, for not only may an undue loss of energy result from rotating the receptacle, but also from the unnecessarily-rapid movement of the conducting fluid. With a view to improving the apparatus in these particulars I devised forms in which the receptacle was stationary and the interior terminal conductor rotated, and by this means I reduced the mass and weight of the moving parts. I also employed a device in the nature of a pump, which formed a part of the circuit-controller proper and was operated by the motor used for rotating the conductor, and thus maintained a flow of conducting fluid from ducts in the receptacle against the rotating conductor with no greater speed than required for efficient operation. By such an apparatus it is not only possible to secure a higher relative speed between the two terminals, but to do this with a smaller expenditure of mechanical energy. To still further increase the relative speed of the terminals, I now provide for rotating each of the terminals with respect to the other, so that the rate of mutual contact is very greatly increased.

Obviously various means may be employed for rotating the conductors, or, in general, the two essential parts which by their movement produce a make and break; but in the annexed drawings I have only shown such forms of the apparatus as best illustrate the present improvement.

Figure 1 is a central vertical section of a circuit-controller comprising a conductor or series of conductors forming one terminal and means for maintaining a jet or jets of conducting fluid constituting the other terminal, which are arranged to be rotated in opposite directions. Fig. 2 is a similar view of a modified form of circuit-controller.

A designates a casting of cylindrical form within which is a standard or socket B, in which is mounted a vertical spindle C, carrying the circuit-controlling mechanism. The said mechanism is contained in a receptacle D, of iron or steel, the top or cover of which is composed of an annular plate E and a cap or dome F, the latter being of insulating material or of a metal of comparatively high specific resistance, such as German silver. The receptacle D as a whole is made air - tight and any suitable means may be employed to effect its rotation, the particular device shown for this purpose being an electromagnetic motor, one element, G, of which is secured to the spindle C or receptacle D and the other, H, to the box or case A. Within the receptacle D and secured to the top of the same, but insulated therefrom, is a circular conductor K, with downwardly-extending projections or teeth L. This conductor is maintained in electrical connection with a plate M outside of the receptacle by means of screws or bolts N, passing through insulated gaskets in the top of the receptacle D. Within the latter is a standard or socket O, in which is mounted a spindle P, concentric with the axis of the receptacle.

Any suitable means may be provided for rotating the spindle P independently of the receptacle D; but for this purpose I again employ an electromagnetic motor, one element, Q, of which is secured to the spindle P within the receptacle D and the other, R, is secured to the box A and surrounds the cap or dome F, within which is mounted the armature Q.

Depending from the spindle P or the armature Q is a cylinder S, to which are secured arms T T, extending radially therefrom and supporting short tubes or ducts V between the peripheral walls of the receptacle D and the series of teeth or projections L.

The tubes V. have openings at one end in close proximity to the inner wall of the receptacle D and turned in a direction opposite to that in which the latter is designed to rotate and at the other end orifices which are adapted to direct a stream or jet of fluid against the projections L.

To operate the apparatus, the receptacle D, into which a suitable quantity of conducting fluid, such as mercury, is first poured, and the spindles P are both set in rotation by their respective motors and in opposite directions. By the rotation of receptacle D the conducting fluid is carried by centrifugal force up the sides or walls of the same and is taken up by the tubes or ducts V and discharged against the rotating conductors L. If, therefore, one terminal of the circuit be connected with any part of the receptacle D or the metal portions of the instrument in electrical connection therewith and the other terminal be connected to the plate M, the circuit between these terminals will be completed whenever a jet from one of the ducts V is discharged against one of the projections Land interrupted when the jets are discharged through the spaces between such projections. I have indicated the necessary circuit connections by wires X and X', connected, respectively, with a brush M', bearing upon the circular plate M, and a binding-post X", set in the frame or casing A.

In Fig. 2 a modified form of apparatus is shown and by means of which similar results are obtained. In this device the top and bottom A' of the receptacle are metal plates, while the cylindrical portion or sides A" is of insulating material, such as porcelain. Within the receptacle and preferably integral with the side walls A" are two annular troughs W W', which contain a conducting fluid B', such as mercury. Terminals C' C", passing through the bottom of the receptacle through insulating and packed sleeves, afford a means of connecting the mercury in the two troughs with the conductors of the circuit. Surrounding that portion of the device in which the troughs W W' lie is a core D', wound with coils D" arranged in any suitable and well-known manner to produce, when energized by currents of different phase, a rotating magnetic field in the space occupied by the two bodies of mercury. To intensify the action, a circular laminated core E' is placed within the receptacle. If by this or any other means the mercury is set in motion and caused to flow around in the troughs, and if a conductor be mounted in position to be rotated by the mercury, and when so rotated to make intermittent contact therewith, a circuit-controller may be obtained of novel and distinctive character and capable of many useful applications independently of the other features which are embodied in the complete device which is illustrated. For the present purpose I provide in the center of the receptacle a socket in which is mounted a spindle P', carrying a disk G'. Depending from said disk are arms H', which afford bearings for a shaft K', supporting two star-shaped wheels L' L", arranged to make contact with the mercury in the two troughs, respectively. The shaft K' is mounted in insulated bearings, so that when both wheels are in contact with mercury the circuit connecting the terminals C' C" will be closed. The disk G' carries an annular core N', which is adapted to be maintained in rotation by a core O' and coils O", supported outside of the receptacle and preferably of the same character as those used for imparting rotation to the mercury; but the direction of rotation should be opposite to that of the mercury. The rate of rotation of the wheels L' L" depends upon the rate of relative movement of the mercury, and hence if the mercury be caused to flow in one direction and the wheels be carried bodily in the opposite direction the rate of rotation, and consequently the frequency of the makes and breaks, will be very greatly increased over that which would be obtained if the wheels L' L" were supported in a stationary bearing.

It is obvious that by means of devices of the character described a rapid interruption of the circuit may be effected, while all the practical advantages which may be derived from inclosing the terminals or contacts in a closed receptacle are readily realized to the fullest extent.

Having now described my invention, what I claim is—

1. In a circuit-controller, the combination with rigid and fluid conductors adapted to be brought intermittently into contact with each other, thereby making and breaking the electric circuit, of means for imparting rotary motion to both of said conductors, as set forth.

2. In a circuit-controller, the combination with a receptacle containing a conducting fluid, means for imparting a movement of rotation to the fluid, and a conductor adapted to be rotated by the movement of said fluid and to thereby make and break electric connection with the fluid, as set forth.

NIKOLA TESLA.

Witnesses:

M. LAWSON DYER,

G. W. MARTLING.

P-288

No. 613,735.

Patented Nov. 8, 1888.

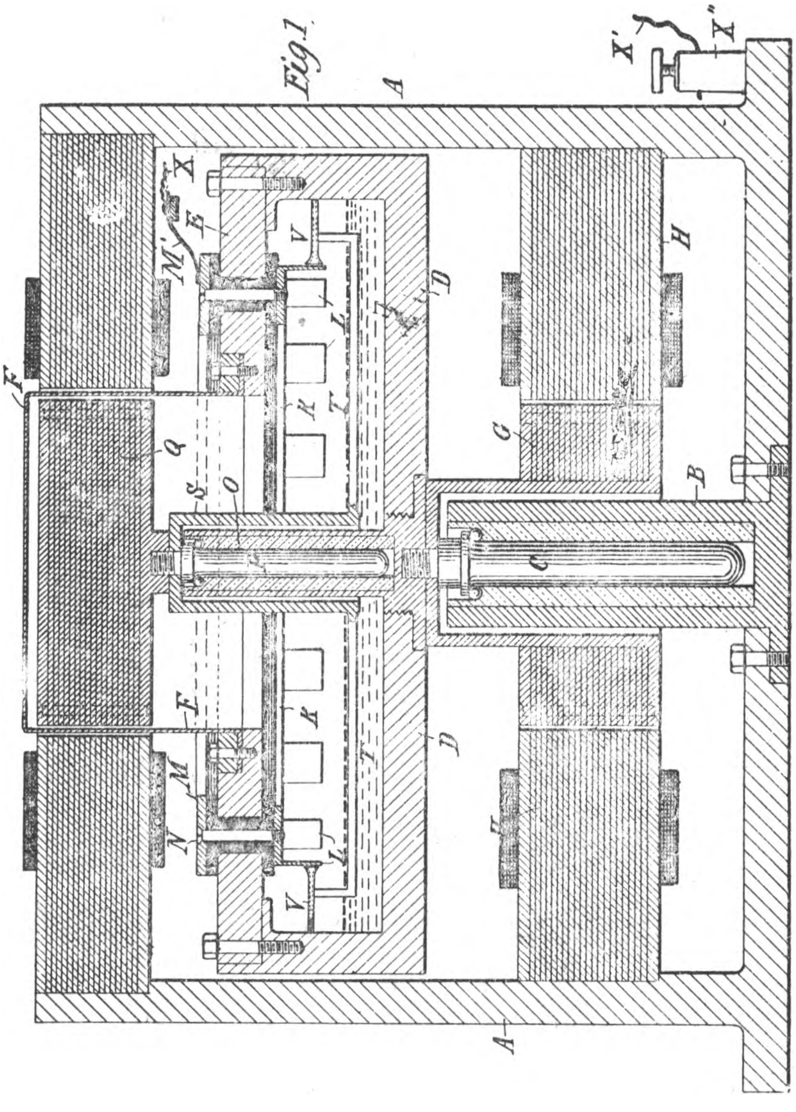
N. TESLA.

ELECTRIC CIRCUIT CONTROLLER.

(Application filed Apr. 19, 1898.)

(No Model.)

2 Sheets—Sheet 1.



Witnesses:
Raphaël Netter
Benjamin Miller

Nikola Tesla, Inventor
Kerr, Curtis & Page, Attys.

P-289

No. 613,735. Patented Nov. 8, 1898.

N. TESLA.

ELECTRIC CIRCUIT CONTROLLER.

(Application filed Apr. 19, 1808.)

(No Model.) 2 Sheets—Sheet 2.

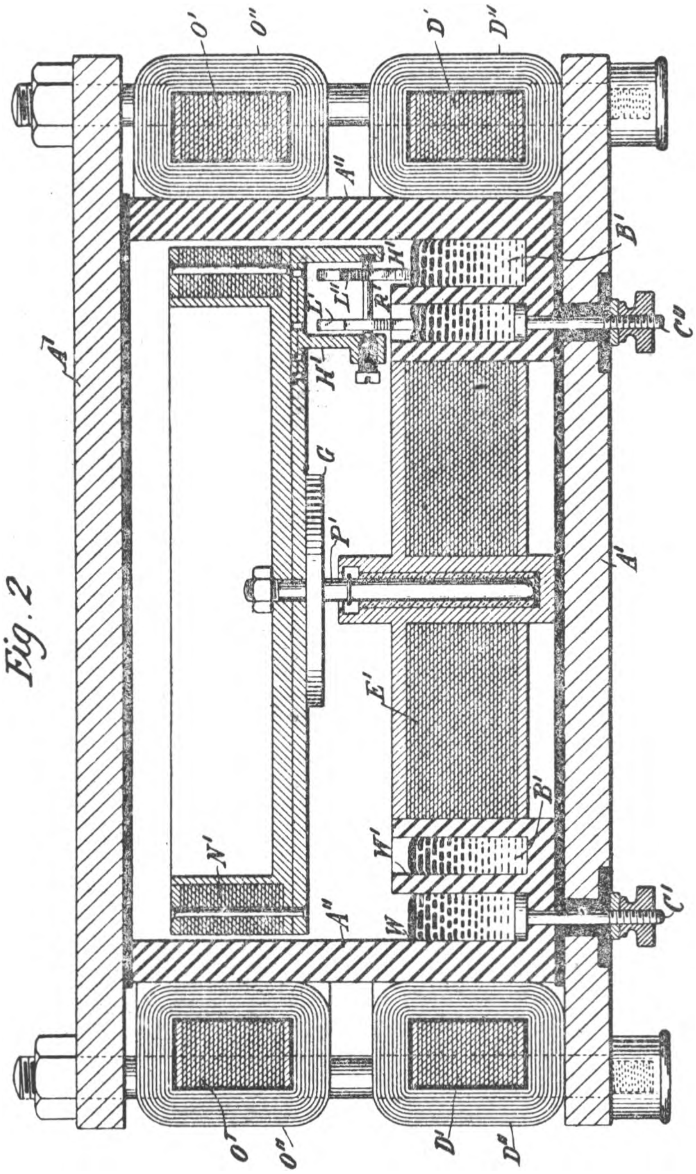


Fig. 2

Witnesses:
Raphaël Netter
Benjamin Miller.

Nikola Tesla, Inventor
by Kerr. Curtis & Page Att'ys

V
RADIO

UNITED STATES PATENT OFFICE.

NIKOLA TESLA, OF NEW YORK. N. Y.

APPARATUS FOR TRANSMISSION OF ELECTRICAL ENERGY.

SPECIFICATION forming part of Letters Patent No. 649,621, dated May 15, 1900.

Original application filed September 2, 1897, Serial No. 650,343. Divided and this application filed February 19, 1900. Serial No. 5,780. (No model.)

To all whom it may concern:

Be it known that I, NIKOLA TESLA, a citizen of the United States, residing at the borough of Manhattan, in the city of New York, county and State of New York, have invented certain new and useful Improvements in Apparatus for the Transmission of Electrical Energy, of which the following is a specification, reference being had to the drawing accompanying and forming a part of the same.

This application is a division of an application filed by me on September 2, 1897, Serial No. 650,343, entitled "Systems of transmissions of electrical energy," and is based upon new and useful features and combinations of apparatus shown and described in said application for carrying out the method therein disclosed and claimed.

The invention which forms the subject of my present application comprises a transmitting coil or conductor in which electrical currents or oscillations are produced and which is arranged to cause such currents or oscillations to be propagated by conduction through the natural medium from one point to another remote therefrom and a receiving coil or conductor at such distant point adapted to be excited by the oscillations or currents propagated from the transmitter.

This apparatus is shown in the accompanying drawing, which is a diagrammatic illustration of the same.

A is a coil, generally of many turns and of a very large diameter, wound in spiral form either about a magnetic core or not, as may be desired. C is a second coil formed by a conductor of much larger size and smaller length wound around and in proximity to the coil A.

The apparatus at one point is used as a transmitter, the coil A in this case constituting a high-tension, secondary, and the coil C the primary, of much lower tension, of a transformer. In the circuit of the primary C is included a suitable source of current G. One terminal of the secondary A is at the center of the spiral coil, and from this terminal the current is led by a conductor B to a terminal D, preferably of large surface, formed or maintained by such means as a balloon at an elevation suitable for the purposes of transmission. The other terminal of the secondary A is connected to earth, and, if desired, to the primary also, in order that the latter may be at substantially the same potential as the adjacent portions of the secondary, thus insuring safety. At the receiving-station a transformer of similar construction is employed; but in this case the longer coil A' constitutes the primary, and the shorter coil C' the secondary, of the transformer. In the circuit of the latter are connected lamps L, motors M, or other devices for utilizing the current. The elevated terminal D' connects with the center of the coil A', and the other terminal of said coil is connected to earth and preferably, also, to the coil C' for the reasons above stated.

The length, of the thin wire coil in each transformer should be approximately one-quarter of the wave length of the electric disturbance in the circuit, this estimate being based on the velocity of propagation of the disturbance through the coil itself and the circuit with which it is designed to be used. By way of illustration, if the rate at which the current traverses the circuit including the coil be one hundred and eighty-five thousand miles per second then a frequency of nine hundred and twenty-five per second would maintain nine hundred and twenty-five stationary moves in a circuit one hundred and eighty-five thousand miles long and each wave would be two hundred miles in length.

For such a low frequency, which would be resorted to only when it is indispensable for the operation of motors of the ordinary kind under the conditions above assumed, I would use a secondary of fifty miles in length. By such an adjustment or proportioning of the length of wire in the secondary coil or coils the points of highest potential are made to coincide with the elevated terminals D D', and it should be understood that whatever length be given to the wires this requirement should be complied with in order to obtain the best results.

It will be readily understood that when the above-prescribed relations exist the best conditions for resonance between the transmitting and receiving circuits are attained, and owing to the fact that the points of highest potential in the coils or conductors A A' are coincident with the elevated terminals the maximum flow of current will take place in the two coils, and this, further, necessarily implies that the capacity and inductance in each of the circuits have such values as to secure the most perfect condition of synchronism with the impressed oscillations.

When the source of current G is in operation and produces rapidly pulsating or oscillating currents in the circuit of coil C, corresponding induced currents of very much higher potential are generated in the secondary coil A, and since the potential in the same gradually increases with the number of turns toward the center and the difference of potential between the adjacent turns is comparatively small a very high potential impracticable with ordinary coils may be successively obtained.

As the main object for which the apparatus is designed is to produce a current of excessively-high potential, this object is facilitated by using a primary current of very considerable frequency; but the frequency of the currents is in a large measure arbitrary, for if the potential be sufficiently high and the terminals of the coils be maintained at the proper elevation where the atmosphere is rarefied the stratum of air will serve as a conducting medium for the current produced and the latter will be transmitted through the air, with, it may be, even less resistance than through an ordinary conductor

As to the elevation of the terminals D D', it is obvious that this is a matter which will be determined by a number of things, as by the amount and quality of the work to be performed, by the condition of the atmosphere, and also by the character of the surrounding country. Thus if there be high mountains in the vicinity the terminals should be at a greater height, and generally they should always be at an altitude much greater than that of the highest objects near them. Since by the means described practically any potential chat is desired maybe produced, the currents through the air strata may be very small, thus reducing the loss in the air.

The apparatus at the receiving-station responds to the currents propagated from the transmitter in a manner which will be well understood from the foregoing description. The primary circuit of the receiver—that is, the thin wire coil A'—is excited by the currents propagated by conduction through the intervening natural medium from the transmitter, and these currents induce in the secondary coil C' other currents which are utilized for operating the devices included in the circuit thereof.

Obviously the receiving-coils, transformers, or other apparatus may be movable—as, for instance, when they are carried by a vessel floating in the air or by a ship at sea. In the former case the connection of one terminal of the receiving apparatus to the ground might not be permanent, but might be intermittently or inductively established without departing from the spirit of my invention.

It is to be noted that the phenomenon here involved in the transmission of electrical energy is one of true conduction and is not to be confounded with the phenomena of electrical radiation which have heretofore been observed and which from the very nature and mode of propagation would render practically impossible the transmission of any appreciable amount of energy to such distances as are of practical importance.

What I now claim as my invention is—

1. The combination with a transmitting coil or conductor connected to ground and to an elevated terminal respectively, and means for producing therein electrical currents or oscillations, of a receiving coil or conductor similarly connected to ground and to an elevated terminal, at a distance from the transmitting-coil and adapted to be excited by currents caused to be propagated from the same by conduction through the intervening natural medium, a secondary conductor in inductive relation to the receiving-conductor and devices for utilizing the current in the circuit of said secondary conductor, as set forth.

2. The combination with a transmitting coil or conductor having its ends connected to ground and to an elevated terminal respectively, a primary coil in inductive relation thereto and a source of electrical oscillations in said primary circuit, of a receiving conductor or coil having its ends connected to ground and to an elevated terminal respectively and adapted to be excited by currents caused to be propagated from the transmitter through the natural medium and a secondary circuit in inductive relation to the receiving-circuit and receiving devices connected therewith, as set forth.

3. The combination with a transmitting instrument comprising a transformer having its secondary connected to ground and to an elevated terminal respectively, and means for impressing electrical oscillations upon its primary, of a receiving instrument comprising a transformer having its primary similarly connected to ground and to an elevated terminal, and a translating device connected with its secondary, the capacity and inductance of the two transformers having such values as to secure synchronism with the impressed oscillations, as set forth.

4. The combination with a transmitting instrument comprising an electrical transformer having its secondary connected to ground and to an elevated terminal respectively, and means for impressing electrical oscillations upon its primary, of a receiving instrument comprising a transformer having its primary similarly connected to ground and to an elevated terminal, and a translat-

ing device connected with its secondary, the capacity and inductance of the secondary of the transmitting and primary of the receiving instruments having such values as to secure synchronism with the impressed oscillations, as set forth.

5. The combination with a transmitting coil or conductor connected to ground and an elevated terminal respectively, and means for producing electrical currents or oscillations in the same, of a receiving coil or conductor similarly connected to ground and to an elevated terminal and synchronized with the transmitting coil or conductor, as set forth.

6. The combination with a transmitting instrument comprising an electrical transformer, having its secondary connected to ground and to an elevated terminal respectively, of a receiving instrument comprising a transformer, having its primary similarly connected to ground and to an elevated terminal, the receiving-coil being synchronized with that of the transmitter, as set forth.

7. The combination with a transmitting coil or conductor connected to ground and to an elevated terminal respectively, and means for producing electrical currents or oscillations in the same, of a receiving coil or conductor similarly connected to ground and to an elevated terminal, the said coil or coils having a length equal to one-quarter of the wave length of the disturbance propagated, as set forth.

8. The combination with a transmitting coil or conductor connected to ground and to an elevated terminal respectively, and adapted to cause the propagation of currents or oscillations by conduction through the natural medium, of a receiving-circuit similarly connected to ground and to an elevated terminal, and of a capacity and inductance such that its period of vibration is the same as that of the transmitter, as set forth.

9. The transmitting or receiving circuit herein described, connected to ground and an elevated terminal respectively, and arranged in such manner that the elevated terminal is charged to the maximum potential developed in the circuit, as set forth.

10. The combination with a transmitting coil or conductor connected to ground and to an elevated terminal respectively of a receiving-circuit having a period of vibration corresponding to that of the transmitting-circuit and similarly connected to ground and to an elevated terminal and so arranged that the elevated terminal is charged to the highest, potential developed in the circuit, as set forth.

NIKOLA TESLA.

Witnesses:
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P-296

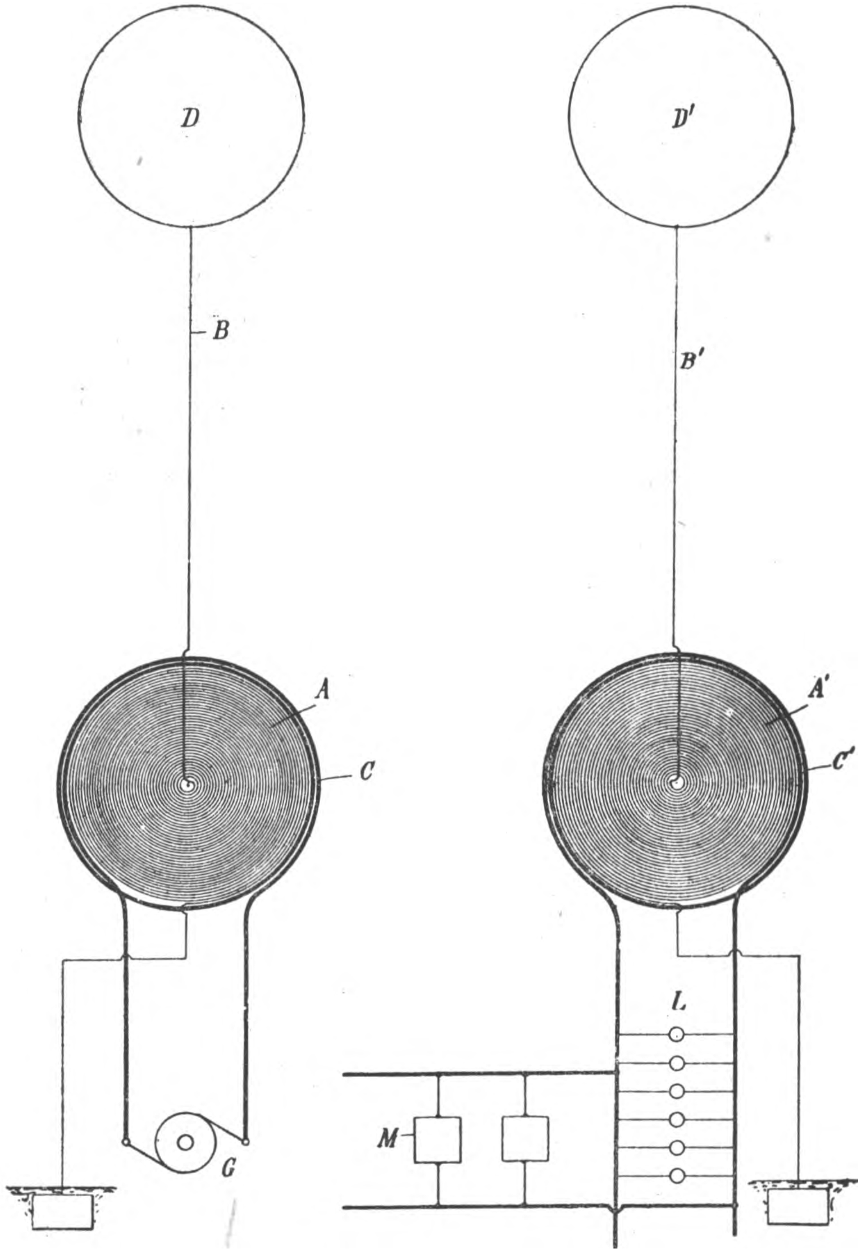
No. 649,621. Patented May 15, 1900

N. TESLA.

APPARATUS FOR TRANSMISSION OF ELECTRICAL ENERGY.

(Application filed Feb. 19, 1900.)

(No Model.)



Witnesses:
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Nikola Tesla, Inventor

by Kerr, Page & Cooper Att'ys

UNITED STATES PATENT OFFICE

NIKOLA TESLA, OF NEW YORK, N. Y.

METHOD OF INTENSIFYING AND UTILIZING EFFECTS TRANSMITTED THROUGH NATURAL MEDIA.

SPECIFICATION forming part of Letters Patent No. 685,953, dated November 5, 1901.

Application filed June 24, 1899. Renewed May 29, 1901. Serial No. 62,315. (No model.)

To all whom, it may concern:

Be it known that I, NIKOLA TESLA, a citizen of the United States, residing at New York, in the county and State of New York, have invented a new and useful Improvement in Methods of Intensifying and Utilizing Effects Transmitted Through the Natural Media, of which the following is a specification, reference being had to the accompanying drawings, which form a part of the same.

The subject of my present invention is an improvement in the art of utilizing effects transmitted from a distance to a receiving device through the natural media; and it consists in a novel method by means of which results hitherto unattainable may be secured.

Several ways or methods of transmitting electrical disturbances through the natural media and utilizing them to operate distant receivers are now known and have been applied with more or less success for accomplishing a variety of useful results. One of these ways consists in producing by a suitable apparatus rays or radiations—that is, disturbances—which are propagated in straight lines through space, directing them upon a receiving or recording apparatus at a distance, and thereby bringing the latter into action. This method is the oldest and best known and has been brought particularly into prominence in recent years through the investigations of Heinrich Hertz. Another method consists in passing a current through a circuit, preferably one inclosing a very large area, inducing thereby in a similar circuit situated at a distance another current and affecting by the same in any convenient way a receiving device. Still another way, which has also been known for many years, is to pass in any suitable manner a current through a portion of the ground, as by connecting to two points of the same, preferably at a considerable distance from each other, the two terminals of a generator and to energize by a part of the current diffused through the earth a distant circuit which is similarly arranged and grounded at two points widely apart and which is made to act upon a sensitive receiver. These various methods have their limitations, one especially, which is common to all, being that the receiving circuit or instrument must be maintained in a definite position with respect to the transmitting apparatus, which often imposes great disadvantages upon the use of the apparatus.

In several applications filed by me and patents granted to me I have disclosed other methods of accomplishing results of this nature, which may be briefly described as follows: In one system the potential of a point or region of the earth is varied by imparting to it intermittent or alternating electrifications through one of the terminals of a suitable source of electrical disturbances which, to heighten the effect, has its other terminal connected to an insulated body, preferably of large surface and at an elevation. The electrifications communicated to the earth spread in all directions through the same, reaching a distant circuit which generally has its terminals arranged and connected similarly to those of the transmitting source and operates upon a highly-sensitive receiver. Another method is based upon the fact that the atmospheric air which behaves as an excellent insulator to currents generated by ordinary apparatus becomes a conductor under the influence of currents or impulses of enormously-high electromotive force which I have devised means for generating. By such means air strata, which are easily accessible, are rendered available for the production of many desired effects at distances, however great. This method, furthermore, allows advantage to be taken of many of those improvements which are practicable in the ordinary system of transmission involving the use of a metallic conductor.

Obviously whatever method be employed it is desirable that the disturbances produced by the transmitting apparatus should be as powerful as possible, and by the use of certain forms of high-frequency apparatus which I have devised and which are now well known important practical advantages are in this respect secured. Furthermore, since in most cases the amount of energy conveyed to the distant circuit is but a minute fraction of the total energy emanating from the source it is necessary for the attainment of the best results that whatever the character of the receiver and the nature of the disturbances as much as possible of the energy conveyed should be made available for the operation of the receiver, and with this object in view I have heretofore among other means employed a receiving-circuit of high self-induction and very small resistance and of a period such as to vibrate in synchronism with the disturbances, whereby a number of separate impulses from the source were made to cooperate, thus magnifying the effect exerted upon and insuring the action of the receiving device. By these means decided advantages have been secured in many instances; but very often the improvement is either not applicable at all or, if so, the gain is very slight. Evidently when the source is one producing a continuous pressure or delivering impulses of long duration it is impracticable to magnify the effects in this manner and when, on the other hand, it is one furnishing short impulses of extreme rapidity of succession the advantage obtained in this way is insignificant, owing to the radiation and the unavoidable frictional waste in the receiving-circuit These losses reduce greatly both the intensity and the number of the cooperative impulses, and since the initial intensity of each of these is necessarily limited only an insignificant amount of energy is thus made available for a single operation of the receiver. As this amount is consequently dependent on the energy conveyed to the receiver by one single impulse it is evidently necessary to employ either a very large and costly, and therefore objectionable, transmitter or else to resort to the equally objectionable use of a receiving device too delicate and too easily deranged. Furthermore, the energy obtained through the cooperation of the impulses is in the form of extremely rapid vibrations and, because of this, unsuitable for the operation of ordinary receivers, the more so as this form of energy imposes narrow restrictions in regard to the mode and time of its application to such devices.

To overcome these and other limitations and disadvantages which have heretofore existed in such systems of transmission of signals or intelligence is the main object of my present invention, which comprises a novel method of accomplishing these ends.

The method, briefly slated, consists in producing arbitrarily-varied or intermittent disturbances or effects, transmitting such disturbances or effects through the natural media to a distant receiving-station, utilizing energy derived from such disturbances or effects at the receiving-station to charge a condenser, and using the accumulated potential energy so obtained to operate a receiving device.

An apparatus by means of which this method may be practiced is illustrated in the drawings hereto annexed, in which—

Figure 1 is a diagrammatic illustration of the apparatus, and Fig. 2 is a modified form or arrangement of the same.

In the practical application of my method I usually proceed as follows: At any two points in the transmitting medium between which there exists or may be obtained in any manner through the action of the disturbances or effects to be investigated or utilized a difference of electrical potential of any magnitude I arrange two plates or electrodes so that they mat be oppositely charged through the agency of such effects or disturbances, and I connect these electrodes to the terminals of a highly insulated condenser, generally of considerable capacity. To the condenser-terminals I also connect the receiver to be operated in series with a device of suitable construction, which performs the function of periodically discharging the condenser through the receiver at and during such intervals of time as may be best suitable for the purpose contemplated. This device may merely consist of two stationary electrodes separated by a feeble dielectric layer of minute thickness or it may comprise terminals one or more of which are movable and actuated by any suitable force and are adapted to be brought into and out of contact with each other in any convenient manner. It will now be readily seen that if the disturbances of whatever nature they may be cause definite amounts of electricity of the same sign to be conveyed to each of the plates or electrodes above mentioned, either continuously or at intervals of time which are sufficiently long, the condenser will be charged to a certain potential, and an adequate amount of energy being thus stored during the time determined by the device effecting the discharge of the condenser the receiver will be periodically operated by the electrical energy so accumulated; but very often the character of the impulses and the conditions of their use are such that without further provision not enough potential energy would be accumulated in the condenser to operate the receiving device. This is the case when, for example, each of the plates or terminals receives electricity of rapidly-changing sign or even when each receives electricity of the same sign, but only during periods which are short as compared with the intervals separating them. In such instances I resort to the use of a special device which I insert in the circuit between the plates and the condenser for the purpose of conveying to each of the terminals of the latter electrical charges of the proper quality and order of succession to enable the required amount of potential energy to be stored in the condenser.

There are a number of well-known devices, either without any moving parts or terminals or with elements reciprocated or rotated by the application of a suitable force, which offer a more ready passage to impulses of one sign or direction than to those of the other, or permit only impulses of one kind or order of succession to traverse a path, and any of these or similar devices capable of fulfilling the requirements may be used in carrying my invention into practice. One such device of familiar construction which will serve to convey a clear understanding of this part of my invention and enable a person skilled in the art to apply the same is illustrated in the annexed drawings. It consists of a cylinder A of insulating material, which is moved at a uniform rate of speed by clockwork or other suitable motive power and is provided with two metal rings B B', upon which bear brushes *a* and *a'*, which are connected, respectively, in the manner shown to the terminal plates P and P', above referred to. From the rings B B' extend narrow metallic segments *s* and *s'*, which by the rotation of the cylinder A are brought alternately into contact with double brushes *b* and *b'*, carried by and in contact with conducting-holders *h* and *h'*, which are adjustable longitudinally in the metallic supports D and D', as shown. The latter are connected to the terminals T and T' of a condenser C, and it should be understood that they are capable of angular displacement, as ordinary brush-supports. The object of using two brushes, as *b* and *b'*, in each of the holders *h* and *h'* is to vary at will the duration of the electric contact of the plates P and P' with the terminals T and T', to which is connected a receiving-circuit including a receiver R and a device *d* of the kind above referred to, which performs the duty of closing the receiving-circuit at predetermined intervals of time and discharging the stored energy through the receiver. In the present case this device consists of a cylinder *d*; made partly of conducting and partly of insulating material *e* and *e'*, respectively, which is rotated at the desired rate of speed by any suitable means. The conducting part *e* is in good electrical connection with the shaft S and is provided with tapering segments *f f*, upon which slides a brush *k*, supported on a conducting-rod *l*, capable of longitudinal adjustment in a metallic support *m*. Another brush *n* is arranged to bear upon the shaft S, and it will be seen that whenever one of the segments *f* comes in contact with the brush *k* the circuit, including the receiver R, is completed and the condenser discharged through the same. By an adjustment of the speed of rotation of the cylinder *d* and a displacement of the brush *k* along the cylinder the circuit may be made to open and close in as rapid succession and remain open or closed during such intervals of time as may be desired. The plates P and P', through which the electrifications are conveyed to the brushes *a* and *a'*, may be at a considerable distance from each other and both in the ground or both in the air, or one in the ground and the other in the air, preferably at some height, or they may be connected to conductors extending to some distance or to the terminals of any kind of apparatus supplying electrical energy which is obtained from the energy of the impulses or disturbances transmitted from a distance through the natural media.

In illustration of the operation of the devices described let it be assumed that alternating electrical impulses from a distant generator, as G, are transmitted through the earth and that it is desired to utilize those impulses in accordance with my method. This may be the case, for example, when such a generator is used for purposes of signaling in one of the ways before enumerated, as by having its terminals connected to two points of the earth distant from each other. In this case the plates P and P' are first connected to two properly-selected points of the earth. The speed of rotation of the cylinder A is varied until it is made to turn in synchronism with the alternate impulses of the generator, and, finally, the position of the brushes *b* and *b'* is adjusted by angular displacement, as usual, or in other ways, so that they are in contact with the segments *s* and *s'* during the periods when the impulses are at or near the maximum of their intensity. Only ordinary electrical skill and knowledge are required to make these adjustments, and a number of devices for effecting synchronous movement being well known, and it being the chief object of my present application to set forth a novel method of utilizing or applying a principle, a detailed description of such devices is not considered necessary. I may state, however, that for practical purposes in the present case it is only necessary to shift the brushes forward or back until the maximum effect is secured. The above requirements being fulfilled, electrical charges of the same sign will be conveyed to each of the condenser-terminals as the cylinder A is rotated, and with each fresh impulse the condenser will be charged to a higher potential. The speed of rotation of the cylinder *d* being adjustable at will, the energy of any number of separate impulses may thus be accumulated in potential form and discharged through the receiver R upon the brush *k* coming in contact with one of the segments *f*. It will be of course understood that the capacity of the condenser should be such as to allow the storing of a much greater amount of energy than is required for the ordinary operation of the receiver. Since by this method a relatively great amount of energy and in a suitable form may be made available for the operation of a receiver, the latter need not be very sensitive; but of course when the impulses are very feeble, as when coming from a great distance or when it is desired to operate a receiver very rapidly, then any of the well-known devices capable of responding to very feeble influences may be used in this connection.

If instead of the alternating impulses short impulses of the same direction are conveyed to the plates P and P', the apparatus described may still readily be used, and for this purpose it is merely necessary to shift the brushes *b* and *b'* into the position indicated by the dotted lines while maintaining the same conditions in regard to synchronism as before, so that the succeeding impulses will be permitted to pass into the condenser, but prevented from returning to the ground or transmitting medium during the intervals between them, owing to the interruption during such intervals of the connections leading from the condenser-terminals to the plates.

Another way of using the apparatus with impulses of the same direction is to take off one pair of brushes, as *b,* disconnect, the plate P from brush *a* and join it directly to the terminal T of the condenser, and to connect brush *a* with brush *a'*. The apparatus thus modified would appear as shown in Fig. 2. Operated in this manner and assuming the speed of rotation of cylinder A to be the same, the apparatus will now be evidently adapted for a number of impulses per unit of time twice as great as in the preceding case. In all cases it is evidently important to adjust the duration of contact of segments *s* and *s'* with brushes *b b'* in the manner indicated.

When the method and apparatus I have described are used in connection with the transmission of signals or intelligence, it will of course be understood that the transmitter is operated in such a way as to produce disturbances or effects which are varied or intermitted in some arbitrary manner—for example, to produce longer and shorter successions of impulses corresponding to the dashes and dots of the Morse alphabet—and the receiving device will respond to and indicate these variations or intermittences, since the storage device will be charged and discharged a number of times corresponding to the duration of the successions of impulses received.

Obviously the special appliances used in carrying out my invention may be varied in many ways without departing from the spirit of the same.

It is to be observed that it is the function of the cylinder A, with its brushes and connections, to render the electrical impulses coming from the plates P and P' suitable for charging the condenser (assuming them to be unsuitable for this purpose in the form in which they are received) by rectifying them when they are originally alternating in direction or by selecting such parts of them as are suitable when all are not, and any other device performing this function will obviously answer the purpose. It is also evident that a device such as I have already referred to which offers a more ready passage to impulses of one sign or permits only impulses of the same sign to pass may also be used to perform this selective function in many cases when alternating impulses are received. When the impulses are long and all of the same direction, and even when they are alternating, but sufficiently long in duration and sustained in electromotive force, the brushes *b* and *b'* may be adjusted so as to bear on the parts B B' of the cylinder A, or the cylinder and its brushes may be omitted and the terminals of the condenser connected directly to the plates P and P'.

It will be seen that by the use of my invention results hitherto unattainable in utilizing disturbances or effects transmitted through natural media may be readily attained, since however great the distance of such transmission and however feeble or attenuated the impulses received enough energy may be accumulated from them by storing up the energy of succeeding impulses for a sufficient interval of time to render the sudden liberation of it highly effective in operating a receiver. In this way receivers of a variety of forms may be made to respond effectively to impulses too feeble to be detected or to be made to produce any sensible effect in any other way of which I am aware, a result of great value in various applications to practical use.

I do not claim herein an apparatus by means of which the above-described method is or may be practiced either in the special form herein shown or in other forms which are possible, having made claims to such apparatus in another application, Serial No. 729,812, filed September 8, 1899, as a division of the present case.

What I claim as my invention, and desire to secure by Letters Patent, is—

1. The method of transmitting and utilizing electrical energy herein described, which consists in producing arbitrarily varied or intermitted electrical disturbances or effects, transmitting the same to a distant receiving-station, charging, for succeeding and predetermined periods of time a condenser with energy derived from such effects or disturbances, and operating a receiving device by discharging at arbitrary intervals, the accumulated potential energy so obtained, as set forth.

2. The method of transmitting and utilizing electrical energy herein described, which consists in producing electrical disturbances or effects capable of being transmitted to a distance through the natural media, charging a condenser at a distant receiving-station with energy derived from such effects or disturbances, and using for periods of time, predetermined as to succession and duration, the potential energy so obtained to operate a receiving device.

3. The method of transmitting and utilizing electrical energy herein described, which consists in producing electrical disturbances or effects capable of being transmitted to a distance through the natural media, charging a condenser at a distant receiving-station for succeeding and predetermined periods of time, with energy derived from such effects or disturbances, and using for periods of time predetermined as to succession and duration, the accumulated energy so obtained to operate a receiving device.

4. The method hereinbefore described of producing arbitrarily varied or intermitted

electrical disturbances or effects, transmitting such disturbances or effects through the natural media to a distant receiving-station, storing in a condenser energy derived from a succession of such disturbances or effects for periods of time which correspond in succession to such effects or disturbances and are predetermined as to duration, and using the accumulated potential energy so obtained to operate a receiving device.

5. The method herein described of producing arbitrarily varied or intermitted electrical disturbances or effects, transmitting such disturbances or effects through the natural media to a distant receiving-station, establishing thereby a flow of electrical energy in a circuit at such station, charging a condenser with energy from such circuit, and using the accumulated potential energy so obtained to operate a receiving device.

6. The method herein described of producing arbitrarily varied or intermitted electrical disturbances or effects, transmitting such disturbances or effects through the natural media to a distant receiving-station, establishing thereby a flow of electrical energy in a circuit at such station, charging a condenser with electrical energy from such circuit, and discharging the accumulated potential energy so obtained into or through a receiving device at arbitrary intervals of time.

7. The method herein described of producing arbitrarily varied or intermitted electrical disturbances or effects, transmitting such disturbances or effects to a distant receiving-station, establishing thereby a flow of electrical energy in a circuit at such station, selecting or directing the impulses in said circuit so as to render them suitable for charging a condenser, charging a condenser with the impulses so selected or directed, and discharging the accumulated potential energy so obtained into, or through a receiving device.

8. The method herein described of producing arbitrarily varied or intermitted electrical disturbances or effects, transmitting such disturbances or effects through the natural media to a distant receiving-station, establishing thereby a flow of electrical energy in a circuit at such station, selecting or directing the impulses in said circuit so as to render them suitable for charging a condenser, charging a condenser with the impulses so selected or directed, and discharging the accumulated potential energy so obtained into, or through a receiving device at arbitrary intervals of time.

9. The method hereinbefore described of transmitting signals or intelligence, which consists in producing at the sending-station arbitrarily varied or intermitted disturbances or effects, transmitting such disturbances or effects through the natural media to a receiving-station, utilizing energy derived from such disturbances or effects at the receiving-station to charge a condenser and using the accumulated potential energy so obtained to operate a receiving device.

10. The method hereinbefore described of transmitting signals or intelligence through the natural media from a sending-station to a receiving-station, which consists in producing at the sending-station, arbitrarily varied or intermitted electrical effects or disturbances, transmitting the same through the natural media to the receiving-station, utilizing the energy derived from such disturbances or effects at the receiving-station to charge a condenser, and discharging the accumulated potential energy so obtained through a receiving device at arbitrary intervals of time.

11. The method hereinbefore described of transmitting signals or intelligence from a sending to a distant receiving station, which consists in producing at the former, arbitrarily varied or intermitted electrical disturbances or effects, transmitting the same to the receiving-station, charging by the energy derived from such disturbances or effects at the receiving-station a condenser, and using for periods of time predetermined as to succession and duration, the potential energy so obtained to operate a receiving device, as set forth.

NIKOLA TESLA.

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P-302

No. 685,953

Patented Nov. 5, 1901.

N. TESLA

METHOD OF INTENSIFYING AND UTILIZING EFFECTS TRANSMITTED THROUGH NATURAL MEDIA

(Application filed June 24, 1899. Renewed May 26, 1901.)

(No Model.)

Fig. 1.

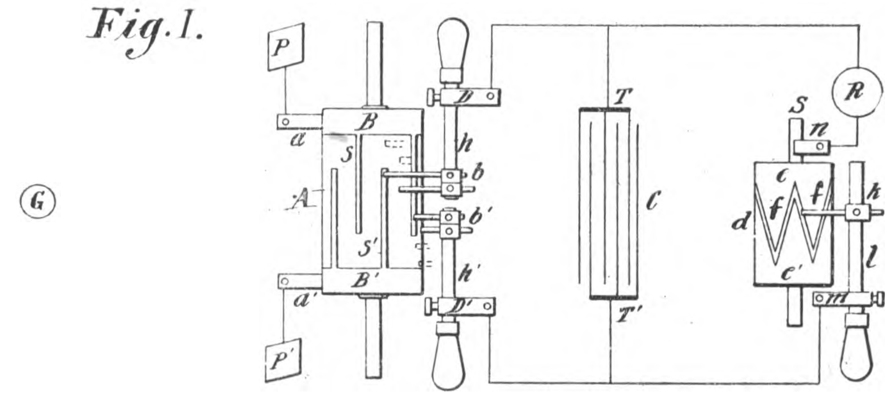
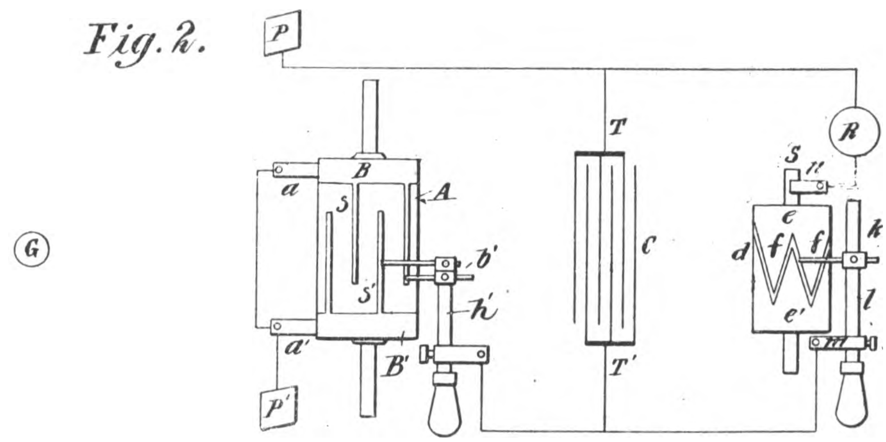


Fig. 2.



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UNITED STATES PATENT OFFICE.

NIKOLA TESLA, OF NEW YORK, N. Y.

METHOD OF UTILIZING EFFECTS TRANSMITTED THROUGH NATURAL MEDIA.

SPECIFICATION forming part of Letters Patent No. 685,954, dated November 5, 1901.

Application filed August 1, 1899. Renewed May 29, 1901. Serial No. 62,316. (No model.)

To all whom it may concern:

Be it known that I, NIKOLA TESLA, a citizen of the United States, residing at New York city, in the county and State of New York, have invented a new and useful Improvement in Methods of Utilizing Effects Transmitted from a Distance to a Receiving Device Through the Natural Media, of which the following is a specification, reference being had to the accompanying drawings, which form a part of the same.

The subject of my present invention is an improvement in the art of utilizing effects transmitted from a distance to a receiving device through the natural media; and it consists in a novel method hereinafter described.

My invention is particularly useful in connection with methods and apparatus for operating distant receiving devices by means of electrical disturbances produced by proper transmitters and conveyed to such receiving devices through the natural media; but it obviously has a wider range of applicability and may be employed, for example, in the investigation or utilization of terrestrial, solar, or other disturbances produced by natural causes.

Several ways or methods of transmitting electrical disturbances through the natural media and utilizing them to operate distant receivers are now known and have been applied with more or less success for accomplishing a variety of useful results. One of these ways consists in producing by a suitable apparatus rays or radiations—that is, disturbances—which are propagated in straight lines through space, directing them upon a receiving or recording apparatus at a distance, and thereby bringing the latter into action. This method is the oldest and best known and has been brought particularly into prominence in recent years through the investigations of Heinrich Hertz. Another method consists in passing a current through a circuit, preferably one inclosing a very large area, inducing thereby in a similar circuit situated at a distance another current and affecting by the same in any convenient way a receiving device. Still another way, which has also been known for many years, is to pass in any suitable manner a current through a portion of the ground, as by connecting to two points of the same, preferably at a considerable distance from each other, the two terminals of a generator and to energize by a part of the current diffused through the earth a distant circuit, which is similarly arranged and grounded at two points widely apart and which is made to act upon a sensitive receiver. These various methods have their limitations, one especially, which is common to all, being that the receiving circuit or instrument must be maintained in a definite position with respect to the transmitting apparatus, which often imposes great disadvantages upon the use of the apparatus.

In several applications filed by mo and patents granted to me I have disclosed other methods of accomplishing results of this nature which may be briefly described as follows: In one system the potential of a point or region of the earth is varied by imparting to it intermittent or alternating electrifications through one of the terminals of a suitable source of electrical disturbances, which to heighten the effect has its other terminal connected to an insulated body, preferably of large surface and at an elevation. The electrifications communicated to the earth spread in all directions through the same, reaching a distant circuit, which generally has its terminals arranged and connected similarly to those of the transmitting source and operates upon a highly-sensitive receiver. Another method is based upon the fact that the atmospheric air, which behaves as an excellent insulator to currents generated by ordinary apparatus, becomes a conductor under the influence of currents or impulses of enormously high electromotive force which I have devised means for generating. By such means air strata, which are easily accessible, are rendered available for the production of many desired effects at distances however great. This method, furthermore, allowed advantage to be taken of many of those improvements which are practicable in the ordinary systems of transmission involving the use of a metallic conductor.

Obviously whatever method be employed it is desirable that the disturbances produced by the transmitting apparatus should be as powerful as possible, and by the use of certain forms of high-frequency apparatus which

I have devised and which are now well known important practical advantages are in this respect secured. Furthermore, since in most cases the amount of energy conveyed to the distant circuit is but a minute fraction of the total energy emanating from the source it is necessary for the attainment of the best results that whatever the character of the receiver and the nature of the disturbances as much as possible of the energy conveyed should be made available for the operation of the receiver, and with this object in view I have heretofore, among other means, employed a receiving-circuit of high self-induction and very small resistance and of a period such as to vibrate in synchronism with the disturbances, whereby a number of separate impulses from the source were made to cooperate, thus magnifying the effect exerted upon and insuring the action of the receiving device. By these means decided advantages have been secured in many instances; but very often the improvement is either not applicable at all, or if so the gain is very slight. Evidently when the source is one producing a continuous pressure or delivering impulses of long duration it is impracticable to magnify the effects in this manner, and when, on the other hand, it is one furnishing short impulses of extreme rapidity of succession the advantage obtained in this way is insignificant, owing to the radiation and the unavoidable frictional waste in the receiving-circuit. These losses reduce greatly both the intensity and the number of the cooperative impulses, and since the initial intensity of each of these is necessarily limited only an insignificant amount of energy is thus made available for a single operation of the receiver. As this amount is consequently dependent on the energy conveyed to the receiver by one single impulse, it is evidently necessary to employ either a very large and costly and therefore objectionable transmitter or else to resort to the equally objectionable use of a receiving device too delicate and too easily deranged. Furthermore, the energy obtained through the cooperation of the impulses is in the form of extremely-rapid vibrations and because of this unsuitable for the operation of ordinary receivers, the more so as this form of energy imposes narrow restrictions in regard to the mode and time of its application to such devices. To overcome these and other limitations and disadvantages that have heretofore existed in such systems of transmission of signals or intelligence and to render possible an investigation of impulses or disturbances propagated through the natural media from any kind of source and their practical utilization for any purpose to which they are applicable, I have devised a novel method, which I have described in a pending application filed June 24, 1899, Serial No. 721,790, and which, broadly stated, consists in effecting during any desired time interval a storage of energy derived from such impulses and utilizing the potential energy so obtained for operating a receiving device.

My present invention is intended for the same general purposes, and it comprises a modified method and apparatus by means of which similar results may be obtained.

The chief feature which distinguishes my present from my former invention just referred to is that the energy stored is not, as in the former instance, obtained from the energy of the disturbances or effects transmitted from a distance, but from an independent source.

Expressed generally, my present method consists in charging a storage device with energy from an independent source controlling the charging of said device by the action of the effects or disturbances transmitted through the natural media and coincidentally using the stored energy for operating a receiving device.

A groat variety of disturbances produced either by suitably-constructed transmitters or by natural causes are at present known to be propagated through the natural media, and there are also a variety of means or devices enabling energy to be stored, and in view of this I wish to say that I consider the utilization of any such disturbances and the employment of any of these means as within the scope of my present invention so long as the use of the general method hereinbefore stated is involved.

The best way of carrying out my invention which I at present know is to store electrical energy obtained from a suitable electrical generator in a condenser and to control the storage or the application of this energy by means of a sensitive device acted upon by the effects or disturbances, and thereby cause the operation of the receiver.

In the practical application of this method I usually proceed as follows: At any point where I desire to investigate or to utilize for any purpose effects or disturbances propagated through the natural media from any kind of source I provide a suitable generator of electricity—as, for example, a battery and a condenser—which I connect to the poles of the generator in series with a sensitive device capable of being modified in its electrical resistance or other property by the action of the disturbances emitted from the source. To the terminals of the condenser I connect the receiver which is to be operated in series with another device of suitable construction which performs the function of periodically discharging the condenser through the receiver at and during such intervals of time as may be best suitable for the purpose contemplated. This latter device may merely consist of two stationary electrodes separated by a feeble dielectric layer of minute thickness, but sufficient to greatly reduce or practically interrupt the current in the circuit under normal conditions, or it may comprise terminals one or more of watch are movable and actuated by any suitable force and are adapted to be brought into and out of contact with each other in any convenient manner. The sensitive device may be any of the many devices of this kind which are known to be affected by the disturbances, impulses, or effects propagated through the media, and it may be of such a character that normally—that is, when not acted upon—it entirely prevents the passage of electricity from the generator to the condenser, or it may be such that it allows a gradual leaking through of the current and a charging of the condenser at a slow rate. In any case it will be seen that if the disturbances, of whatever nature they may be, cause an appreciable diminution in the electrical resistance of the sensitive device the current from the battery will pass more readily into the condenser, which will be charged at a more rapid rate, and consequently each of its discharges through the receiver, periodically effected by the special device before referred to which performs this function, will be stronger than normally—that is, when the sensitive device is not acted upon by the disturbances. Evidently, then, if the receiver be so adjusted that it does not respond to the comparatively feeble normal discharges of the condenser, if they should occur, but only to those stronger ones which take place upon the diminution of the resistance of the sensitive device, it will be operated only when this device is acted upon by the disturbances, thus making it possible to investigate and to utilize the latter for any desired purpose.

The general principle underlying my invention and the operation of the various devices used will be clearly understood by reference to the accompanying drawings, in which—

Figure 1 is a diagram illustrating a typical arrangement of apparatus which may be used in carrying my method into practice, and Figs. 2, 3, 4, and 5 similar diagrams of modified arrangements of apparatus for the same purpose.

In Fig. 1, C is a condenser, to the terminals T and T' of which is connected a charging-circuit including a battery B, a sensitive device *a*, and a resistance *r,* all connected in series, as illustrated. The battery should be preferably of very constant electromotive force and of an intensity carefully determined to secure the best results. The resistance *r*, which may be a frictional or an inductive one, is not absolutely necessary; but it is of advantage to use it in order to facilitate adjustment, and for this purpose it may be made variable in any convenient and preferably continuous manner. Assuming that the disturbances which are to be investigated or utilized for some practical end are rays identical with or resembling those of ordinary light, the sensitive device *a* may be a selenium cell properly prepared, so as to be highly susceptible to the influence of the rays, the action of which should be intensified by the use of a reflector A, shown in the drawings. It is well known that when cells of this kind are exposed to such rays of greatly-varying intensity they undergo corresponding modifications of their electrical resistance; but in the ways they have been heretofore used they have been of very limited utility. In addition to the circuit including the sensitive device or cell *a* another circuit is provided, which is likewise connected to the terminals T T' of the condenser. This circuit, which may be called the "receiving-circuit", includes the receiver R and in series with it a device *d,* before referred to, which performs the duty of periodically discharging the condenser through the receiver. It will be noted that, as shown in Fig. 1, the receiving-circuit is in permanent connection with the battery and condenser terminal T, and it should be staled that it is sometimes desirable to entirely insulate the receiving-circuit at all times except the moments when the device *d* operates to discharge the condenser, thus preventing any disturbing influence which might otherwise be caused in this circuit by the battery or the condenser during the period when the receiver should not be acted upon. In such a case two devices, as *d,* may be used—one in each connection from the condenser to the receiving-circuit—or else one single device of this kind, but of a suitably-modified construction, so that it will make and break simultaneously and. at proper intervals of time both of the connections of this circuit with the condenser T and T'.

From the foregoing the operation of the apparatus as illustrated in Fig. 1 will be at once understood. Normally—that is, when it is not influenced by the rays at all or very slightly—the cell *a* being of a comparatively high resistance permits only a relatively feeble current to pass from the battery into the condenser, and hence the latter is charged at too slow a rate to accumulate during the time interval between two succeeding operations of the device *d* sufficient energy to operate the receiver or, generally speaking, to produce the required change in the receiving-circuit. This condition is readily secured by a proper selection and adjustment of the various devices described, so that the receiver will remain unresponsive to the feeble discharges of the condenser which may take place when the cell *a* is acted upon but slightly or not at all by the rays or disturbances; but if now new rays are permitted to fall upon the cell or if the intensity of those already acting upon it be increased by any cause then its resistance will be diminished and the condenser will be charged by the battery at a more rapid rate, enabling sufficient potential energy to be stored in the condenser during the period of inaction of the device *d* to operate the receiver or to bring about any desired change in the receiving-circuit when the device *d* acts. If the rays acting upon the cell or sensitive device *a* are varied or intermitted in any arbitrary manner, as when transmitting intelligence in the usual way from a distant station by means of short and long signals, the apparatus may readily be made to record or to enable an operator to read the message, since the receiver, supposing it to be an ordinary magnetic relay, for example, will be operated by each signal from the sending-station a certain number of times having some relation to the duration of each signal. It will be readily seen, however, that if the rays are varied in any other way, as by impressing upon them changes in intensity, the succeeding condenser discharges will undergo corresponding changes in intensity, which may be indicated or recorded by a suitable receiver and distinguished irrespectively of duration.

With reference to Fig. 1, it may be useful to state that the electrical connections of the various devices illustrated may be made in many different ways. For instance, the sensitive device instead of being in series, as shown, may be in a shunt to the condenser, this modification being illustrated in Fig. 3, in which the devices already described are indicated by similar letters to correspond with those of Fig. 1. In this case it will be observed that the condenser which is being charged from the battery D through the resistance *r*, preferably inductive and properly related to the capacity of the condenser, will store less energy when the sensitive device *a* is energized by the rays and its resistance thereby diminished. The adjustment of the various instruments may then be such that the receiver will be operated only when the rays are diminished in intensity or interrupted and entirely prevented from falling upon the sensitive cell, or the sensitive device may be placed, as shown in Fig. 4, in a shunt to the resistance *r* or inserted in any suitable way in the circuit containing the receiver—for example, as illustrated in Fig. 5—in both of which figures the various devices are lettered to correspond with those in Fig. 1, so that the figures become self-explanatory. Again, the several instruments may be connected in the manner of a Wheatstone bridge, as will be hereinafter explained with reference to Fig. 2, or otherwise connected or related; but in each case the sensitive device will have the same duty to perform—that is, to control the energy stored and utilized in some suitable way for causing the operation of the receiver in correspondence with the intermittences or variations of the effects or disturbances, and in each instance by a judicious selection of the devices and careful adjustment the advantages of my method may be more or less completely secured. I find it preferable, however, to follow the plan which I have illustrated and described.

It will be observed that the condenser is an important element in the combination. I have shown that by reason of its unique properties it greatly adds to the efficacy of this method. It allows the energy accumulated in it to be discharged instantaneously, and therefore in a highly effective manner. It magnifies in a large degree the current supplied from the battery, and owing to these features it permits energy to be stored and discharged at practically any rate desired, and thereby makes it possible to obtain in the receiving-circuit very great changes of the current strength by impressing upon the battery-current very small variations. Other means of storage possessing these characteristics to a useful degree may be employed without departing from the broad spirit of my invention; but I prefer to use a condenser, since in these respects it excels any other storage device of which I have knowledge.

In Fig. 2 a modified arrangement of apparatus is illustrated which is particularly adapted for the investigation and utilization of very feeble impulses or disturbances, such as may be used in conveying signals or producing other desired effects at very great distances. In this case the energy stored in the condenser is passed through the primary of a transformer the secondary circuit of which contains the receiver, and in order to render the apparatus still more suitable for use in detecting feeble impulses in addition to the sensitive device which is acted upon by the impulses another such device is included in the secondary circuit of the transformer. The scheme of connections is in the main that of a Wheatstone bridge the four branches of which are formed by the sensitive device *a* and resistances L, L', and L'', all of which should be preferably inductive and also adjustable in a continuous manner or at least by very small steps. The condenser C', which is generally made of considerable capacity, is connected to two opposite points of the bridge, while a battery B, in series with a continuously-adjustable non-inductive resistance *r'*, is connected to the other pair of opposite points, as usual. The four resistances included in the branches of the bridge—namely, *a,* L, L', and L''—are of a suitable size and so proportioned that under normal conditions—that is, when the device *a* is not influenced at all or only slightly by the disturbances—there will be no difference of potential or in any case the minimum of the same at the terminals T and T' of the condenser It is assumed in the present instance that the disturbances to be investigated or utilized are such as will produce a difference of electric potential, however small, between two points or regions in the natural media—as the earth, the water, or the air—and in order to apply this potential difference effectively to the sensitive device *a* the terminals of the same are connected to two plates P and P', which should be of as large a surface as practicable and so located in the media that the largest possible difference of potential will be produced by the disturbances between the terminals of the sensitive device. This device is in the present case one of familiar construction, consisting of an insulating-tube, which is indicated by the heavy lines in the drawings and which has its ends closed tightly by two conducting-plugs with reduced extensions, upon which bear two brushes *b b,* through which the currents are conveyed to the device. The tubular space between the plugs is partially filled with a conducting sensitive powder, as indicated, the proper amount of the same and the size of its grains being determined and adjusted beforehand by experiment. This tube I rotate by clockwork or other means at a uniform and suitable rate of speed, and under these conditional find that this device behaves toward disturbances of the kind before assumed in a manner similar to that of a stationary cell of celenium toward rays of light. Its electrical resistance is diminished when it is acted upon by the disturbances and is automatically restored upon the cessation of their influence. It is of advantage to employ round grains of powder in the tube, and in any event it is important that they should be of as uniform size and shape as possible and that provision should be made for maintaining an unchanging and very dry atmosphere in the tube. To the terminals T and T' of the condenser C' is connected a coil *p,* usually consisting of a few turns of a conductor of very small resistance, which is the primary of the transformer before referred to, in series with a device *d,* which effects the discharge of the condenser through the coil *p* at predetermined intervals of time. In the present case this device consists of a cylinder made partly of conducting and partly of insulating material *e* and *e'*, respectively, which is rotated at the desired rate of speed by any suitable means. The conducting part *e* is in good electrical connection with shaft S and is provided with tapering segments, as *f*, upon which slides a brush *k*, which should preferably be capable of longitudinal adjustment along the cylinder. Another brush *b'*, which is connected to the condenser-terminal T', being arranged to bear upon the shaft S, it will be seen that whenever the brush *k* comes in contact with a conducting-segment *f* the circuit including the primary *p* will be completed and the condenser, if energized, discharged through the same. By an adjustment of the speed of rotation of the cylinder and a displacement of the brush *k* along the axis of the same the circuit may be made to open and close in as rapid succession and remain open or closed during such intervals of time as may be desired, In inductive relation to the primary *p* is a secondary coil s, usually of much thinner wire and of many more turns than the former, to which are connected in a series a receiver R, (illustrated as an ordinary magnetic relay,) a continuously-adjustable non-inductive resistance *r''* , a battery B' of a properly determined and very constant electromotive force, and finally a sensitive device *a'* of the same or similar construction as a, which is likewise rotated at a uniform speed and which with its brushes *b'' b''* closes the secondary circuit. The electromotive force of the battery B' is so graduated by means of the adjustable resistance *r''* that the dielectric layers in the sensitive device *a'* are strained very nearly to the point of breaking down and give way upon a slight increase of the electrical pressure on the terminals of the device. It will of course be understood that the resistance *r''* is used mainly because of convenience and that it may be dispensed with, in which case the adjustment may be effected in many other ways, as by determining the proper amount or coarseness of the sensitive powder or by varying the distance apart of the metallic plugs in the ends of the tube. The same may be said of the resistance *r'*, which is in series with the battery B and serves to graduate the force of the latter, so that the dielectric layers of the sensitive device *a* are subjected to a similar strain and maintained in a state of delicate poise. The various instruments being connected and adjusted in the manner described, it will now be readily seen from the foregoing that under normal conditions, the device *a* being unaffected by the disturbances, or practically so, and there being no or only a very insignificant amount of energy stored in the condenser, the periodical closure of the primary circuit of the transformer through the operation of the device *d* will have no appreciable effect upon the primary coil *p*, and hence no currents will be generated in the secondary coil *s*, at least not such as would disturb the state of delicate balance existing in the secondary circuit including the receiver, and therefore the latter will not be actuated by the battery B'; but when, owing to the disturbances or impulses propagated through the media from a distant source, an additional electromotive force, however small, is created between the terminals of the device *a* the dielectric layers in the same, unable to support the increased strain, give way and allow the current of the battery B to pass through, thus causing a difference of potential at the terminals T and T' of the condenser. A sufficient amount of energy being now stored in this instrument during the time interval between each two succeeding operations of the device *d*, each closure of the primary circuit by the latter results in the passage of a sudden current impulse through the coil *p,* which induces a corresponding current of relatively high electromotive force in the secondary coil *s.* Owing to this the dielectric in the device *a'* gives way, and the current of the battery B' being allowed to pass the receiver R is operated, but only for a moment, since by the rotation of the devices *a, a'*, and *d,* which may be all driven from the same shaft, the original conditions are restored, assuming, of course, that the electromotive force set up by the disturbances at the terminals of the sensitive device *a* is only momentary or of a duration not longer than the time of closure of the primary circuit; otherwise the receiver will be actuated a number of times and so long as the influence of the disturbances upon the device a continues. In order to render the discharged energy of the condenser more effective in causing the operation of the receiver, the resistance of the primary circuit should be very small and the secondary coil *s* should have a number of turns many times greater than that of the primary coil *p*. It will be noted that since the condenser under the above assumptions is always charged in the same direction the strongest current impulse in the secondary coil, which is induced at the moment when the brush *k* comes in contact with segment *f,* is also of unchanging direction, and for the attainment of the best results it is necessary to connect the secondary coil so that the electromotive force of this impulse will be added to that of the battery and will momentarily strengthen the same. However, under certain conditions, which are well understood by those skilled in the art, the devices will operate whichever way the secondary be connected. It is preferable to make the inductive resistances L and L' relatively large, as they are in a shunt to the device *a* and might if made too small impair its sensitiveness. On the other hand, the resistance L'' should not be too large and should be related to the capacity of the condenser and the number of makes and breaks effected by the device *d* in well-known ways. Similar considerations apply, of course, to the circuits including the primary *p* and secondary *s*, respectively.

By carefully observing well-known rules of scientific design and adjustment of the instruments the apparatus may be made extremely sensitive and capable of responding to the feeblest influences, thus making it possible to utilize impulses or disturbances transmitted from very great distances and too feeble to be detected or utilized in any of the ways heretofore known, and on this account the method here described lends itself to many scientific and practical uses of great value. Obviously the character of the devices and the manner in which they are connected or related may be greatly varied without departing from the spirit of my invention.

What I claim as new, and desire to secure by Letters Patent, is—

1. The method hereinbefore described of utilizing effects or disturbances transmitted through the natural media, which consists in charging a storage device with energy from an independent source, controlling the charging of said device by the action of the effects or disturbances, and coincidently using the stored energy for operating a receiving device.

2. The method hereinbefore described of utilizing effects or disturbances transmitted from a distant source, which consists in charging the storage device with electrical energy from an independent source, controlling the charging of said device by the action of the effects or disturbances, and coincidently using the stored electrical energy for operating the receiving device.

3. The method hereinbefore described of utilizing effects or disturbances transmitted through, the natural media, which consists in controlling, by means of such effects or disturbances, the charging of an electrical storage device from an independent source and discharging the stored energy through a receiving-circuit.

4. The method hereinbefore described of utilizing effects or disturbances transmitted through the natural media, which consists in controlling, by means of such effects or disturbances, the charging of an electrical condenser from an independent source, and discharging the stored energy through a receiving-circuit.

5. The method hereinbefore described of utilizing effects or disturbances transmitted through the natural media, which consists in effecting a storage during any desired time interval and under control of such effects or disturbances, of energy derived from an independent source, and utilizing the potential energy so obtained for operating a receiving device.

6. The method hereinbefore described of utilizing effects or disturbances transmitted through the natural media, which consists in effecting a storage, during any desired time interval and under the control of such disturbances or effects of electrical energy derived from an independent source, and utilizing the potential energy so obtained for operating a receiving device.

7. The method hereinbefore described of utilizing effects or disturbances transmitted through the natural media, which consists in effecting a storage in a condenser during any desired time interval and under the control of such disturbances or effects, of electrical energy derived from an independent source, and utilizing the potential energy so obtained for operating a receiving device.

8. The method hereinbefore described of utilizing effects or disturbances transmitted through the natural media from a distant source, which consists in storing, during succeeding intervals of time determined by means of such effects or disturbances, electrical energy derived from an independent source, and utilizing the potential energy so accumulated to operate a receiving device.

9. The method hereinbefore described of utilizing effects or disturbances transmitted through the natural media from a distant source, which consists in storing in a condenser during succeeding intervals of time determined by means of such effects or disturbances, electrical energy derived from an independent source, and utilizing the poten-

tial energy so accumulated to operate a receiving device.

10. The method hereinbefore described of utilizing effects or disturbances transmitted through the natural media from a distant source, which consists in storing, during succeeding intervals of time determined by means of such effects or disturbances, electrical energy derived from an independent source, and using, for periods of time predetermined as to succession and duration, the accumulated energy so obtained to operate a receiving device.

11. The method hereinbefore described of utilizing effects or disturbances transmitted through the natural media from a distant source, which consists in storing in a condenser during succeeding intervals of time determined by means of such effects or disturbances, electrical energy derived from an independent source, and using, for periods of time predetermined as to succession and duration, the accumulated energy so obtained to operate a receiving device.

12. The method hereinbefore described of utilizing electrical effects or disturbances transmitted through the natural media from a distant source, which consists in effecting by means of such disturbances or effects a storage in a storage device of electrical energy derived from an independent source for periods of time corresponding in succession and duration to such disturbances or effects, and discharging the electrical energy so accumulated into or through a receiving device at predetermined intervals of time.

13. The method hereinbefore described of utilizing electrical effects or disturbances transmitted from a distant source, which consists in effecting by means of such disturbances or effects a storage in a condenser of electrical energy derived from an independent source for periods of time corresponding in succession and duration to such disturbances or effects, and discharging the electrical energy so accumulated into or through a receiving device at predetermined intervals of time.

14. The method hereinbefore described of utilizing electrical effects or disturbances transmitted from a distant source, which consists in producing, by means of such effects or disturbances, variations of resistance in a circuit including an independent electrical source and a device adapted to be charged with electrical energy therefrom, thereby causing the storage device to be charged with energy from such independent source, and using the potential electrical energy so accumulated to operate a receiving device.

15. The method hereinbefore described of utilizing effects or disturbances transmitted through the natural media from a distant source, which consists in producing, by means of such effects or disturbances, variations of resistance in a circuit including an independent electrical source and a condenser, thereby causing the condenser to be charged with energy from the independent source, and using the potential electrical energy so accumulated to operate a receiving device.

16. The method hereinbefore described of utilizing effects or disturbances transmitted through the natural media from a distant source, which consists in causing, by means of such effects or disturbances, electrical energy from an independent source to be stored in a storage device, using the electrical energy so accumulated to operate a transformer and employing the secondary currents from such transformer to operate a receiving device.

17. The method hereinbefore described of utilizing effects or disturbances transmitted through the natural media from a distant source, which consists in causing, by means of such effects or disturbances, electrical energy from an independent source to be stored in a condenser, using the electrical energy so accumulated to operate a transformer and employing the secondary currents from such transformer to operate a receiving device.

18. The method hereinbefore described of utilizing effects or disturbances transmitted through the natural media from a distant source, which consists in causing, by means of such disturbances, variations of resistance in a circuit including an independent source of electricity and a storage device and thereby causing the storage device to be charged from such independent source, discharging the energy so accumulated in the storage device through the primary of a transformer at predetermined intervals of time, and operating a receiver by the currents so developed in the secondary of the transformer.

19. The method hereinbefore described of utilizing effects or disturbances transmitted through the natural, media from a distant source, which consists in causing, by means, of such disturbances, variations of resistance in a circuit including an independent source of electricity and a condenser and thereby causing the condenser to be charged from such independent source, discharging the energy so accumulated in the condenser through the primary of a transformer at predetermined intervals of time and operating a receiver by the currents so developed in the secondary of the transformer.

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P-310

No 685,954. Patented Nov. 5. 1901.

N. TESLA.

METHOD OF UTILIZING EFFECTS TRANSMITTED THROUGH NATURAL MEDIA.

(Application filed Aug. 1, 1809. Renewed May 29, 1901.)

(No Model.) 2 Sheets—Sheet 1.

Fig 1.

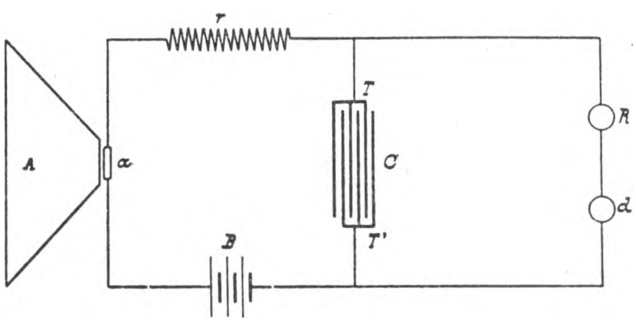
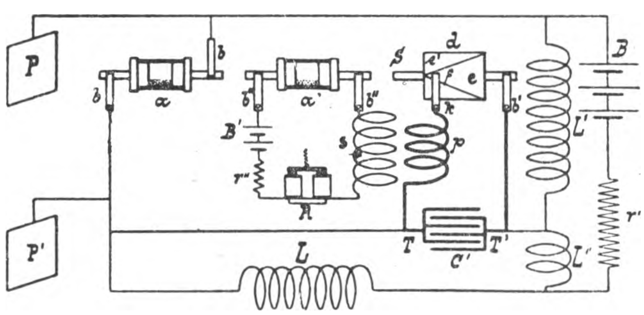


Fig 2.



WITNESSES

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Fig. 3

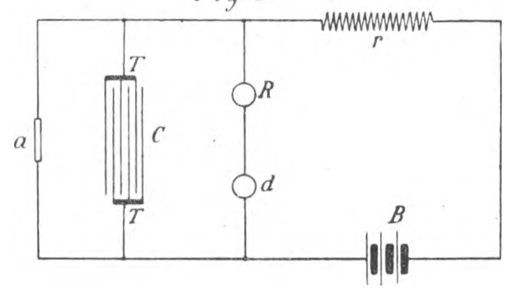


Fig. 4

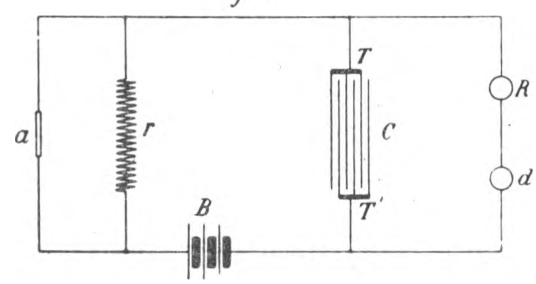
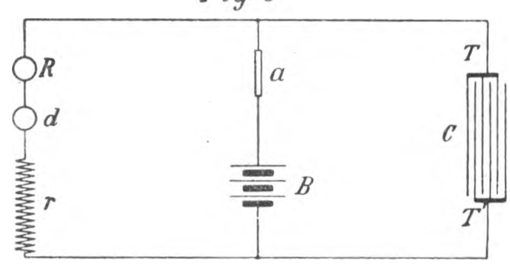


Fig. 5



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Nikola Tesla Inventor
by Kerr, Page & Cooper Att'ys

UNITED STATES PATENT OFFICE.

NIKOLA TESLA, OF NEW YORK, N. Y.

APPARATUS FOR UTILIZING EFFECTS TRANSMITTED FROM A DISTANCE TO A RECEIVING DEVICE THROUGH NATURAL MEDIA.

SPECIFICATION forming part of Letters Patent No. 685,955, dated November 5, 1901.

Original application filed June 24, 1899, Serial No. 721,790. Divided and this application filed September 8, 1899. Renewed May 29, 1901. Serial No. 62,317. (No model.)

To all whom it may concern:

Be it known that I, NIKOLA TESLA, a citizen of the United States, residing at the borough of Manhattan, in the city, county, and State of New York, have invented certain new and useful Improvements in Apparatus for Utilizing Effects Transmitted from a Distance to a Receiving Device Through the Natural Media, of which the following is a specification, reference being had to the accompanying drawings, which form a part of the same.

This application is a division of an application filed by me June 24, 1899, Serial No. 721,790, in which a method of utilizing effects or disturbances transmitted through the natural media from a distant source is described and made the subject of the claims. The invention of my present application consists in the apparatus hereinafter described and claimed, by the use of which the method claimed in my said prior application may be practiced and by means of which results hitherto unattainable may be secured.

Several ways of methods of transmitting electrical disturbances through the natural media and utilizing them to operate distant receivers are now known and have been applied with more or less success for accomplishing a variety of useful results. One of these ways consists in producing by a suitable apparatus rays or radiations—that is, disturbances—which are propagated in straight lines through space, directing them upon a receiving or recording apparatus at a distance, and thereby bringing the latter into action. This method is the oldest and best known, and has been brought particularly into prominence in recent years through the investigations of Heinrich Hertz. Another method consists in passing a current through a circuit, preferably one inclosing a very large area, inducing thereby in a similar circuit, situated at a distance, another current and affecting by the same in any convenient way a receiving device. Still another way, which has also been known for many years, is to pass in any suitable manner a current through a portion of the ground, as by connecting to two points of the name, preferably at a considerable distance from each other, the two terminals of a generator and to energize by a part of the current diffused through the earth a distant circuit, which is similarly arranged and grounded at two points widely apart and which is made to act upon a sensitive receiver. These various methods have their limitations, one, especially, which is common to all, being that the receiving circuit or instrument must be maintained in a definite position with respect to the transmitting apparatus, which often imposes great disadvantages upon the use of the apparatus.

In several applications filed by me and patents granted to me I have disclosed other methods of accomplishing results of this nature, which may be briefly described as follows: In one system the potential of a point or region of the earth is varied by imparting to it intermittent or alternating electrifications through one of the terminals of a suitable source of electrical disturbances, which to heighten the effect has its other terminal connected to an insulated body, preferably of large surface and at an elevation. The electrifications communicated to the earth spread in all directions through the same, reaching a distant circuit, which generally has its terminals arranged and connected similarly to those of the transmitting source, and operates upon a highly-sensitive receiver. Another method is based upon the fact that the atmospheric air, which behaves as an excellent insulator to currents generated by ordinary apparatus, becomes a conductor under the influence of currents of impulses of enormously high electromotive force which I have devised means for generating. By such means air strata, which are easily accessible, are rendered available for the production of many desired effects at distances, however great. This method, furthermore, allows advantage to be taken of many of those improvements which are practicable in the ordinary systems of transmission involving the use of a metallic conductor.

Obviously whatever method be employed it is desirable that the disturbances produced by the transmitting apparatus should be as powerful as possible, and by the use of certain forms of high-frequency apparatus which

I have devised and which are now well known important practical advantages are in this respect secured. Furthermore, since in most cases the amount of energy conveyed to the distant circuit is but a minute fraction of the total energy emanating from the source, it is necessary for the attainment of the best results that whatever the character of the receiver and the nature of the disturbances as much as possible of the energy conveyed should be made available for the operation of the receiver, and with this object in view I have heretofore, among other means, employed a receiving circuit of high self-induction and very small resistance and of a period such as to vibrate in synchronism with the disturbances, whereby a number of separate impulses from the source were made to cooperate, thus magnifying the effect exerted upon and insuring the action of the receiving device. By these means decided advantages have been secured in many instances; but very often the improvement is either not applicable at all or if so the gain is very slight. Evidently when the source is one producing a continuous pressure or delivering impulses of long duration it is impracticable to magnify the effects in this manner, and when, on the other hand, it is one furnishing short impulses of extreme rapidity of succession the advantage obtained in this way is insignificant, owing to the radiation and the unavoidable frictional waste in the receiving-circuit. These losses reduce greatly both the intensity and the number of the cooperative impulses, and since the initial intensity of each of these is necessarily limited only an insignificant amount of energy is thus made available for a single operation of the receiver. As this amount is consequently dependent on the energy conveyed to the receiver by one single impulse, it is evidently necessary to employ either a very large and costly, and therefore objectionable transmitter, or else resort to the equally objectionable use of a receiving device too delicate and too easily deranged. Furthermore, the energy obtained through the cooperation of the impulses is in the form of extremely-rapid vibrations and because of this unsuitable for the operation of ordinary receivers the more so as this form of energy imposes narrow restrictions in regard to the mode and time of its application to such devices. To overcome these and other limitations and disadvantages which have heretofore existed in such systems of transmission of signals or intelligence is the object of my invention, which comprises a novel form of apparatus for accomplishing these results.

The apparatus which is employed at the receiving-station, described in general terms, consists in the combination of a storage device included in a circuit connecting points at a distance from the source of the disturbances and between which a difference of potential is created by such disturbances a receiving-circuit connected with the storage device, a receiver included in such receiving-circuit, and means for closing the receiving-circuit at any desired moment, and thereby causing the receiver to be operated by the energy with which the storage device has been charged.

The best form of apparatus for carrying out my invention of which I am now aware and the manner of using the same will be understood from the following description and the accompanying drawings, in which—

Figure 1 is a diagrammatic illustration of such apparatus, and Fig. 2 a modified form or arrangement of the same.

At any two points in the transmitting medium between which there exists or may be obtained in any manner through the action of the disturbances or effects to be investigated or utilized a difference of electrical potential of any magnitude I arrange two plates or electrodes so that they may be oppositely charged through the agency of such effects or disturbances, and I connect these electrodes to the terminals of a highly-insulated condenser, generally of considerable capacity. To the condenser-terminals I also connect the receiver to be operated in series with a device of suitable construction which performs the function of periodically discharging the condenser through the receiver at and during such intervals of time as may be best suitable for the purpose contemplated. This device may merely consist of two stationary electrodes separated by a feeble dielectric layer of minute thickness, or it may comprise terminals one or more of which are movable and actuated by any suitable force and are adapted to be brought into and out of contact with each other in any convenient manner. It will now be readily seen that if the disturbances, of whatever nature they may be, cause definite amounts of electricity of the same sign to be conveyed to each of the plates or electrodes above mentioned either continuously or at intervals of time which are sufficiently long the condenser will be charged to a certain potential and an adequate amount of energy being thus stored during the time determined by the device effecting the discharge of the condenser the receiver will be periodically operated by the electrical energy so accumulated; but very often the character of the impulses and the conditions of their use are such that without further provision not enough potential energy would be accumulated in the condenser to operate the receiving device. This is the case when, for example, each of the plates or terminals receives electricity of rapidly-changing sign or oven when each receives electricity of the same sign, but only during periods which are short as compared with the intervals separating them. In such instances I resort to the use of a special device which I insert in the circuit between the plates and the condenser for the purpose of conveying to each of the terminals of the latter electrical charges of the proper quality and order of succession to enable the required amount of potential energy to be stored in the condenser.

There are a number of well-known devices, either without any moving parts or terminals or with elements reciprocated or rotated by the application of a suitable force, which offer a more ready passage to impulses of one sign or direction than to those of the other or permit only impulses of one kind or order of succession to traverse a path, and any of these or similar devices capable of fulfilling the requirements may be used in carrying my invention into practice. One such device of familiar construction which will serve to convey a clear understanding of this part of my invention and enable a person skilled in the art to apply the same is illustrated in the annexed drawings. It consists of a cylinder A, of insulating material, which is moved at a uniform rate of speed by clockwork or other suitable motive power and is provided with two metal rings B B', upon which bear brushes *a* and *a'*, which are connected, respectively, in the manner shown to the terminal plates P and P', above referred to. From the rings B B' extend narrow metallic segments *s* and *s'*, which by the rotation of the cylinder A are brought alternately into contact with double brushes *b* and *b'*, carried by and in contact with conducting-holders *h* and *h'*, which are adjustable longitudinally in the metallic supports D and D', as shown. The latter are connected to the terminals T and T' of a condenser C, and it should be understood that they are capable of angular displacement as ordinary brush-supports. The object of using two brushes, as *b* and *b'*, in each of the holders *h* and *h'* is to vary at will the duration of the electric contact of the plates P and P' with the terminals T and T', to which is connected a receiving-circuit, including a receiver R and a device *d* of the kind above referred to, which performs the duty of closing the receiving-circuit at predetermined intervals of time and discharging the stored energy through the receiver. In the present case this device consists of a cylinder made partly of conducting and partly of insulating material *e* and *e'*, respectively, which is rotated at the desired rate of speed by any suitable means. The conducting part *e* is in good electrical connection with the shaft S and is provided with tapering segments *f f*, upon which slides a brush *k*, supported on a conducting-rod *l*, capable of longitudinal adjustment in a metallic support *m*. Another brush *n* is arranged to bear upon the shaft S, and it will be seen that whenever one of the segments *f* comes in contact with the brush *k* the circuit including the receiver R is completed and the condenser discharged through the same. By an adjustment of the speed of rotation of the cylinder *d* and a displacement of the brush *k* along the cylinder the circuit may be made to open and close in as rapid succession and remain open or closed during such intervals of time as may be desired. The plates P and P' through which the electrifications are conveyed to the brushes *a* and *a'* may be at a considerable distance from each other and both in the ground or both in the air or one in the ground and the other in the air, preferably at some height, or they may be connected to conductors extending to some distance or to the terminals of any kind of apparatus supplying electrical energy which is obtained from the energy of the impulses or disturbances transmitted from a distance through the natural media.

In illustration of the operation of the devices described let it be assumed that alternating electrical impulses from a distant generator, as G, are transmitted through the earth and that it is desired to utilize these impulses in accordance with my method. This may be the case, for example, when such a generator is used for purposes of signaling in one of the ways before enumerated, as by having its terminals connected at two points of the earth distant from each other. In this case the plates P and P' are first connected to two properly-selected points of the earth, the speed of rotation of the cylinder A is varied until it is made to turn in synchronism with the alternate impulses of the generator, and, finally, the position of the brushes *b* and *b'* is adjusted by angular displacement, as usual, or in other ways, so that they are in contact with the segments *s* and *s'* during the periods when the impulses are at or near the maximum of their intensity. Only ordinary electrical skill and knowledge are required to make these adjustments, and a number of devices for effecting synchronous movement being well known and it being the chief object of my present application to set forth a novel apparatus embodying a general principle a detailed description of such devices is not considered necessary. I may state, however, that for practical purposes in the present case it is only necessary to shift the brushes back and forth until the maximum effect is secured. The above requirements being fulfilled, electrical charges of the same sign will be conveyed to each of the condenser-terminals as the cylinder A is rotated, and with each fresh impulse the condenser will be charged to a higher potential. The speed of rotation of the cylinder *d* being adjustable at will, the energy of any number of separate impulses may thus be accumulated in potential form and discharged through the receiver R upon the brush *k* coming in contact with one of the segments *f*. It will be of course understood that the capacity of the condenser should be such as to allow the storing of a much greater amount of energy than is required for the ordinary operation of the receiver. Since by this method a relatively great amount of energy and in a suitable form may be made available for the operation of a receiver, the latter need not be very sensitive but of course when the impulses are very feeble, as when coming from a great distance or when it is desired to operate a receiver very rapidly, then any of the well-known devices capable of responding to very feeble influences may be used in this connection.

If instead of the alternating impulses short impulses of the same direction are conveyed to the plates P and P', the apparatus described may still readily be used, and for this purpose it is merely necessary to shift the brushes *b* and *b'* into the position indicated by the dotted lines, while maintaining the same conditions in regard to synchronism as before, so that the succeeding impulses will be permitted to pass into the condenser, but prevented from returning to the ground or transmitting medium during the intervals between them, owing to the interruption during such intervals of the connections leading from the condenser-terminals to the plates.

Another way of using the apparatus with impulses of the same direction is to take off one pair of brushes, as *b,* disconnect the plate P from brush *a* and join it directly to the terminal T of the condenser, and to connect brush a with brush *a'*. When thus modified, the apparatus appears as shown in fig. 2. Operated in this manner and assuming the speed of rotation of cylinder A to be the same, the apparatus will now be evidently adapted for a number of impulses per unit of time twice as great as in the preceding case. In all cases it is evidently important to adjust the duration of contact of segments *s* and *s'* with brushes *b b'* in the manner indicated.

When the apparatus I have described is used in connection with the transmission of signals or intelligence, it will of course be understood, that the transmitter is operated in such a way as to produce disturbances or effects which are varied or intermitted in some arbitrary manner—for example, to produce longer and shorter successions of impulses, corresponding to the dashes and dots of the Morse alphabet—and the receiving device will respond to and indicate these variations or intermittences, since the storage device will be charged and discharged a number of times corresponding to the duration of the successions of impulses received.

Obviously the special appliances used in carrying out my invention may be varied in many ways without departing from the spirit of the same.

It is to be observed that it is the function of the cylinder A, with its brushes and connections, to render the electrical impulses coming from the plates P and P' suitable for charging the condenser (assuming them to be unsuitable for this purpose in the form in which they are received) by rectifying them when they are originally alternating in direction or by selecting such parts of them as are suitable when all are not, and any other device performing this function will obviously answer the purpose. It is also evident that a device such as I have already referred to which offers a more ready passage to impulses of one sign or permits only impulses of the same sign to pass may also be used to perform this selective function in many cases when alternating impulses are received. When the impulses are long and all of the same direction, and even when they are alternating but sufficiently long in duration and sustained in electromotive force, the brushes *b* and *b'* may be adjusted so as to bear on the parts B B' of the cylinder A, or the cylinder and its brushes may be omitted and the terminals of the condenser connected directly to the plates P and P'.

It will be seen that by the use of my invention results hitherto unattainable in utilizing disturbances or effects transmitted through natural media may be readily attained, since however great the distance of such transmission and however feeble or attenuated the impulses received enough energy may be accumulated from them by storing up the energy of succeeding impulses for a sufficient interval of time to render the sudden liberation of it highly effective in operating a receiver. In this way receivers of a variety of forms may be made to respond effectively to impulses too feeble to be detected or to be made to produce any sensible effect in any other way of which I am aware—a result of great value in scientific research as well as in various applications to practical use.

What I claim as my invention, and desire to secure by Letters Patent, is—

1. In an apparatus for utilizing electrical effects or disturbances transmitted through the natural media, the combination with a source of such effects or disturbances of a charging-circuit adapted to be energized by the action of such effects or disturbances, a storage device included in the charging-circuit and adapted to be charged thereby, a receiver, and means for causing the receiver to be operated by the energy accumulated in the storage device at arbitrary intervals of time, substantially as described.

2. In an apparatus for utilizing electrical effects or disturbances transmitted through the natural media, the combination with a source of such effects or disturbances of a charging-circuit adapted to be energized by the action of such effects or disturbances, a storage device included in the charging-circuit and adapted to be charged thereby, means for commutating, directing or selecting the current impulses in the charging-circuit, a receiving-circuit, and means for discharging the storage device through the receiving-circuit, substantially as described.

3. In an apparatus for utilizing electrical effects or disturbances transmitted through the natural media, the combination with a source of such effects or disturbances of a charging-circuit adapted to be energized by the action of such effects or disturbances, a condenser included in the charging-circuit

and adapted to be charged thereby, means for commutating, directing or selecting the current impulses in the charging-circuit, a receiving-circuit, and means for discharging the condenser through the receiving-circuit, substantially as described.

4. In an apparatus for utilizing electrical effects or disturbances transmitted through the natural media, the combination with a source of such effects or disturbances of a charging-circuit adapted to be energized by the action of such effects or disturbances, a storage device included in the charging-circuit and adapted to be charged thereby, means for commutating, directing or selecting the current impulses in the charging-circuit so as to render them suitable for charging the storage device, a receiving-circuit, and means for discharging the storage device through the receiving-circuit, substantially as described.

5. In an apparatus for utilizing electrical effects or disturbances transmitted through the natural media, the combination with a source of such effects or disturbances of a charging-circuit adapted to be energized by the action of such effects or disturbances, a condenser included in the charging-circuit and adapted to be charged thereby, means for commutating, directing or selecting the current impulses in the charging-circuit so as to render them suitable for charging the condenser, a receiving-circuit, and means for discharging the condenser through the receiving-circuit, substantially as described.

6. In an apparatus for utilizing electrical effects or disturbances transmitted through the natural media, the combination with a source of such effects or disturbances of a charging-circuit adapted to be energized by the action of such effects or disturbances, a storage device included in the charging-circuit and adapted to be charged thereby, means for commutating, directing or selecting the current impulses in the charging-circuit so as to render them suitable for charging the storage device, a receiving-circuit, and means for discharging the storage device through the receiving-circuit at arbitrary intervals of time, substantially as described.

7. In an apparatus for utilizing electrical effects or disturbances transmitted to a distant receiving-station, the combination with a source of such effects or disturbances of a circuit distant from the source and adapted to have current impulses set up in it by the action of the effects or disturbances, a storage device, means for commutating, directing or selecting the impulses and connecting the circuit with the storage device at succeeding intervals of time synchronizing with the impulses, a receiving-circuit, and means for periodically discharging the storage device through the receiving-circuit, substantially as described.

8. In an apparatus for utilizing electrical effects or disturbances transmitted to a distant receiving-station, the combination with a source of such effects or disturbances of a circuit distant from the source and adapted to have current impulses set up in it by the action of the effects or disturbances, a condenser, means for commutating, directing or selecting the impulses and connecting the circuit with the condenser at succeeding intervals of time synchronizing with the impulses, a receiving-circuit, and means for periodically discharging the condenser through the receiving-circuit, substantially as described.

9. In an apparatus for utilizing electrical effects or disturbances transmitted through the natural media, the combination with a source of such effects or disturbances of a circuit connecting points at a distance from the source between which a difference of potential is created by such effects or disturbances, a storage device included in such circuit and adapted to be charged with the energy supplied by the same, a receiving-circuit connected with the storage device, a receiver included in such receiving-circuit, and means for closing the receiving-circuit and thereby causing the receiver to be operated by the energy accumulated in the storage device, substantially as described.

10. In an apparatus for utilizing electrical effects or disturbances transmitted through the natural media, the combination with a source of such effects or disturbances of a circuit at a distance from the source which is energized by such effects or disturbances, a storage device adapted to be charged with the energy supplied by such circuit, means for connecting the storage device with the said circuit for periods of time predetermined as to succession and duration, a receiving-circuit connected with the storage device, a receiver included in such receiving-circuit, and means for closing the receiving-circuit and thereby causing the receiver to be operated by the energy accumulated in the storage device, substantially as described.

11. In an apparatus for utilizing electrical effects or disturbances transmitted through the natural media, the combination of a circuit connecting points at a distance from the source between which a difference of potential is created by such effects or disturbances, a storage device included in such circuit and adapted to be charged with the energy supplied by the same, a receiving-circuit, a receiver included in such circuit, and means for connecting the receiving-circuit with the storage device for periods of time predetermined as to succession and duration and thereby causing the receiver to be operated by the energy accumulated in the storage device, substantially as described.

12. In an apparatus for utilizing electrical effects or disturbances transmitted through the natural media, the combination of a circuit connecting points at a distance from the source between which a difference of potential is created by such effects or disturbances, a

storage device adapted to be charged with the energy supplied by such circuit for succeeding and predetermined periods of time, a receiving-circuit, a receiver included in the receiving-circuit, and means for connecting the receiving-circuit with the storage device for periods of time predetermined as to succession and duration and thereby causing the receiver to be operated by the energy accumulated in the storage device, substantially as described.

13. In an apparatus for Utilizing electrical effects or disturbances transmitted through the natural media, the combination of a circuit connecting points at a distance from the source between which a difference of potential is created by such effects or disturbances, a condenser included in such circuit and adapted to be charged by the current in the same, a receiving-circuit connected with the condenser, a receiver included in such receiving-circuit, and a device adapted to close the receiving-circuit at arbitrary intervals of time and thereby cause the receiver to be operated by the electrical energy accumulated in the condenser, substantially as described.

14. In an apparatus for utilizing electrical effects or disturbances transmitted through the natural media, the combination of a charging-circuit distant from the source and energized by the effects or disturbances, a storage device included in the charging-circuit, means included in the charging-circuit and acting in synchronism with the impulses therein for commutating, directing or selecting the impulses, a receiving-circuit. and means for periodically discharging the storage device through the receiving-circuit, substantially as described.

15. In an apparatus for utilizing electrical effects or disturbances transmitted through the natural media, the combination of a charging-circuit distant from the source and energized by the effects or disturbances, a condenser included in the charging-circuit, means included in the charging-circuit and acting in synchronism with the impulses therein for commutating, directing or selecting the impulses, a receiving-circuit and means for periodically discharging the condenser through the receiving-circuit, substantially as described.

16. In an apparatus for transmitting signals or intelligence through the natural media from a sending-station to a distant point, the combination of a generator or transmitter adapted to produce arbitrarily varied or intermitted electrical disturbances or effects in the natural media, a charging-circuit at the distant point adapted to receive corresponding electrical impulses or effects from the disturbances or effects so produced, a storage device included in the charging-circuit, means included in the charging-circuit and acting in synchronism with the impulses therein for commutating, directing or selecting the impulses so as to render them suitable for charging the storage device, a receiving-circuit and means for periodically discharging the storage device through the receiving-circuit, substantially as described.

17. In an apparatus for transmitting signals or intelligence through the natural media from a sending-station to a distant point, the combination of a generator or transmitter adapted to produce arbitrarily varied or intermitted electrical disturbances or effects in the natural media, a charging-circuit at the distant point adapted to receive corresponding electrical impulses or effects from the disturbances or effects so produced, a condenser included in the charging-circuit, means included in the charging-circuit and acting in synchronism with the impulses therein for commutating, directing or selecting the impulses so as to render them suitable for charging the condenser, a receiving-circuit and means for periodically discharging the condenser through the receiving-circuit, substantially as described.

18. In an apparatus for transmitting signals or intelligence through the natural media from a sending-station to a distant point, the combination of a generator or transmitter adapted to produce arbitrarily varied or intermitted electrical disturbances or effects in the natural media, a circuit at the distant point adapted to receive corresponding electrical impulses or disturbances from the disturbances or effects so transmitted, a storage device included in such circuit and adapted to be charged thereby, a receiving-circuit connected with the storage device, a receiver included in the receiving-circuit and a device for closing the receiving-circuit at arbitrary intervals of time and thereby causing the receiver to be operated by the energy accumulated in the storage device, substantially as described.

NIKOLA TESLA

Witnesses
C. E. TITUS,
LEONARD E. CURTIS.

P-318

No. 685,955 Patented Nov. 5, 1901.

N. TESLA

APPARATUS FOR UTILIZING EFFECTS TRANSMITTED FROM A DISTANCE TO A RECEIVING DEVICE THROUGH NATURAL MEDIA.

(Application filed Sept. 8, 1899. Renewed May 29, 1901.)

(No Model.)

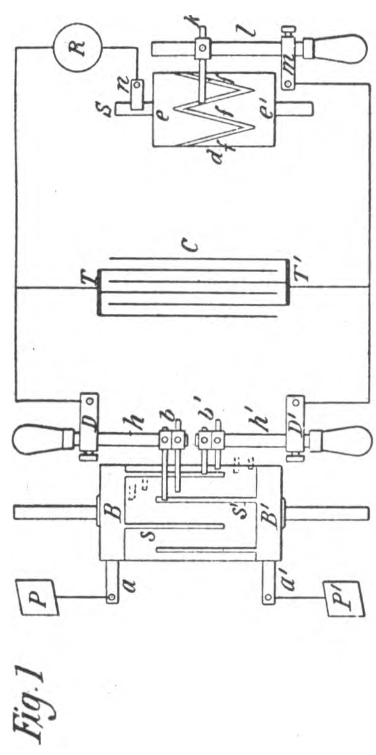

Fig. 1

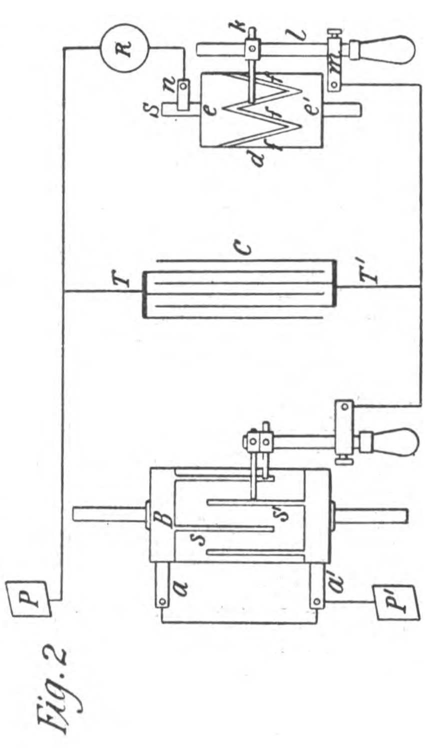

Fig. 2

Witnesses:
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Att'ys

UNITED STATES PATENT OFFICE.

NIKOLA TESLA, OF NEW YORK, N. Y.

APPARATUS FOR UTILIZING EFFECTS TRANSMITTED THROUGH NATURAL MEDIA.

SPECIFICATION forming part of Letters Patent No. 685,950, dated November 5, 1901

Original application filed August 1, 1899, Serial No. 725,749. Divided and this application filed November 2. 1899. Renewed May 29, 1901. Serial No. 62,318. (No model.)

To all whom it may concern:

Be it known that I, NIKOLA TESLA, a citizen of the United States, residing at New York city, in the county and State of New York, have invented a new and useful Improvement in Apparatus for Utilizing Effects Transmitted from a Distance to a Receiving Device Through the Natural Media, of which the following is a specification, reference being had to the accompanying drawings, which form a part of the same.

The subject of my present invention is an improvement in the art of utilizing effects transmitted from a distance to a receiving device through the natural media; and it consists in the novel apparatus hereinafter described.

This application is a division of one filed by me August 1, 1899, Serial No. 725,749, and based upon and claiming the method herein described and which may be practiced by the use of the apparatus forming the subject of this application.

My invention is particularly useful in connection with methods and apparatus for operating distant receiving devices by means of electrical disturbances produced by proper transmitters and conveyed to such receiving devices through the natural media; but it obviously has a wider range of applicability and may be employed, for example, in the investigation or utilization of terrestrial, solar, or other disturbances produced by natural causes.

Several ways or methods of transmitting electrical disturbances through the natural media and utilizing them to operate distant receivers are now known and have been applied with more or less success for accomplishing a variety of useful results. One of these ways consists in producing by a suitable apparatus rays or radiations—that is, disturbances—which are propagated in straight lines through space, directing them upon a receiving or recording apparatus at a distance, and thereby bringing the latter into action. This method is the oldest and best known and has been brought particularly into prominence in recent years through the investigations of Heinrich Hertz. Another method consists in passing a current through a circuit, preferably one inclosing a very large area, inducing thereby in a similar circuit situated at a distance another current and affecting by the same in any convenient way a receiving device. Still another way, which has also been known for many years, is to pass in any suitable manner a current through a portion of the ground, as by connecting to two points of the same, preferably at a considerable distance from each other, the two terminals of a generator and to energize by a part of the current diffused through the earth a distant circuit, which is similarly arranged and grounded at two points widely apart and which is made to act upon a sensitive receiver. These various methods have their limitations, one especially, which is common to all, being that the receiving circuit or instrument must be maintained in a definite position with respect to the transmitting apparatus, which often imposes great disadvantages upon the use of the apparatus.

In several applications filed by me and patents granted to me I have disclosed other methods of accomplishing results of this nature, which may be briefly described as follows; In one system the potential of a point or region of the earth is varied by imparting to it intermittent or alternating electrifications through one of the terminals of a suitable source of electrical disturbances, which, to heighten the effect, has its other terminal connected to an insulated body, preferably of large surface and at an elevation. The electrifications communicated to the earth spread in all directions through the same, reaching a distant circuit, which generally has its terminals arranged and connected similarly to those of the transmitting source and operates upon a highly-sensitive receiver. Another method is based, upon the fact that the atmospheric air, which behaves as an excellent insulator to currents generated by ordinary apparatus, becomes a conductor under the influence of currents or impulses of enormously high electromotive force, which I have devised means for generating. By such means air strata, which are easily accessible, are rendered available for the production of many desired effects at distances however great. This method, furthermore, allows advantage to be taken of many of those improvements which are practicable in the ordinary systems of transmission involving the use of a metallic conductor.

Obviously whatever method be employed it is desirable that the disturbances produced by the transmitting apparatus should be as powerful as possible, and by the use of certain forms of high-frequency apparatus, which I have devised and which are now well known, important practical advantages are in this respect secured. Furthermore, since in most cases the amount of energy conveyed to the distant circuit is but a minute fraction of the total energy emanating from the source it is necessary for the attainment of the best results that whatever the character of the receiver and the nature of the disturbances as much as possible of the energy conveyed should be made available for the operation of the receiver, and with this object in view I have heretofore, among other means, employed a receiving-circuit of high self-induction and very small resistance and of a period such as to vibrate in synchronism with the disturbances, whereby a number of separate impulses from the source were made to cooperate, thus magnifying the effect exerted upon and insuring the action of the receiving device. By these means decided advantages have been secured in many instances; but very often the improvement is either not applicable at all, or, if so, the gain is very slight, Evidently when the source is one producing a continuous pressure or delivering impulses of long duration it is impracticable to magnify the effects in this manner, and when, on the other hand, it is one furnishing short impulses of extreme rapidity of succession the advantage obtained in this way is insignificant, owing to the radiation and the unavoidable frictional waste in the receiving-circuit. These losses reduce greatly both the intensity and the number of the cooperative impulses, and since the initial intensity of each of these is necessarily limited only an insignificant amount of energy is thus made available for a single operation of the receiver. As this amount is consequently dependent on the energy conveyed to the receiver by one single impulse, it is evidently necessary to employ either a very large and costly, and therefore objectionable, transmitter, or else to resort to the equally objectionable use of a receiving device too delicate and too easily deranged. Furthermore, the energy obtained through the cooperation of the impulses is in the form of extremely rapid vibrations and because of this unsuitable for the operation of ordinary receivers, the more so as this form of energy imposes narrow restrictions in regard to the mode and time of its application to such devices. To overcome these and other limitations and disadvantages that have heretofore existed in such systems of transmission of signals or intelligence and to render possible an investigation of impulses or disturbances propagated through the natural media from any kind of source and their practical utilization for any purpose to which they are applicable, I have devised a novel method, which I have described in a pending application, filed June 24, 1899, Serial No. 721,790, and which, broadly stated, consists in effecting during any desired time interval a storage of energy derived from such impulses and utilizing the potential energy so obtained for operating a receiving device.

My present invention is intended for the same general purposes, and it comprises another apparatus by means of which similar results may be obtained.

The chief feature which distinguishes the method of my present from that of my former invention, just referred to, is that the energy stored is not, as in the former instance, obtained from the energy of the disturbances or effects transmitted from a distance, but from an independent source.

Expressed generally, the present method consists in charging a storage device with energy from an independent source, controlling the charging of said device by the action of the effects or disturbances transmitted through the natural media, and coincidently using the stored energy for operating a receiving device.

A great variety of disturbances, produced either by suitably-constructed transmitters or by natural causes, are at present known to be propagated through the natural media, and there are also a variety of means or devices enabling energy to be stored, and in view of this I wish to say that I consider the utilization of any such disturbances and the employment of any of these means as within the scope of my present invention so long as the use of the general method hereinbefore stated is involved.

The best way of carrying out my invention which I at present know is to store electrical energy obtained from a suitable electrical generator in a condenser and to control the storage or the application of this energy by means of a sensitive device acted upon by the effects or disturbances, and thereby cause the operation of the receiver.

In the practical application of this method I usually proceed as follows: At any point where I desire to investigate or to utilize for any purpose effects or disturbances propagated through the natural media from any kind of source I provide a suitable generator of electricity—as, for example, a battery and a condenser—which I connect to the poles of the generator in series with a sensitive device capable of being modified in its electrical resistance or other property by the action of the disturbances emitted from the source. To the terminals of the condenser I connect the receiver which is to be operated in series with another device of suitable construction, which performs the function of periodically discharging the condenser through the receiver at and during such intervals of time as may be best suitable for the purpose contemplated. This latter device may merely consist of two stationary electrodes separated by a feeble dielectric layer of minute thickness, but sufficient to greatly reduce or practically interrupt the current in the circuit under normal conditions, or it may comprise terminals one or more of which are movable and actuated by any suitable force and are adapted to be brought into and out of contact with each other in any convenient manner. The sensitive device may be any of the many devices of this kind which are known to be affected by the disturbances, impulses, or effects propagated through the media, and it may be of such a character that normally—that is, when not acted upon—it entirely prevents the passage of electricity from the generator to the condenser, or it may be such that it allows a gradual leaking through of the current and a charging of the condenser at a slow rate. In any case it will be seen that if the disturbances, of whatever nature they may be, cause an appreciable diminution in the electrical resistance of the sensitive device the current from the battery will pass more readily into the condenser, which will be charged at a more rapid rate, and consequently each of its discharges through the receiver, periodically effected by the special device before referred to which performs this function, will be stronger than normally—that is, when the sensitive device is not acted upon by the disturbances. Evidently then if the receiver be so adjusted that it does not respond to the comparatively feeble normal discharges of the condenser, if they should occur, but only to those stronger ones which take place upon the diminution of the resistance of the sensitive device it will be operated only when this device is acted upon by the disturbances, thus making it possible to investigate and to utilize the latter for any desired purpose.

The general principle underlying my invention and the operation of the various devices used will be clearly understood by reference to the accompanying drawings, in which—

Figure 1 is a diagram illustrating a typical arrangement of apparatus which may be used in carrying my method into practice, and Figs. 2, 3, 4, and 5 similar diagrams of modified arrangements of apparatus for the same purpose.

In Fig. 1, C is a condenser, to the terminals T and T' of which is connected a charging-circuiy, including a battery B, a sensitive device *a*, and a resistance *r*, all connected in series, as illustrated. The battery should be preferably of very constant electromotive force and of an intensity carefully determined to secure the best results. The resistance *r*, which may be a frictional or an inductive one, is not absolutely necessary; but it is of advantage to use it in order to facilitate adjustment, and for this purpose it may be made variable in any convenient and preferably continuous manner. Assuming that the disturbances which are to be investigated or utilized for some practical end are rays identical with or resembling those of ordinary light, the sensitive device *a* may be a selenium cell properly prepared, so as to be highly susceptible to the influence of the rays, the action of which should be intensified by the use of a reflector A. (Shown in the drawings.) It is well known that when cells of this kind are exposed to such rays of greatly-varying intensity they undergo corresponding modifications of their electrical resistance; but in the ways they have been heretofore used they have been of very limited utility.

In addition to the circuit including the sensitive device or cell *a* another circuit is provided, which is likewise connected to the terminals T T' of the condenser. This circuit, which may be called the "receiving-circuit", includes the receiver R and in series with it a device *d,* before referred to, which performs the duty of periodically discharging the condenser through the receiver. It will be noted that, as shown in Fig. 1, the receiving-circuit is in permanent connection with the battery and condenser-terminal T, and it should be stated that it is sometimes desirable to entirely insulate the receiving-circuit at all times, except the moments when the device *d* operates to discharge the condenser, thus preventing any disturbing influence which might otherwise be caused in this circuit by the battery or the condenser during the period when the receiver should not be acted upon. In such a case two devices, as *d,* may be used, one in each connection from the condenser to the receiving-circuit, or else one single device of this kind, but of a suitably-modified construction, so that it will make and break simultaneously and at proper intervals of time both of the connections of this circuit with the condenser T and T'.

From the foregoing the operation of the apparatus, as illustrated in Fig. 3, will be at once understood. Normally—that is, when it is not influenced by the rays at all or very slightly—the cell *a*, being of a comparatively high resistance, permits only a relatively feeble current to pass from the battery into the condenser, and hence the latter is charged at too slow a rate to accumulate during the time interval between two succeeding operations of the device *d* sufficient energy to operate the receiver or, generally speaking, to produce the required change in the receiving-circuit. This condition is readily secured by a proper selection and adjustment of the various devices described, so that the receiver will remain unresponsive to the feeble discharges of the condenser which may take place when the cell *a* is acted upon but slightly or not at all by the rays or disturbances; but if now new rays are permitted to fall upon the cell or if the intensity of those already acting upon it be increased by any cause then its resistance will be diminished and the condenser will be charged by the battery at a more rapid rate, enabling sufficient potential energy to be stored in the condenser during the period of inaction of the device *d* to operate the receiver or to bring about any desired change in the receiving-circuit when the device *d* acts. If the rays acting upon the cell or sensitive device *a* are varied or intermitted in any arbitrary manner, as when transmitting intelligence in the usual way from a distant station by means of short and long signals, the apparatus may readily be made to record or to enable an operator to read the message, since the receiver—supposing it to be an ordinary magnetic relay, for example—will be operated by each signal from the sending-station a certain number of times, having some relation to the duration of each signal. It will be readily seen, however, that if the rays are varied in any other way, as by impressing upon them changes in intensity, the succeeding condenser, discharges will undergo corresponding changes in intensity, which may be indicated or recorded by a suitable receiver and distinguished irrespectively of duration.

With reference to Fig. 1 it may be useful to state that the electrical connections of the various devices illustrated may be made in many different ways. For instance, the sensitive device instead of being in series, as shown, may be in a shunt to the condenser, this modification being illustrated in Fig. 3, in which the devices already described are indicated by similar letters to correspond with those of Fig. 1. In this case it will be observed that the condenser, which is being charged from the battery B through the resistance *r*, preferably inductive and properly related to the capacity of the condenser, will store less energy when the sensitive device *a* is energized by the rays, and its resistance thereby diminished. The adjustment of the various instruments may then be such that the receiver will be operated only when the rays are diminished in intensity or interrupted and entirely prevented from falling upon the sensitive cell, or the sensitive device may be placed, as shown in Fig. 4, in a shunt to the resistance *r* or inserted in any suitable way in the circuit containing the receiver—for example, as illustrated in Fig. 5—in both of which figures the various devices are lettered to correspond with those in Fig. 1, so that the figures become self-explanatory. Again, the several instruments may be connected in the manner of a Wheatstone bridge, as will be hereinafter explained with reference to Fig. 2, or otherwise connected or related; but, in each case the sensitive device will have the same duty to perform—that is, to control the energy stored and utilized in some suitable way for causing the operation of the receiver in correspondence with the intermittances or variations of the effects or disturbances—and in each instance by a judicious selection of the devices and careful adjustment the advantages of my method may be more or less completely secured. I find it preferable, however, to follow the plan which I have illustrated and described.

It will be observed that the condenser is an important element in the combination. I have shown that by reason of its unique properties it greatly adds to the efficacy of this method. It allows the energy accumulated in it to be discharged instantaneously, and therefore in a highly effective manner. It magnifies in a large degree the current supplied from the battery, and owing to these features it permits energy to be stored and discharged at practically any rate desired, and thereby makes it possible to obtain in the receiving-circuit very great changes of the current strength by impressing upon the battery-current very small variations. Other means of storage possessing these characteristics to a useful degree may be employed without departing from the broad spirit of my invention; but I prefer to use a condenser, since in these respects it excels any other storage device of which I have knowledge.

In Fig. 2 a modified arrangement of apparatus is illustrated which is particularly adapted for the investigation and utilization of very feeble impulses or disturbances, such as may be used in conveying signals or producing other desired effects at very great distances. In this case the energy stored in the condenser is passed through the primary of a transformer, the secondary circuit of which contains the receiver, and in order to render the apparatus still more suitable for use in detecting feeble impulses, in addition to the sensitive device which is acted upon by the impulses, another such device is included in the secondary circuit of the transformer. The scheme of connections is in the main that of a Wheatstone bridge, the four branches of which are formed by the sensitive device *a* and resistances L, L', and L'', all of which should be preferably inductive and also adjustable in a continuous manner, or at least by very small steps. The condenser C', which is generally made of considerable capacity, is connected to two opposite points of the bridge, while a battery B, in series with a continuously-adjustable non-inductive resistance *r'*, is connected to the other pair of opposite points, as usual. The four resistances included in the branches of the bridge—namely, *a*, L, L', and L''—are of a suitable size and so proportioned that under normal conditions—that is, when the device *a* is not influenced at all or only slightly by the disturbances—there will be no difference of potential, or, in any case, the minimum of the same at the terminals T and T' of the condenser. It is assumed in the present instance that the disturbances to be investigated or utilized are such as will produce a difference of electric potential, however small, between two points or regions in the natural media, as the earth, the water, or the air, and in order to apply this potential difference effectively to the sensitive device *a* the terminals of the same are connected to two plates P and P', which should be of as large a surface as practicable and so located in the media that the largest possible difference of potential will be produced by the disturbances between the terminals of the sensitive device. This device is in the present case one of familiar construction, consisting of an insulating-tube, which is indicated by the heavy lines in the drawings and which has its ends closed tightly by two conducting-plugs with reduced extensions, upon which bear two brushes *b b*, through which the currents are conveyed to the device. The tubular space between the plugs is partially filled with a conducting sensitive powder, as indicated, the proper amount of the same and the size of its grains being determined and adjusted beforehand by experiment. This tube I rotate by clockwork or other means at a uniform and suitable rate of speed, and under these conditions I find that this device behaves toward disturbances of the kind before assumed in a manner similar to that of a stationary cell of celenium toward rays of light. Its electrical resistance is diminished when it is acted upon by the disturbances and is automatically restored upon the cessation of their influence. It is of advantage to employ round grains of powder in the tube, and in any event it is important that they should be of as uniform size and shape as possible and that provision should be made for maintaining an unchanging and very dry atmosphere in the tube. To the terminals T and T' of the condenser C' is connected a coil *p*, usually consisting of a few turns of a conductor of very small resistance, which is the primary of the transformer before referred to; in series with a device *d*, which effects the discharge of the condenser through the coil *p* at predetermined intervals of time. In the present case this device consists of a cylinder made partly of conducting and partly of insulating material *e* and *e*', respectively, which is rotated at the desired rate of speed by any suitable means. The conducting part *e* is in good electrical connection with shaft S and is provided with tapering segments, as *f*, upon which slides a brush *k*, which should preferably be capable of longitudinal adjustment along the cylinder. Another brush *b*', which is connected to the condenser-terminal T', being arranged to bear upon the shaft S, it will, be seen that whenever the brush *k* comes in contact with a conducting-segment *e* the circuit including the primary *p* will be completed and the condenser, if energized, discharged through the same. By an adjustment of the speed of rotation of the cylinder and a displacement of the brush *k* along the axis of the same the circuit may be made to open and close in as rapid succession and remain open or closed during such intervals of time as may be desired. In inductive relation to the primary *p* is a secondary coil *s*, usually of much thinner wire and of many more turns than the former, to which are connected in a series a receiver R, illustrated as an ordinary magnetic relay, a continuously-adjustable non-inductive resistance *r″* , a battery B' of a properly-determined and very constant electromotive force, and finally a sensitive device *a′* of the same or similar construction as *a*, which is likewise rotated at a uniform speed and which, with its brushes *b′ b″,* closes the secondary circuit. The electromotive force of the battery B' is so graduated by means of the adjustable resistance *r″* that the dielectric layers in the sensitive device *a′* are strained very nearly to the point of breaking down and give way upon a slight increase of the electrical pressure on the terminals of the device. It will of course be understood that the resistance *r″* is used mainly because of convenience and that it may be dispensed with, in which case the adjustment may be effected in many other ways, as by determining the proper amount or coarseness of the sensitive powder or by varying the distance apart of the metallic plugs in the ends of the tube. The same may be said of the resistance *r′*, which is in series with the battery B and serves to graduate the force of the latter, so that the dielectric layers of the sensitive device *a* are subjected to a similar strain and maintained in a state of delicate poise.

The various instruments being connected and adjusted in the manner described, it will now be readily seen from the foregoing that under normal conditions, the device *a* being unaffected by the disturbances, or practically so, and there being no or only a very insignificant amount of energy stored in the condenser, the periodical closure of the primary circuit of the transformer through the operation of the device *d* will have no appreciable effect upon the primary coil *p*, and hence no currents will be generated in the secondary coil *s,* at least not such as would disturb the State of delicate balance existing in the secondary circuit including the receiver, and therefore the latter will not be actuated by the battery B'; but when, owing to the disturbances or impulses propagated through the media from a distant source, an additional electromotive force, however small, is created between the terminals of the device *a* the dielectric layers in the same, unable to support the increased strain, give way and allow the current of the battery B to pass through, thus causing a difference of potential at the terminals T and T' of the condenser. A sufficient amount of energy being now stored in this instrument during the time interval between each two succeeding operations of the device *d,* each closure of the primary circuit by the latter results in the passage of a sudden current impulse through the coil *p*, which induces a corresponding current of relatively high electromotive force in the secondary coil *s*. Owing to this the dielectric in the device *a'* gives way, and the current of the battery B' being allowed to pass the receiver R is operated, but only for a moment, since by the rotation of the devices *a*, *a'*, and *d,* which may be all driven from the same shaft, the original conditions are restored, assuming, of course, that the electromotive force set up by the disturbances at the terminals of the sensitive device *a* is only momentary or of a duration not longer than the time of closure of the primary circuit; otherwise the receiver will be actuated a number of times and so long as the influence of the disturbances upon the device *a* continues. In order to render the discharged energy of the condenser more effective in causing the operation of the receiver, the resistance of the primary circuit should be very small and the secondary coil *s* should have a number of turns many times greater than that of the primary coil *p*. It will be noted that since the condenser under the above assumptions is always charged in the same direction the strongest current impulse in the secondary coil, which is induced at the moment when the brush *k* comes in contact with segment *e*, is also of unchanging direction, and for the attainment of the best results it is necessary to connect the secondary coil so that the electromotive force of this impulse will be added to that of the battery and will momentarily strengthen the same. However, under certain conditions, which are well understood by those skilled in the art, the devices will operate whichever way the secondary be connected. It is preferable to make the inductive resistances L and L' relatively large, as they are in a shunt to the device *a* and might, if made too small, impair its sensitiveness. On the other hand, the resistance L" should not be too large and should be related to the capacity of the condenser and the number of makes and breaks effected by the device *d* in well-known ways. Similar considerations apply, of course, to the circuits including the primary *p* and secondary *s,* respectively.

By carefully observing well-known rules of scientific design and adjustment of the instruments the apparatus may be made extremely sensitive and capable of responding to the feeblest influences, thus making it possible to utilize impulses or disturbances transmitted from very great distances and too feeble to be detected or utilized in any of the ways heretofore known, and on this account the method here described lends itself to many scientific and practical uses of great value.

Obviously the character of the devices and the manner in which they are connected or related may be greatly varied without departing from the spirit of my invention.

What I claim as new, and desire to secure by Letters Patent, is—

1. In an apparatus for utilizing effects or disturbances transmitted through the natural media from a distant source, the combination of an electrical storage device, a charging-circuit connected therewith and including a device sensitive to the action of the effects or disturbances and determining under their control the flow of current in the charging-circuit, a receiving-circuit including a receiver, and means for periodically discharging the storage device through the receiving-circuit, substantially as described.

2. In an apparatus for utilizing effects or disturbances transmitted through the natural media from a distant source, the combination of a condenser, a charging-circuit connected therewith and including a source of electricity and a device sensitive to the action of the effects or disturbances and determining under their control the flow of current in the charging-circuit, a receiving-circuit including a receiver, and means for periodically discharging the condenser through the receiving-circuit, substantially as described.

3. In an apparatus for utilizing effects or disturbances transmitted through the natural media from a distant source, the combination of a circuit including a source of electricity, a storage device adapted to be charged thereby and a device normally of very high resistance but adapted to have its resistance reduced when acted upon by the effects or disturbances, with a receiving-circuit connected with the storage device and including a receiver and a device adapted to open and close the receiving-circuit at predetermined intervals of time, substantially as described.

4. In an apparatus for utilizing effects or disturbances transmitted through the natural media from a distant source, the combination of a circuit including a source of electricity, a condenser and a device normally of very high resistance but adapted to have its resistance reduced when acted upon by the effects or disturbances, with a receiving-circuit connected with the condenser and including a receiver and a device adapted to open and close the receiving-circuit at predetermined intervals of time, substantially as described.

5. In an apparatus for utilizing effects or disturbances transmitted from a distant source, the combination of a circuit including a source of electricity, a storage device adapted to be charged thereby and a device, normally of very high resistance but adapted to have its resistance reduced when acted upon by the effects or disturbances, with a receiving-circuit connected with the storage device and including the primary of a transformer and a device adapted to open and close such second circuit at predetermined intervals of time, and a receiver included in the secondary of the transformer, substantially as described.

6. In an apparatus for utilizing effects or disturbances transmitted from a distant source, the combination of an electrical storage device, a charging-circuit connected therewith and including a device sensitive to the

action of the effects or disturbances and determining under their control the flow of the current in the charging-circuit, and a receiving-circuit supplied with energy from the storage device and including a receiver and a device sensitive to electrical variations in the receiving-circuit, substantially as described.

7. In an apparatus for utilizing effects or disturbances transmitted through the natural media from a distant source, the combination of a condenser, a charging-circuit connected therewith and including a device sensitive to the action of the effects or disturbances and determining under their control the flow of the current in the charging-circuit, and a receiving-circuit supplied with energy from the condenser and including a receiver and a device sensitive to electrical variations in the receiving-circuit, substantially as described.

8. In an apparatus for utilizing effects or disturbances transmitted through the natural media from a distant source, the combination of a circuit, an independent local source of electricity included therein, a storage device connected with the said circuit and adapted to receive energy from the said source, a device normally of very high resistance, but adapted to have its resistance reduced when acted upon by the effects or disturbances, a receiving-circuit connected with the storage device, a transformer, the primary of which is included in said receiving-circuit, a device adapted to open and close the receiving-circuit at predetermined intervals of time, a receiver, and a device, normally of very high resistance, but adapted to have its resistance reduced when acted upon by the effects or disturbances, and included in the secondary circuit of the transformer, as set forth.

9. In an apparatus for utilizing effects or disturbances transmitted from a distant source, the combination with a storage device and an independent source of energy for charging the same, of a receiving-circuit connected with the storage device, a device sensitive to the effects or disturbances and determining under their control the flow of current in the receiving-circuit, substantially as set forth.

10. In an apparatus for utilizing effects or disturbances transmitted through the natural media from a distant source, the combination with a storage device and an independent source of energy for charging the same, of a receiving-circuit connected with the storage device, a device sensitive to the effects or disturbances and adapted to have its resistance varied by the action thereon of such effects or disturbances and determining under their control the flow of current in the receiving-circuit, substantially as set forth.

11. In an apparatus for utilizing effects or disturbances transmitted from a distant source, the combination of a storage device, a battery or similar independent source of energy for charging the same, a sensitive device adapted to have its resistance varied under the influence of the effects or disturbances, a receiver adapted to be operated by the discharge of the storage device, the sensitive device being in one branch of a Wheatstone bridge, the storage device in one of the cross connections between two opposite points of the bridge, and the battery in the other cross connection, and resistances L, L' and L" in the three remaining branches of the bridge, as set forth.

12. In an apparatus for utilizing effects or disturbances transmitted through the natural media from a distant source, the combination of a storage device, a battery or like independent source of energy for charging the same, a sensitive device adapted to have its resistance varied under the influence of the effects or disturbances, a circuit connected with the terminals of the storage device, a transformer having its primary in said circuit and a receiver in the secondary circuit of the transformer, the sensitive device being in one branch of a Wheatstone bridge, the storage device in one of the cross connections between opposite points of the bridge and the battery in the other cross connection, and resistances L, L' and L" in the three remaining branches of the bridge, as set forth.

NIKOLA TESLA.

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P-326

No. 685,956 Patented Nov. 5, 1901.

N. TESLA.

APPARATUS FOR UTILIZING EFFECTS TRANSMITTED THROUGH NATURAL MEDIA.

(Application filed Nov 2, 1899. Renewed May 29, 1901.)

(No Model.)

Fig 1

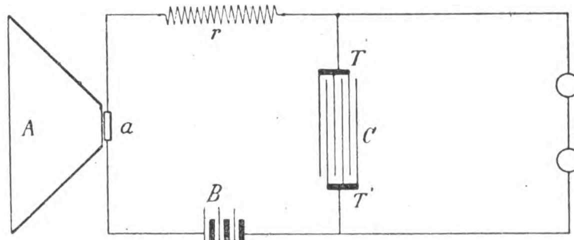


Fig 2

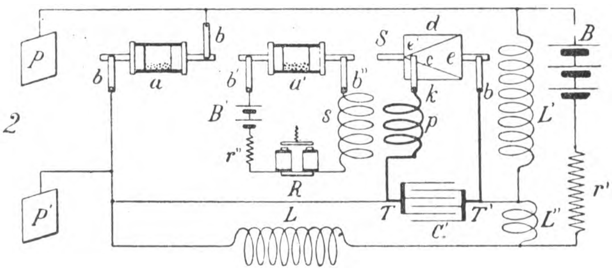


Fig 3

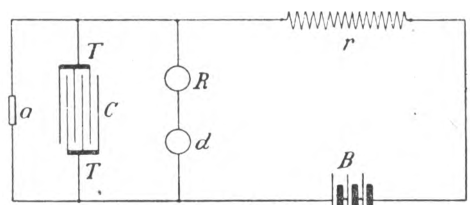


Fig 4

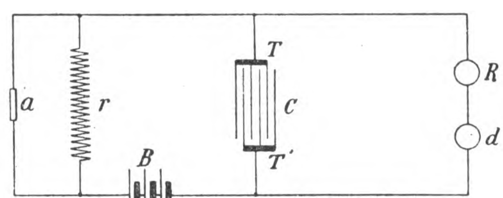
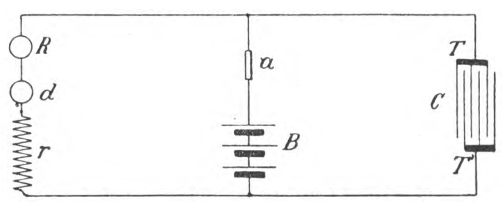


Fig 5



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UNITED STATES PATENT OFFICE

NIKOLA TESLA, OF NEW YORK, N. Y.

MEANS FOR INCREASING THE INTENSITY OF ELECTRICAL OSCILLATIONS.

SPECIFICATION forming part of Letters Patent No. 685,012, dated October 22, 1901.

Application filed March 21, 1900. Renewed July 3, 1901. Serial No. 66,980. (No model.)

To all whom it may concern:

Be it known that I, NIKOLA TESLA, a citizen of the United States, residing at the borough of Manhattan, in the city, county, and State of New York, have invented certain new and useful Improvements in Means for Increasing the Intensity of Electrical Oscillations, of which the following is a specification, reference being had to the drawings accompanying and forming part of the same.

In many scientific and practical uses of electrical impulses or oscillations—as, for example, in systems of transmitting intelligence to distant points—it is of great importance to intensify as much as possible the current impulses or vibrations which are produced in the circuits of the transmitting and receiving instruments, particularly of the latter.

It is well known that when electrical impulses are impressed upon a circuit adapted to oscillate freely the intensity of the oscillations developed in the same is dependent on the magnitude of its physical constants and the relation of the periods of the impressed and of the free oscillations. For the attainment of the best result it is necessary that the periods of the impressed should be the same as that of the free oscillations, under which conditions the intensity of the latter is greatest and chiefly dependent on the inductance and resistance of the circuit, being directly proportionate to the former and inversely to the latter. In order, therefore, to intensify the impulses or oscillations excited in the circuit—in other words, to produce the greatest rise of current or electrical pressure in the same—it is desirable to make its inductance as large and its resistance as small as practicable. Having this end in view I have devised and used conductors of special forms and of relatively very large cross-section; but I have found that limitations exist in regard to the increase of the inductance as well as to the diminution of the resistance. This will be understood when it is borne in mind that the resonant rise of current or pressure in a freely-oscillating circuit is proportionate to the frequency of the impulses and that a large inductance in general involves a slow vibration. On the other hand, an increase of the section of the conductor with the object of reducing its resistance is, beyond a certain limit, of little or no value, principally because electrical oscillations, particularly those of high frequency, pass mainly through the superficial conducting layers, and while it is true that this drawback may be overcome in a measure by the employment of thin ribbons, tubes, or stranded cables, yet in practice other disadvantages arise, which often more than offset the gain.

It is a well-established fact that as the temperature of a metallic conductor rises its electrical resistance increases, and in recognition of this constructors of commercial electrical apparatus have heretofore resorted to many expedients for preventing the coils and other parts of the same from becoming heated when in use, but merely with a view to economizing energy and reducing the cost of construction and operation of the apparatus.

Now I have discovered that when a circuit adapted to vibrate freely is maintained at a low temperature the oscillations excited in the same are to an extraordinary degree magnified and prolonged, and I am thus enabled to produce many valuable results which have heretofore been wholly impracticable.

Briefly stated, then, my invention consists in producing a great increase in the intensity and duration of the oscillations excited in a freely-vibrating or resonating circuit by maintaining the same at a low temperature.

Ordinarily in commercial apparatus such provision is made only with the object of preventing wasteful heating, and in any event its influence upon the intensity of the oscillations is very slight and practically negligible, for as a rule impulses of arbitrary frequency are impressed upon a circuit, irrespective of its own free vibrations, and a resonant rise is expressly avoided.

My invention, it will be understood, does not primarily contemplate the saving of energy, but aims at the attainment of a distinctly novel and valuable result—that is, the increase to the greatest practicable degree of the intensity and duration of free oscillations. It may be usefully applied in all cases when this special object is sought, but offers exceptional advantages in those instances in which the freely-oscillating discharges of a condenser are utilized.

The best and most convenient manner of

carrying out the invention of which I am now aware is to surround the freely-vibrating circuit or conductor, which is to be maintained at a low temperature, with a suitable cooling medium, which may be any kind of freezing mixture or agent, such as liquid air, and in order to derive the fullest benefit from the improvement the circuit should be primarily constructed so as to have the greatest possible self-induction and the smallest practicable resistance, and other rules of construction which are now recognized should be observed. For example, when in a system of transmission of energy for any purpose through the natural media the transmitting and receiving conductors are connected to earth and to an insulated terminal, respectively, the lengths of these conductors should be one-quarter of the wave length of the disturbance propagated through them.

In the accompanying drawing I have shown graphically a disposition of apparatus which may be used in applying practically my invention.

The drawing illustrates in perspective two devices, either of which maybe the transmitter, while the other is the receiver. In each there is a coil of few turns and low resistance, (designated in one by A and in the other by A'.) The former coil, supposed to be forming part of the transmitter, is to be connected with a suitable source of current, while the latter is to be included in circuit with a receiving device. In inductive relation to said coils in each instrument is a flat spirally-wound coil B or B', one terminal of which is shown as connected to a ground-plate C, while the other, leading from the center, is adapted to be connected to an insulated terminal, which is generally maintained at an elevation in the air. The coils B B' are placed in insulating-receptacles D, which contain the freezing agent and around which the coils A and A' are wound.

Coils in the form of a flat spiral, such as those described, are eminently suited for the production of free oscillations; but obviously conductors or circuits of any other form may be used, if desired.

From the foregoing the operation of the apparatus will now be readily understood. Assume, first, as the simplest case that upon the coil A of the transmitter impulses or oscillations of an arbitrary frequency and irrespective of its own free vibrations are impressed. Corresponding oscillations will then be induced in the circuit B, which, being constructed and adjusted, as before indicated, so as to vibrate at the same rate, will greatly magnify them, the increase being directly proportionate to the product of the frequency of the oscillations and the inductance of circuit B and inversely to the resistance of the latter. Other conditions remaining the same, the intensity of the oscillations in the resonating-circuit B will be increased in the same proportion as its resistance is reduced. Very often, however, the conditions may be such that the gain sought is not realized directly by diminishing the resistance of the circuit. In such cases the skilled expert who applies the invention will turn to advantage the reduction of resistance by using a correspondingly longer conductor, thus securing a much greater self-induction, and under all circumstances he will determine the dimensions of the circuit, so as to get the greatest value of the ratio of its inductance to its resistance, which determines the intensity of the free oscillations. The vibrations of coil B, greatly strengthened, spread to a distance and on reaching the tuned receiving-conductor B' excite corresponding oscillations in the same, which for similar reasons are intensified, with the result of inducing correspondingly stronger currents or oscillations in circuit A', including the receiving device. When, as may be the case in the transmission of intelligible signals, the circuit A is periodically closed and opened, the effect upon the receiver is heightened in the manner above described not only because the impulses in the coils B and B' are strengthened, but also on account of their persistence through a longer interval of time. The advantages offered by the invention are still more fully realized when the circuit A of the transmitter instead of having impulses of an arbitrary frequency impressed upon it is itself permitted to vibrate at its own rate, and more particularly so if it be energized by the freely-oscillating high-frequency discharges of a condenser. In such a case the cooling of the conductor A, which may be effected in any suitable manner, results in an extraordinary magnification of the oscillation in the resonating-circuit B, which I attribute to the increased intensity as well as greater number of the high-frequency oscillations obtained in the circuit A. The receiving-coil B' is energized stronger in proportion and induces currents of greater intensity in the circuit A'. It is evident from the above that the greater the number of the freely-vibrating circuits which alternately receive and transmit energy from one to another the greater, relatively, will be the gain secured by applying my invention.

I do not of course intend to limit myself to the specific manner and means described of artificial cooling, nor to the particular forms and arrangements of the circuits shown. By taking advantage of the facts above pointed out and of the means described I have found it possible to secure a rise of electrical pressure in an excited circuit very many times greater than has heretofore been obtainable, and this result makes it practicable, among other things, to greatly extend the distance of transmission of signals and to exclude much more effectively interference with the same than has been possible heretofore.

Having now described my invention, what I claim is—

1. The combination with a circuit adapted

to vibrate freely, of means for artificially cooling the same to a low temperature, as herein set forth.

2. In an apparatus for transmitting or receiving electrical impulses or oscillations, the combination with a primary and a secondary circuit, adapted to vibrate freely in response to the impressed oscillations, of means for artificially cooling the same to a low temperature, as herein set forth.

3. In a system for the transmission of electrical energy, a circuit upon which electrical oscillations are impressed, and which is adapted to vibrate freely, in combination with a receptacle containing an artificial refrigerant in which said circuit is immersed, as herein set forth.

4. The means of increasing the intensity of the electrical impulses or oscillations impressed upon a freely-vibrating circuit, consisting of an artificial refrigerant combined with and applied to such circuit and adapted to maintain the same at a low temperature.

5. The means of intensifying and prolonging the electrical oscillations produced in a freely-vibrating circuit, consisting of an artificial refrigerant applied to such circuit and adapted to maintain the same at a uniformly-low temperature.

6. In a system for the transmission of energy, a series of transmitting and receiving circuits adapted to vibrate freely, in combination with means for artificially maintaining the same at a low temperature, as set forth.

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JOHN C. KERR,
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P-330

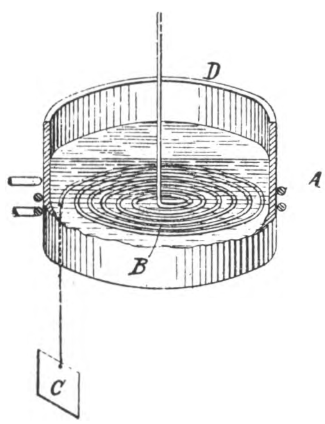
No. 685,012 Patented Oct. 22. 1901

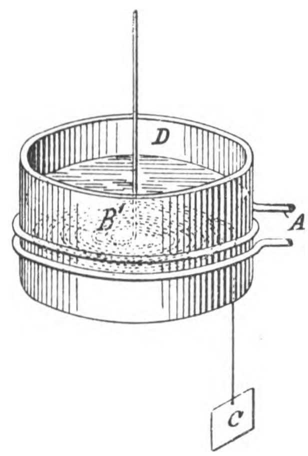
N. TESLA.

MEANS FOR INCREASING THE INTENSITY OF ELECTRICAL OSCILLATIONS.

(Application filed Mar. 21, 1900. Renewed July 3, 1901.)

(No Model.)





Witnesses:
Raphaël Netter
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Nikola Tesla, Inventor
by Kerr, Page & Cooper Att'y

No. 787,412. Patented April 18, 1905.

UNITED STATES PATENT OFFICE.

NIKOLA TESLA, OF NEW YORK, N. Y.

ART OF TRANSMITTING ELECTRICAL ENERGY THROUGH THE NATURAL MEDIUMS.

SPECIFICATION forming part of Letters Patent No. 787,412, dated April 18, 1905.

Application filed May 16, 1900. Renewed June 17, 1902. Serial No. 112,034.

To all whom it may concern:

Be it known that I, NIKOLA TESLA, a citizen of the United States, residing in the borough of Manhattan, in the city, county, and State of New York, have discovered a new and useful Improvement in the Art of Transmitting Electrical Energy Through the Natural Media, of which the following is a specification, reference being had to the drawings accompanying and forming a part of the same.

It is known since a long time that electric currents may be propagated through the earth, and this knowledge has been utilized in many ways in the transmission of signals and the operation of a variety of receiving devices remote from the source of energy, mainly with the object of dispensing with a return conducting-wire. It is also known that electrical disturbances may be transmitted through portions of the earth by grounding only one of the poles of the source, and this fact I have made use of in systems which I have devised for the purposes of transmitting through the natural media intelligible signals or power and which are now familiar; but all experiments and observations heretofore made have tended to confirm the opinion held by the majority of scientific men that the earth, owing to its immense extent, although possessing conducting properties, does not behave in the manner of a conductor of limited dimensions with respect to the disturbances produced, but, on the contrary, much like a vast reservoir or ocean, which while it may be locally disturbed by a commotion of some kind remains unresponsive and quiescent in a large part or as a whole. Still another fact now of common knowledge is that when electrical waves or oscillations are impressed upon such a conducting-path as a metallic wire reflection takes place under certain conditions from the ends of the wire, and in consequence of the interference of the impressed and reflected oscillations the phenomenon of "stationary waves" with maxima and minima in definite fixed positions is produced. In any case the existence of these waves indicates that some of the outgoing waves have reached the boundaries of the conducting-path and have been reflected from the same. Now I have discovered that notwithstanding its vast dimensions and contrary to all observations heretofore made the terrestrial globe may in a large part or as a whole behave to want disturbances impressed upon it in the same manner as a conductor of limited size, this fact being demonstrated by novel phenomena, which I shall hereinafter describe.

In the course of certain investigations which I carried on for the purpose of studying the effects of lightning discharges upon the electrical condition of the earth I observed that sensitive receiving instruments arranged so as to be capable of responding to electrical disturbances created by the discharges at times failed to respond when they should have done so, and upon inquiring into the causes of this unexpected behavior I discovered it to be due to the character of the electrical waves which were produced in the earth by the lightning discharges and which had nodal regions following at definite distances the shifting source of the disturbances. From data obtained in a large number of observations of the maxima and minima of these waves I found their length to vary approximately from twenty-live, to seventy kilometers, and these results and certain theoretical deductions led me to the conclusion that waves of this kind may be propagated in all directions over the globe and that they may be of still more widely differing lengths, the extreme limits being imposed by the physical dimensions and properties of the earth. Recognizing in the existence of these waves an unmistakable evidence that the disturbances created had been conducted from their origin to the most remote portions of the globe and had been thence reflected, I conceived the idea of producing such waves in the earth by artificial means with the object of utilizing them for many useful purposes for which they are or might be found applicable. This problem was rendered extremely difficult owing to the immense dimensions of the planet, and consequently enormous movement of electricity or rate at which electrical energy had to be delivered in order to approximate, even in a remote degree, movements or rates which are manifestly attained in the displays of electrical forces in nature and which seemed at first unrealizable by any human agencies; but by gradual and continuous improvements of a generator of electrical oscillations, which I have described in my Patents Nos. 645,576 and 649,621, I finally succeeded in reaching electrical movements or rates of delivery of electrical energy not only approximating, but, as shown in many comparative tests and measurements, actually surpassing those of lightning discharges, and by means of this apparatus I have found it possible to reproduce whenever desired phenomena in the earth the same as or similar to those due to such discharges. With the knowledge of the phenomena discovered by me and the means at command for accomplishing these results I am enabled not only to carry out many operations by the use of known instruments, but also to offer a solution for many important problems involving the operation or control of remote devices which for want of this knowledge and the absence of these means have heretofore been entirely impossible. For example, by the use of such a generator of stationary waves and receiving apparatus properly placed and adjusted in any other locality, however remote, it is practicable to transmit intelligible signals or to control or actuate at will any one or all of such apparatus for many other important and valuable purposes, as for indicating wherever desired the correct time of an observatory or for ascertaining the relative position of a body or distance of the same with reference to a given point or for determining the course of a moving object, such as a vessel at sea, the distance traversed by the same or its speed, or for producing many other useful effects at a distance dependent on the intensity, wave length, direction or velocity of movement, or other feature or property of disturbances of this character.

I shall typically illustrate the manner of applying my discovery by describing one of the specific uses of the same—namely, the transmission of intelligible signals or messages between distant points—and with this object reference is now made to the accompanying drawings, in which—

Figure 1 represents diagrammatically the generator which produces stationary waves in the earth, and Fig. 2 an apparatus situated in a remote locality for recording the effects of these waves.

In Fig. 1, A designates a primary coil forming part of a transformer and consisting generally of a few turns of a stout cable of inappreciable resistance, the ends of which are connected to the terminals of a source of powerful electrical oscillations, diagrammatically represented by B. This source is usually a condenser charged to a high potential and discharged in rapid succession through the primary, as in a type of transformer invented by me and not well known; but when it is desired to produce stationary waves of great lengths an alternating dynamo of suitable construction may be used to energize the primary A. C is a spirally-wound secondary coil within the primary having the end nearer to the latter connected to the ground E' and the other end to an elevated terminal E. The physical constants of coil C, determining its period of vibration, are so chosen and adjusted that the secondary system E' C E is in the closest possible resonance with the oscillations impressed upon it by the primary A. It is, moreover, of the greatest importance in order to still further enhance the rise of pressure and to increase the electrical movement in the secondary system that its resistance be as small as practicable and its self-induction as large as possible under the conditions imposed. The ground should be made with great care, with the object of reducing its resistance. Instead of being directly grounded, as indicated, the coil C may be joined in series or otherwise to the primary A, in which case the latter will be connected to the plate E'; but be it that none or a part or all of the primary or exciting turns are included in the coil C the total length of the conductor from the ground-plate E' to the elevated terminal E should be equal to one-quarter of the wave length of the electrical disturbance in the system E' C E or else equal to that length multiplied by an odd number. This relation being observed, the terminal E will be made to coincide with the points of maximum pressure in the secondary or excited circuit, and the greatest flow of electricity will take place in the same. In order to magnify the electrical movement in the secondary as much as possible, it is essential that its inductive connection with the primary A should not be very intimate, as in ordinary transformers, but loose, so as to permit free oscillation—that is to say, their mutual induction should be small. The spiral form of coil C secures this advantage, while the turns near the primary A are subjected to a strong inductive action and develop a high initial electromotive force. These adjustments and relations being carefully completed and other constructive features indicated rigorously observed, the electrical movement produced in the secondary system by the inductive action of the primary A will be enormously magnified, the increase being directly proportionate to the inductance and frequency and inversely to the resistance of the secondary system. I have found it practicable to produce in this manner an electrical movement thousands of times greater than the initial—that is, the one impressed upon the secondary by the primary A—and I have thus reached activities or rates of flow of electrical energy in the system E' C E measured by many tens of thousands of horse-power. Such immense movements of electricity give rise to a variety of novel and striking phenomena, among which are those already described. The powerful electrical oscillations in the system E' C E being communicated to the ground cause corresponding vibrations to be propagated to distant parts of, the globe, whence they are reflected and by interference with the outgoing vibrations produce stationary waves the crests and hollows of which lie in parallel circles relatively to which the ground-plate E' may be, considered to be the pole. Stated otherwise, the terrestrial conductor is thrown into resonance with the oscillations impressed upon it just like a wire. More than this, a number of facts ascertained by me clearly show that the movement of electricity through it follows certain laws with nearly mathematical rigor. For the present it will be sufficient to state that the planet behaves like a perfectly smooth or polished conductor of inappreciable resistance with capacity and self induction uniformly distributed along the axis of symmetry of wave propagation and transmitting slow electrical oscillations without sensible distortion and attenuation.

Besides the above three requirements seem to be essential to the establishment of the resonating condition.

First. The earth's diameter passing through the pole should be an odd multiple of the quarter wave length—that is, of the ratio between the velocity of light—and four times the frequency of the currents.

Second. It is necessary to employ oscillations in which the rate of radiation of energy into space in the form of Hertzian or electromagnetic waves is very small. To give an idea, I would say that the frequency should be smaller than twenty thousand per second, though shorter waves might be practicable. The lowest frequency would appear to be six per second, in which case there will be but one node, at or near the ground-plate, and, paradoxical as it may seem, the effect will increase with the distance and will be greatest in a region diametrically opposite the transmitter. With oscillations still slower the earth, strictly speaking, will not resonate, but simply act as a capacity, and the variation of potential will be more or less uniform over its entire surface.

Third. The most essential requirement is, however, that irrespective of frequency the wave or wave-train should continue for a certain interval of time, which I have estimated to be not less than one-twelfth or probably 0.08484 of a second and which is taken in passing to and returning from the region diametrically opposite the pole over the earth's surface with a mean velocity of about four hundred and seventy-one thousand two hundred and forty kilometers per second.

The presence of the stationary waves may be detected in many ways. For instance, a circuit may be connected directly or inductively to the ground and to an elevated terminal and tuned to respond more effectively to the oscillations. Another way is to connect a tuned circuit to the ground at two points lying more or less in a meridian passing through the pole E' or, generally stated, to any two points of a different potential.

In Fig. 2 I have shown a device for detecting the presence of the waves such as I have used in a novel method of magnifying feeble effects which I have described in my Patents Nos. 685,953 and 685,955. It consists of a cylinder D, of insulating material, which is moved at a uniform rate of speed by clockwork or other suitable motive power and is provided with two metal rings F F', upon which bear brushes *a* and *a'*, connected, respectively, to the terminal plates P and P'. From the rings F F' extend narrow metallic segments *s* and *s'* which by the rotation of the cylinder D are brought alternately into contact with double brushes *b* and *b'*, carried by and in contact with conducting-holders *h* and *h'*, supported in metallic bearings G and G', as shown. The latter are connected to the terminals T and T' of a condenser H, and it should be understood that they are capable of angular displacement as ordinary brush-supports. The object of using two brushes, as *b* and *b'*, in each of the holders *h* and *h'* is to vary at will the duration of the electric contact of the plates P and P' with the terminals T and T', to which is connected a receiving-circuit including a receiver R and a device *d*, performing the duty of closing the receiving-circuit at predetermined intervals of time and discharging the stored energy through the receiver. In the present case this device consists of a cylinder made partly of conducting and partly of insulating material *e* and *e'* respectively, which is rotated at the desired rate of speed by any suitable means. The conducting part *e* is in good electrical connection with the shaft S and is provided with tapering segments *f f*, upon which slides a brush *k*, supported on a conducting-rod *l*, capable of longitudinal adjustment in a metallic support *m*. Another brush, *n*, is arranged to bear upon the shaft S, and it will be seen that whenever one of the segments *f* comes in contact with the brush *k* the circuit including the receiver R is completed and the condenser discharged through the same. By an adjustment of the speed or rotation of the cylinder *d* and a displacement of the brush *k* along the cylinder the circuit may be made to open and close in as rapid succession and remain open or closed during such intervals of time as may, be desired. The plates P and P', through which the electrical energy is conveyed to the brushes *a* and *a'*, may be at a considerable distance from each other in the ground or one in the ground and the other in the air, preferably at some height. If but one plate is connected to earth and the other maintained at an elevation, the location of the apparatus must be determined with reference to the position of the stationary waves established by the generator, the effect evidently being greatest in a maximum and zero in a nodal region. On the other hand, if both plates be connected to earth the points of connection must be selected with reference to the difference of potential which it is desired to secure, the strongest effect being of course obtained when the plates are at a distance equal to half the wave length.

In illustration of the operation of the system let it be assumed that alternating electrical impulses from the generator are caused to produce stationary waves in the earth, as above described, and that the receiving apparatus is properly located with reference to the position of the nodal and ventral regions of the waves. The speed of rotation of the cylinder D is varied until it is made to turn in synchronism with the alternate impulses of the generator, and the position of the brushes *b* and *b'* is adjusted by angular displacement or otherwise, so that they are in contact with the segments S and S' during the periods when the impulses are at or near the maximum of their intensity. These requirements being fulfilled, electrical charges of the same sign will be conveyed to each of the terminals of the condenser, and with each fresh impulse it will be charged to a higher potential. The speed of rotation of the cylinder *d* being adjustable at will, the energy of any number of separate impulses may thus be accumulated in potential form and discharged through the receiver R upon the brush *k* coming in contact with one of the segments *f'*. It will be understood that the capacity of the condenser should be such as to allow the storing of a much greater amount of energy than is required for the ordinary operation of the receiver. Since by this method a relatively great amount of energy and in a suitable form may be made available for the operation of a receiver, the latter need not be very sensitive; but when the. impulses are very weak or when it is desired to operate a receiver very rapidly any of the well-known sensitive devices capable of responding to very feeble influences may be used in the manner indicated or in other ways. Under the conditions described it is evident that during the continuance of the stationary waves the receiver will be acted upon by current impulses more or less intense, according to its location with reference to the maxima and minima of said waves; but upon interrupting or reducing the flow of the current the stationary waves will disappear or diminish in intensity. Hence a great variety of effects may be produced in a receiver, according to the mode in which the waves are controlled. It is practicable, however, to shift the nodal and ventral regions of the waves at will from the sending-station, as by varying the length of the waves under observance of the above requirements. In this manner the regions of maximum and minimum effect may be made to coincide with any receiving station or stations. By impressing upon the earth two or more oscillations of different wave length a resultant stationary wave may be made to travel slowly over the globe, and thus a great variety of useful effects may be produced. Evidently the course of a vessel may be easily determined without the use of a compass, as by a circuit connected to the earth at two points, for the effect exerted upon the circuit will be greatest when the plates P P' are lying on a meridian passing through ground-plate E' and will be *nil* when the plates are located at a parallel circle. If the nodal and ventral regions are maintained in fixed positions, the speed of a vessel carrying a receiving apparatus may be exactly computed from observations of the maxima and minima regions successively traversed. This will be understood when it is stated that the projections of all the nodes and loops on the earth's diameter passing through the pole or axis of symmetry of the wave movement are all equal. Hence in any region at the surface the wave length can be ascertained from simple rules of geometry. Conversely, knowing the wave length, the distance from the source can be readily calculated. In like ways the distance of one point from another, the latitude and longitude, the hour, &c., may be determined from the observation of such stationary waves. If several such generators of stationary waves, preferably of different length, were installed in judiciously-selected localities, the entire globe could be subdivided in definite zones of electric activity, and such and other important data could be at once obtained by simple calculation or readings from suitably-graduated instruments. Many other useful applications of my discovery will suggest themselves, and in this respect I do not wish to limit myself. Thus the specific plan herein described of producing the stationary waves might be departed from. For example, the circuit which impresses the powerful oscillations upon the earth might be connected to the latter at two points. In this application I have advanced various improvements in means and methods of producing and utilizing electrical effects which either in connection with my present discovery or independently of the same may be usefully applied.

I desire it to be understood that such novel features as are not herein specifically claimed will form the subjects of subsequent applications.

What I now claim is—

1. The improvement in the art of transmitting electrical energy to a distance which consists in establishing stationary electrical waves in the earth, as set forth.

2. The improvement in the art of transmit-

ting electrical energy to a distance which consists in impressing upon the earth electrical oscillations of such character as to produce stationary electrical waves therein, as set forth.

3. The improvement in the art of transmitting and utilizing electrical energy which consists in establishing stationary electrical waves in the natural conducting media, and operating thereby one or more receiving devices remote from the source of energy, as set forth.

4. The improvement in the art of transmitting and utilizing electrical energy which consists in establishing in the natural conducting media, stationary electrical waves of predetermined length and operating thereby one or more receiving devices remote from the source of energy and properly located with respect to the position of such waves, as herein set forth.

5. The improvement in the art of transmitting and utilizing electrical energy, which consists in establishing in the natural conducting media, stationary electrical waves, and varying the length of such waves, as herein set forth.

6. The improvement in the art of transmitting and utilizing electrical energy, which consists in establishing in the natural conducting media stationary electrical waves and shifting the nodal and ventral regions of these waves, as described.

NIKOLA TESLA.

Witnesses:

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BENJAMIN MILLER

P-336

No. 787,412. PATENTED APR. 18, 1905.

N. TESLA.

ART OF TRANSMITTING ELECTRICAL ENERGY THROUGH THE NATURAL MEDIUMS.

APPLICATION FILED MAY 16, 1900. RENEWED JUNE 17, 1902.

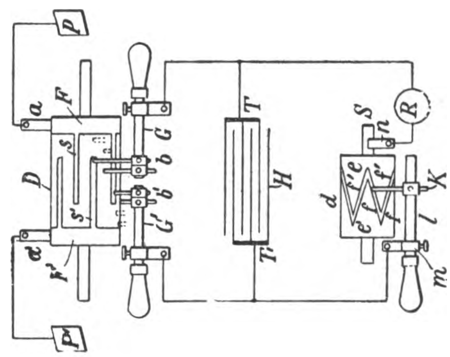

Fig. 2

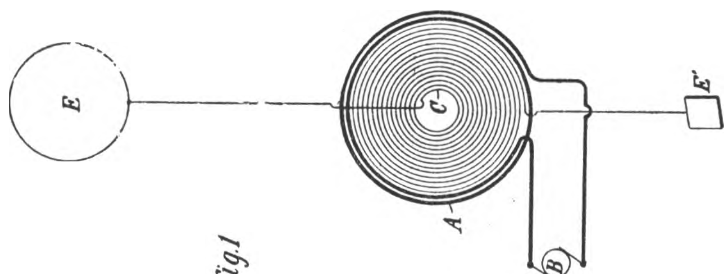

Fig. 1

Witnesses:
Raphaël Netter
M. Lawson Dyer.

Nikola Tesla Inventor
by Ker, Page & Cooper Attys

UNITED STATES PATENT OFFICE

NIKOLA TESLA. OF NEW YORK, N. Y.

SYSTEM OF SIGNALING.

SPECIFICATION forming part of Letters Patent No. 725,605, dated April 14, 1903.

Application filed July 16, 1900. Serial No. 23,847. (No model.)

To all whom it may concern:

Be it known that I, NIKOLA TESLA, a citizen of the United States, residing in the borough of Manhattan, in the city, county, and State of New York, have invented certain new and useful Improvements in Systems of Signaling, of which the following is a specification, reference being had to the drawings accompanying and forming a part of the same.

In certain systems for transmitting intelligible messages or governing the movements and operations of distant automata electrical impulses or disturbances produced by suitable apparatus are conveyed through the natural media to a distant receiving-circuit capable of responding to the impulses, and thereby effecting the control of other appliances. Generally a special device highly sensitive is connected to the receiving-circuit, which in order to render it still more susceptible and to reduce the liability of its being affected by extraneous disturbances is carefully adjusted so as to be in tune with the transmitter. By a scientific design of the sending and receiving circuits and other apparatus and skilful adjustment of the same these objects may be in a measure attained; but in long experience I have found that notwithstanding all constructive advantages and experimental resources this method is in many cases inadequate. Thus while I have succeeded in so operating selectively under certain favorable conditions more than one hundred receivers in most cases it is practicable to work successfully but a few, the number rapidly diminishing as, either owing to great distance or other causes, the energy available in the tuned circuits becomes smaller and the receivers necessarily more delicate. Evidently a circuit however well constructed and adjusted to respond exclusively to vibrations of one period is apt to be affected by higher harmonics and still more so by lower ones. When the oscillations are of a very high frequency, the number of the effective harmonics may be large, and the receiver consequently easily disturbed by extraneous influences to such an extent that when very short waves, such as those produced by Hertzian spark apparatus, are used little advantage in this respect is derived from tuning the circuits. It being an imperative requirement in most practical applications of such systems of signaling or intelligence transmission that the signals or messages should be exclusive or private, it is highly desirable to do away with the above limitations, especially in view of the fact, which I have observed, that the influence of powerful electrical disturbances upon sensitive receivers extends, even on land, to distances of many hundreds of miles, and consequently in accordance with theory still farther on sea. To overcome these drawbacks and to enable a great number of transmitting and receiving stations to be operated selectively and exclusively and without any danger of the signals or messages being disturbed, intercepted, or interfered with in any way is the object of my present invention.

Broadly stated, this invention consists in the combination of means for generating and transmitting two or more kinds or classes of disturbances or impulses of distinctive character with respect to their effect upon a receiving-circuit and a distant receiver which comprises two or more circuits of different electrical character or severally tuned, so as to be responsive to the different kinds or classes of impulses and which is dependent for operation upon the conjoint or resultant action of the two or more circuits or the several instrumentalities controlled or operated thereby. By employing only two kinds of disturbances or series of impulses instead of one, as has heretofore been done to operate a receiver of this kind, I have found that safety against the disturbing influences of other sources is increased to such an extent that I believe this number to be amply sufficient in most eases for rendering the exchange of signals or messages reliable and exclusive; but in exceptional instances a greater number may be used and a degree of safety against mutual and extraneous interference attained, such as is comparable to that afforded by a combination-lock. The liability of a receiver being affected by disturbances emanating from other sources, as well as that of the signals or messages being received by instruments for which they are not intended, may, however, be reduced not only by an increased number of the cooperative disturbances or series of impulses, but also by a judicious choice of the same and the order in which they are made to act upon the receiver.

Evidently there are a great many ways of generating impulses or disturbances of any wave length, wave form, number or order of succession, or of any special character such as will be capable of fulfilling the requirements above stated, and there are also many ways in which such impulses or disturbances may be made to cooperate and to cause the receiver to be actuated, and inasmuch as the skill and practical knowledge in these novel fields can only be acquired by long experience the degree of safety and perfection attained will necessarily depend upon the ability and resource of the expert who applies my invention; but in order to enable the same to be successfully practiced by any person possessed only of the more general knowledge and experience in these branches I shall describe the simplest plan of carrying it out which is at present known to me.

For a better understanding of the subject reference is now made to the accompanying drawings, in which—

Figures 1 and 2 represent diagrammatically the apparatus and circuit connections employed at the sending and receiving stations, respectively; and Figs. 3, 4, and 5 modified means which may be employed in the practical application of the invention.

In Fig. 1, S' and S^2 are two spirally-wound coils or conductors connected with their inner ends to elevated terminals D' and D^2, respectively, and with their outer ends to an earth-plate E. These two-coils, conductors, or systems D' S' E and D^2 S^2 E have different and suitably-chosen periods of vibration, and, as pointed out in other patents relating to my system of energy and intelligence transmission, their lengths should be such that the points of maximum pressure developed therein coincide with the elevated terminals D' D^2. The two systems may have electrical oscillations impressed upon them in any desired manner, conveniently by energizing them through primaries P' and P^2, placed in proximity to them. Adjustable inductances L' and L^2 are preferably included in the primary circuits chiefly for the purpose of regulating the rates of the primary oscillations. In the drawings these primaries P' and P^2 surround the coils S' S^2 and are joined in series through the inductances L' L^2, conductor F, condensers C' and C^2, brush-holders B' and B^2, and a toothed disk D, which is connected to the conductor F and, if desired, also to the ground-plate E, as shown, two independent primary circuits being thus formed. The condensers C' and C^2 are of such capacity and the inductances L' and L^2 are so adjusted that each primary is in close resonance with its secondary system, as I have explained in other patents granted to me. The brush-holders B' and B^2 are capable independently of angular and, if necessary, also of lateral adjustment, so that any desired order of succession or any difference of time interval between the discharges occurring in the two primary circuits may be obtained. The condensers being energized from a suitable source S, preferably of high potential, and the disk D being rotated, its projections or teeth *p p*, coming at periodically-recurring intervals in very close proximity to or, as the case may be, in contact with conducting rods or brushes *n n*, cause the condensers to be discharged in rapid succession through their respective circuits. In this matter the two secondary systems D' S' E and D^2 S^2 E are set in vibration and oscillate freely, each at its proper rate, for a certain period of time at every discharge. The two vibrations are impressed upon the ground through the plate E and spread to a distance reaching the receiving-station, which has two similar circuits or systems *e s' d'* and $e\ s^2\ d^2$ arranged and connected in the same manner and tuned to the systems at the sending-station, so that each responds exclusively to one of the two vibrations produced by the transmitting apparatus. The same rules of adjustment are observed with respect to the receiving-circuits, care being, furthermore, taken that the tuning is effected when all the apparatus is connected to the circuits and placed in position, as any change may more or less modify the vibration. Each of the receiving-coils *s'* and s^2 is shunted by a local circuit containing, respectively, sensitive devices *a'* a^2, batteries *b'* b^2, adjustable resistances *r'* r^2, and sensitive relays R' R^2, all joined in series, as shown. The precise connections and arrangements of the various receiving instruments are largely immaterial and may be varied in many ways. The sensitive devices *a'* a^2 may be any of the well-known devices of this kind—as, for example, two conducting-terminals separated by a minute air-gap or a thin film of dielectric which is strained or weakened by a battery or other means to the point of breaking down and gives way to the slightest disturbing influence. Its return to the normal sensitive state may be secured by momentarily interrupting the battery-circuit after each operation or otherwise. The relays R' R^2 have armatures $l\ l^2$, which are connected by a wire *w* and when attracted establish electrical contacts at *c'* and c^2, thus closing a circuit containing a battery b^3, an adjustable resistance r^3, and a relay R^3.

From the above description it will be readily seen that the relay R^3 will be operated only when both contacts *c'* and c^2 are closed.

The apparatus at the sending-station may be controlled in any suitable manner—as, for instance, by momentarily closing the circuit of the source S, two different electric vibrations being emitted simultaneously or in rapid succession, as may be desired, at each closure of the circuit. The two receiving-circuits at the distant station, each tuned to respond to the vibrations produced by one of the elements of the transmitter, affect the sensitive devices *a'* and a^2 and cause the relays R' and R^2 to be operated and contacts *c'* and c^2 to be closed, thus actuating the receiver or relay R^3, which in turn establishes a contact c^3 and brings into action a device a^3 by means of a battery d^4, included in a local circuit, as shown; but evidently if through any extraneous disturbance only one of the circuits at the receiving-station is affected the relay R^3 will fail to respond. In this way communication may be carried on with greatly-increased safety against interference and privacy of the messages may be secured. The receiving-station (shown in Fig. 2) is supposed to be one requiring no return message; but if the use of the system is such that this is necessary then the two stations will be similarly equipped and any well-known means, which it is not thought necessary to illustrate here, may be resorted to for enabling the apparatus at each station to be used in turn as transmitter and receiver. In like manner the operation of a receiver, as R^3, may be made dependent, instead of upon two, upon more than two such transmitting systems or circuits, and thus any desired degree of exclusiveness or privacy and safety against extraneous disturbances may be attained. The apparatus as illustrated in Figs. 1 and 2 permits, however, special results to be secured by the adjustment of the order of succession of the discharge of the primary circuits P' and P^2 or of the time interval between such discharges. To illustrate, the action of the relays R' R^2 may be regulated either by adjusting the weights of the levers *l'* l^2, or the strength of the batteries *b'* b^2, or the resistances *r'* r^2, or in other well-known ways, so that when a certain order of succession or time interval between the discharges of the primary circuits P' and P^2 exists at the sending-station the levers *l'* and l^2 will close the contacts *c'* and c^2 at the same instant, and thus operate the relay R^3; but it will fail to produce this result when the order of succession of or the time interval between the discharges in the primary circuits is another one. By these or similar means additional safety against disturbances from other sources may be attained and, on the other hand, the possibility afforded of effecting the operation of signaling by varying the order of succession of the discharges of the two circuits. Instead of closing and opening the circuit of the source S, as before indicated, for the purpose of sending distinct signals it may be convenient to merely alter the period of either of the transmitting-circuits arbitrarily, as by varying the inductance of the primaries.

Obviously there is no necessity for using transmitters with two or more distinct elements or circuits, as S' and S^2, since a succession of waves or impulses of different characteristics may be produced by an instrument having but one such circuit. A few of the many ways which will readily suggest themselves to the expert who applies my invention are illustrated in Figs. 3, 4, and 5. In Fig. 3 a transmitting system *e* s^3 d^3 is partly shunted by a rotating wheel or disk D^3, which may be similar to that illustrated in Fig. 1 and which cuts out periodically a portion of the coil or conductor s^3 or, if desired, bridges it by an adjustable condenser C^3, thus altering the vibration of the system *e* s^3 d^3 at suitable intervals and causing two distinct kinds or classes of impulses to be emitted in rapid succession by the sender. In Fig. 4 a similar result is produced in the system *e* s^4 d^4 by periodically short-circuiting, through an induction-coil L^3 and a rotating disk D^4 with insulating and conducting segments, a circuit p^4 in inductive relation to said system. Again, in Fig. 5 three distinct vibrations are caused to be emitted by a system *e* s^5 d^5, this result being produced by inserting periodically a suitable number of turns of an induction-coil L^4 in series with the oscillating system by means of a rotating disk B^5 with two projections p^5 p^5 and three rods or brushes n^5, placed at an angle of one hundred and twenty degrees relatively to each other. The three transmitting systems or circuity thus produced may be energized in the same manner as those of Fig. 1 or in any other convenient way. Corresponding to each of these cases the receiving-station may be provided with two or three circuits in an analogous manner to that illustrated in Fig. 2, it being understood, of course, that the different vibrations or disturbances emitted by the sender follow in such rapid succession upon each other that they are practically simultaneous, so far as the operation of such relays as R' and R^2 is concerned. Evidently, however, it is not necessary to employ two or more receiving-circuits; but a single circuit may be used also at the receiving-station constructed and arranged like the transmitting circuits or systems illustrated in Figs. 3, 4, and 5, in which case the corresponding disks, as D^3 D^4 D^5, at the sending will be driven in synchronism with those at the receiving stations as far as may be necessary to secure the desired result; but whatever the nature of the specific devices employed it will be seen that the fundamental idea in my invention is the operation of a receiver by the conjoint or resultant effect of two or more circuits each tuned to respond exclusively to waves, impulses, or vibrations of a certain kind or class produced either simultaneously or successively by a suitable transmitter.

It will be seen from a consideration of the nature of the method hereinbefore described that the invention is applicable not only in the special manner described, in which the transmission of the impulses is effected through natural media, but for the transmission of energy for any purpose and whatever the medium through which the impulses are conveyed.

What I claim is—

1. In a system for the transmission of electrical energy, the combination with means for producing two or more distinctive kinds of disturbances or impulses, of receiving-circuits, each tuned to respond to the waves or impulses of one kind only, and a receiving device dependent for operation upon the conjoint action of the several receiving-circuits, as set forth.

2. In a system for the transmission of electrical impulses and the operation or control, of signaling or other apparatus thereby, the combination with a transmitter adapted to produce two or more distinctive kinds or classes of disturbances or impulses, of sensitive receiving-circuits, each tuned to respond to the impulses or disturbances of one kind or class only, and a receiving device dependent for operation upon the conjoint action of the sensitive circuits, as set forth.

3. In a system for the transmission of electrical impulses, and the operation or control of signaling, or other apparatus thereby, the combination with a transmitter adapted to produce two or more distinctive kinds or classes of disturbances or impulses, of sensitive circuits at the receiving point or station, each tuned to respond to the impulses or disturbances of one kind or class only, a local circuit arranged to be completed by the conjoint action of the sensitive circuits and a receiving device connected therewith, as set forth.

4. In a system for the transmission of electrical impulses, and the operation or control of signaling or other apparatus thereby, the combination with a transmitting apparatus adapted to produce two or more distinctive kinds of disturbances or impulses, of means for varying the time intervals of the emission of the. impulses of the several kinds, sensitive circuits each tuned to respond to the impulses or disturbances of one kind only, and a receiving apparatus dependent for operation upon the conjoint action of the sensitive circuits, as set forth.

5. In a system, such as herein described, the combination with a transmitter adapted to produce a plurality of distinctive kinds of electrical disturbances or impulses, of a receiving apparatus comprising a plurality of circuits, a sensitive device and a relay included in each circuit, and each said circuit being tuned to respond to the impulses or disturbances of one kind only, and a receiving apparatus in a local circuit controlled by the relays and adapted to be completed by the conjoint action of all of said relays, as set forth.

6. In a system of the kind described, the combination with a transmitter adapted to produce two or more series of electrical oscillations or impulses of different frequencies, of a receiving apparatus comprising a plurality of sensitive circuits each tuned to respond to the impulses of one of the series produced by the transmitter, and a signaling device dependent for its operation upon the conjoint action of said circuits, as set forth.

7. The combination with a plurality of transmitter elements, each adapted to produce a series of impulses or disturbances of a distinctive character, and means for controlling and adjusting the same, of a receiver having a plurality of sensitive circuits each tuned so as to be affected by one of the series of impulses only, and dependent for operation upon the conjoint action of all of said circuits, as set forth.

8. The combination with a transmitter adapted to produce series of electrical impulses or disturbances of distinctive character and in a given order of succession, of a receiving apparatus comprising tuned circuits responding to such impulses in a corresponding order, and dependent for operation upon the conjoint action of said elements, as set forth.

9. In a receiving apparatus, the combination with a plurality of sensitive circuits, severally turned to respond to waves or impulses of a different kind or class, a receiving-circuit controlled by the sensitive circuits and a device connected with the receiving-circuits adapted to be operated when said circuit is completed by the conjoint action of two or more of the sensitive circuits, as set forth.

10. A system for the transmission of electrical energy, having in combination means for producing and transmitting two or more impulses of different periodicities to form a signal in a predetermined order of succession, as set forth.

11. In a system for the transmission of electrical energy, the combination with a transmitting apparatus comprising one or more circuits, means for impressing therein oscillations or impulses of different character and a receiving apparatus comprising a plurality of circuits each tuned to respond to the impulses of one kind produced by the transmitter and a receiver dependent for operation upon the conjoint action of the receiving-circuits, as set forth.

12. In a system for the transmission of electrical energy, the combination with a transmitting apparatus comprising a transformer and means for impressing upon the secondary element of the same oscillations or impulses of different character, of a receiving apparatus comprising a plurality of circuits each tuned to the impulses of one kind emitted by the secondary of the transmitting-transformer, and a receiver dependent for operation upon the conjoint action of the receiving-circuits, as set forth.

13. In a system for the transmission of electrical energy, the combination with a transmitting apparatus comprising a transformer and means for impressing upon the secondary

elements of the same oscillations or impulses of different periodicities and in a given order of succession, of a receiving apparatus comprising a plurality of circuits each tuned to respond to the transmitted impulses of one period, and a receiver dependent for operation upon the conjoint action of the receiving-circuits, as set forth.

14. In a signaling system, the combination of means for generating a series of electrical impulses of different periodicities, receiving-circuits of differing electrical periods of vibration, and an indicating mechanism operated to give an intelligible indication only when currents are induced in the receiving-circuits in a predetermined order, as set forth.

15. In a system for the transmission of energy, the combination of two or more circuits differing with respect of one of their electrical constants, means for energizing said circuits, and an indicating mechanism operative only by conjoint action of two or more currents generated by waves from the sending-station, as set forth.

16. In a system for the transmission of electrical energy, the combination with a transmitter adapted to produce electrical waves or oscillations varying in character in a predetermined order, of a receiving instrument responsive to said oscillations and dependent for operation upon the action thereof in a corresponding order, as set forth.

NIKOLA TESLA.

Witnesses:
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P-342

No. 725,605. PATENTED APR. 14, 1903.

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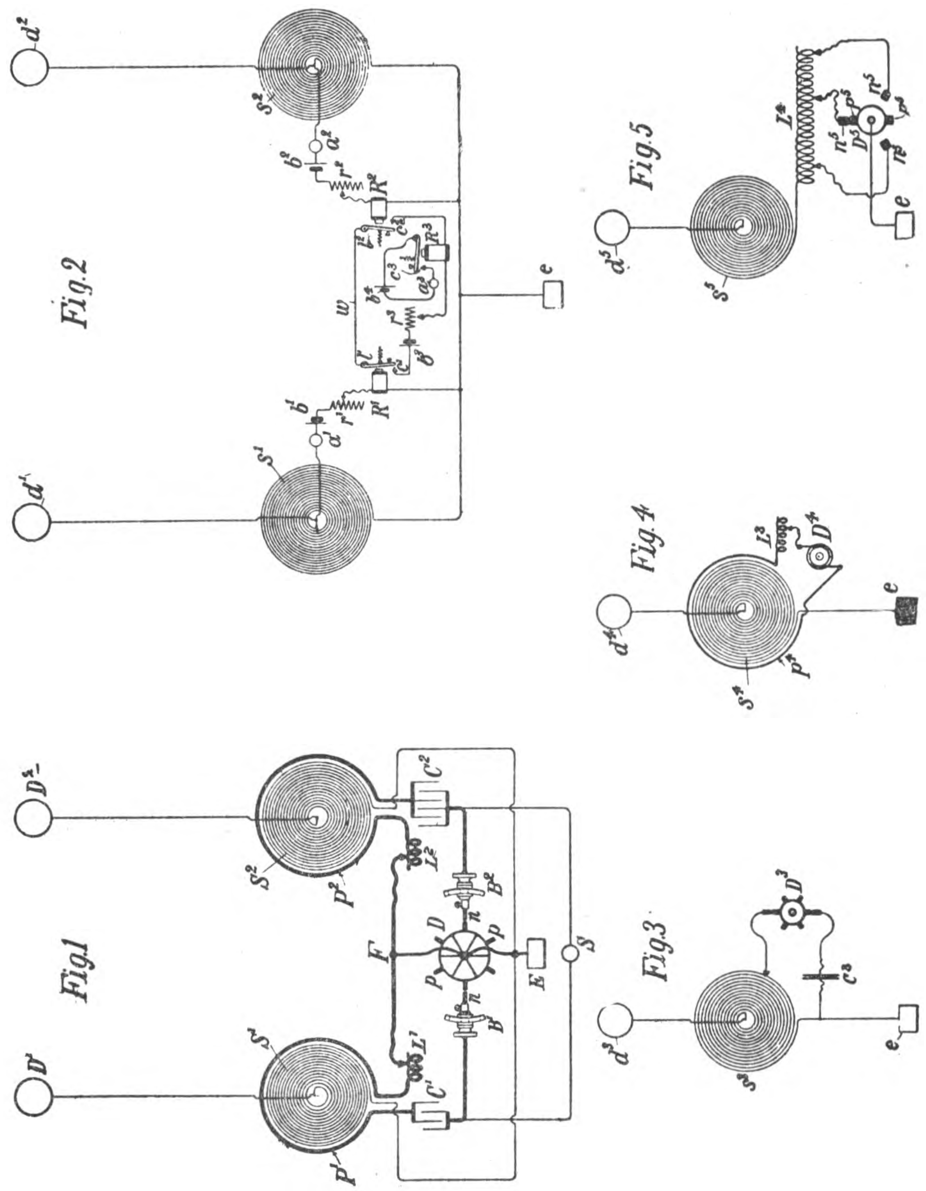
SYSTEM OF SIGNALING.

APPLICATION FILED JULY 18, 1900.

NO MODEL.



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Nikola Tesla, Inventor
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UNITED STATES PATENT OFFICE.

NIKOLA TESLA. OF NEW YORK, N. Y.

APPARATUS FOR THE UTILIZATION OF RADIANT ENERGY.

SPECIFICATION forming part of Letters Patent No. 685,957, dated November 5, 1901.

Application filed March 21, 1901. Serial No. 52,163. (No model.)

To all whom, it may concern:

Be it known that I, NIKOLA TESLA, a citizen of the United States, residing at the borough of Manhattan, in the city, county, and State of New York, have invented certain new and useful Improvements in Apparatus for the Utilization of Radiant Energy, of which the following is a specification, reference being had to the drawings accompanying and forming a part of the same.

It is well known that certain radiations—such as those of ultra-violet light, cathodic, Roentgen rays, or the like—possess the property of charging and discharging conductors of electricity, the discharge being particularly noticeable when the conductor upon which the rays impinge is negatively electrified. These radiations are generally considered to be ether vibrations of extremely small wave lengths, and in explanation of the phenomena noted it has been assumed by some authorities that they ionize or render conducting the atmosphere through which they are propagated. My own experiments and observations, however, lead me to conclusions more in accord with the theory heretofore advanced by me that sources of such radiant energy throw off with great velocity minute particles of matter which are strongly electrified, and therefore capable of charging an electrical conductor, or, even if not so, may at any rate discharge an electrified conductor either by carrying off bodily its charge or otherwise.

My present application is based upon a discovery which I have made that when rays or radiations of the above kind are permitted to fall upon an insulated conducting-body connected to one of the terminals of a condenser while the other terminal of the same is made by independent means to receive or to carry away electricity a current flows into the condenser so long as the insulated body is exposed to the rays, and under the conditions hereinafter specified an indefinite accumulation of electrical energy in the condenser takes place. This energy after a suitable time interval, during which the rays are allowed to act, may manifest itself in a powerful discharge, which may be utilized for the operation or control of mechanical or electrical devices or rendered useful in many other ways.

In applying my discovery I provide a condenser, preferably of considerable electrostatic capacity, and connect one of its terminals to an insulated metal plate or other conducting-body exposed to the rays or streams of radiant matter. It is very important, particularly in view of the fact that electrical energy is generally supplied at a very slow rate to the condenser, to construct the same with the greatest care. I use, by preference, the best quality of mica as dielectric, taking every possible precaution in insulating the armatures, so that the instrument may withstand great electrical pressures without leaking and may leave no perceptible electrification when discharging instantaneously. In practice I have found that the best results are obtained with condensers treated in the manner described in a patent granted to me February 23, 1897, No. 577,671. Obviously the above precautions should be the more rigorously observed the slower the rate of charging and the smaller the time interval during which the energy is allowed to accumulate in the condenser. The insulated plate or conducting-body should present as large a surface as practicable to the rays or streams of matter, I having ascertained that the amount of energy conveyed to it per unit of time is under otherwise identical conditions proportionate to the area exposed, or nearly so. Furthermore, the surface should be clean and preferably highly polished or amalgamated. The second terminal or armature of the condenser may be connected to one of the poles of a battery or other source of electricity or to any conducting body or object whatever of such properties or so conditioned that by its means electricity of the required sign will be supplied to the terminal. A simple way of supplying positive or negative electricity to the terminal is to connect the same either to an insulated conductor supported at some height in the atmosphere or to a grounded conductor, the former, as is well known, furnishing positive and the latter negative electricity. As the rays or supposed streams of matter generally convey a positive charge to the first condenser-terminal, which is connected to the plate or conductor above mentioned, I usually connect the second terminal of the condenser to the ground, this being the most, convenient way of obtaining negative electricity, dispensing with the necessity of providing an artificial source. In order to utilize for any useful purpose the energy accumulated in the condenser, I furthermore connect to the terminals of the same a circuit including an instrument or apparatus which it is desired to operate and another instrument or device for alternately closing and opening the circuit. This latter may be any form of circuit-controller, with fixed or movable parts or electrodes, which may be actuated either by the stored energy or by independent means.

My discovery will be more fully understood from the following description and annexed drawings, to which reference is now made, and in which—

Figure 1 is a diagram showing the general arrangement of apparatus as usually employed. Fig. 2 is a similar diagram illustrating more in detail typical forms of the devices or elements used in practice, and Figs. 3 and 4 are diagrammatical representations of modified arrangements suitable for special purposes.

As illustrative of the manner in which the several parts or elements of the apparatus in one of its simplest forms are to be arranged and connected for useful operation, reference is made to Fig. 1, in which C is the condenser, P the insulated plate or conducting-body which is exposed to the rays, and P' another plate or conductor which is grounded, all being joined in series, as shown. The terminals T T' of the condenser are also connected to a circuit which includes a device R to be operated and a circuit-controlling device *d* of the character above referred to.

The apparatus being arranged as shown, it will be found that when the radiations of the sun or of any other source capable of producing the effects before described fall upon the plate P an accumulation of electrical energy in the condenser C will result. This phenomenon, I believe, is best explained as follows: The sun, as well as other sources of radiant energy, throws off minute particles of matter positively electrified, which, impinging upon the plate P, communicate continuously an electrical charge to the same. The opposite terminal of the condenser being connected to the ground, which may be considered as a vast reservoir of negative electricity, a feeble current flows continuously into the condenser, and inasmuch as these supposed particles are of an inconceivably small radius or curvature, and consequently charged to a relatively very high potential, this charging of the condenser may continue, as I have actually observed, almost indefinitely, even to the point of rupturing the dielectric, If the device *d* be of such character that it will operate to close the circuit in which it is included when the potential in the condenser has readied a certain magnitude, the accumulated charge will pass through the circuit, which also includes the receiver R, and operate the latter.

In illustration of a particular form of apparatus which may be used in carrying out my discovery I now refer to Fig. 2. In this figure, which in the general arrangement of the elements is identical to Fig. 1, the device *d* is shown as composed of two very thin conducting-plates *t t'*, placed in close proximity and very mobile, either by reason of extreme flexibility or owing to the character of their support. To improve their action, they should be inclosed in a receptacle, from which the air may be exhausted. The plates *t t'* are connected in series with a working circuit, including a suitable receiver, which in this case is shown as consisting of an electromagnet M, a movable armature *a,* a retractile spring *b,* and a ratchet-wheel *w,* provided with a spring-pawl *r*, which is pivoted to armature *a,* as illustrated. When the radiations of the sun or other radiant source fall upon plate P, a current flows into the condenser, as above explained, until the potential therein rises sufficiently to attract and bring into contact the two plates *t t'*, and thereby close the circuit connected to the two condenser-terminals. This permits a flow of current which energizes the magnet M, causing it to draw down the armature *a* and impart a partial rotation to the ratchet-wheel *w*. As the current ceases the armature is retracted by the spring *b*, without, however, moving the wheel *w*. With the stoppage of the current the plates *t t'* cease to be attracted and separate, thus restoring the circuit to its original condition.

Fig. 3 shows a modified form of apparatus used in connection with an artificial source of radiant energy, which in this instance may be an arc emitting copiously ultra-violet rays. A suitable reflector may be provided for concentrating and directing the radiations. A magnet R and circuit-controller *d* are arranged as in the previous figures; but in the present case the former instead of performing itself the whole work only serves the purpose of alternately opening and closing a local circuit, containing a source of current B and a receiving or translating device D. The controller *d*, if desired, may consist of two fixed electrodes separated by a minute air-gap or weak dielectric film, which breaks down more or less suddenly when a definite difference of potential is reached at the terminals of the condenser and returns to its original state upon the passage of the discharge.

Still another modification is shown in Fig. 4, in which the source S of radiant energy is a special form of Roentgen tube devised by me, having but one terminal *k*, generally of aluminium, in the form of half a sphere, with a plain polished surface on the front side, from which the streams are thrown off. It may be excited by attaching it to one of the terminals of any generator of sufficiently high electromotive force; but whatever apparatus be used; it is important that the tube be exhausted to a high degree, as otherwise it might prove entirely ineffective. The working or discharge circuit connected to the terminals T T' of the condenser includes in this case the primary *p* of a transformer and a circuit-controller comprising a fixed terminal or brush *t* and a movable terminal *t'* in the shape of a wheel, with conducting and insulating segments, which may be rotated at an arbitrary speed by any suitable means. In inductive relation to the primary wire or coil *p* is a secondary *s*, usually of a much greater number of turns, to the ends of which is connected a receiver R. The terminals of the condenser being connected, as indicated, one to an insulated plate P and the other to a grounded plate P', when the tube S is excited rays or streams of matter are emitted from the same, which convey a positive charge to the plate B and condenser-terminal T, while terminal T' is continuously receiving negative electricity from the plate P'. This, as before explained results in an accumulation of electrical energy in the condenser, which goes on as long as the circuit including the primary *p* is interrupted. Whenever the circuit is closed owing to the rotation of the terminal *t'*, the stored energy is discharged through the primary *p,* this giving rise in the secondary *s* to induced currents, which operate the receiver R.

It is clear from what has been stated above that if the terminal T' is connected to a plate supplying positive instead of negative electricity the rays should convey negative electricity to plate P. The source S may be any form of Roentgen or Lenard tube; but it is obvious from the theory of action that in order to be very effective the electrical impulses exciting it should be wholly or at least preponderatingly of one sign. If ordinary symmetrical alternating currents are employed, provision should be made for allowing the rays to fall upon, the plate P only during those periods when they are productive of the desired result. Evidently if the radiations of the source be stopped or intercepted or their intensity varied in any manner, as by periodically interrupting or rythmically varying the current exciting the source, there will be corresponding changes in the action upon the receiver R, and thus signals may be transmitted and many other useful effects produced. Furthermore, it will be understood that any form of circuit-closer which will respond to or be set in operation when a predetermined amount of energy is stored in the condenser may be used in lieu of the device specifically described with reference to Fig. 2 and also that the special details of construction and arrangement of the several parts of the apparatus may be very greatly varied without departure from the invention.

Having described my invention, what I claim is—

1. An apparatus for utilizing radiant energy, comprising in combination a condenser, one armature of which is subjected to the action of rays or radiations, independent means for charging the other armature, a circuit and apparatus therein adapted to be operated or controlled by the discharge of the condenser, as set forth.

2. An apparatus for utilizing radiant energy, comprising in combination, a condenser, one armature of which is subjected to the action of rays or radiations, independent means for charging the other armature, a local circuit connected with the condenser-terminals, a circuit-controller therein and means adapted to be operated or controlled by the discharge of the condenser when the local circuit is closed, as set forth.

3. An apparatus for utilizing radiant energy, comprising in combination, a condenser, one terminal of which is subjected to the action of rays or radiations, independent means for charging the other armature, a local circuit connected with the condenser-terminals, a circuit-controller therein dependent for operation on a given rise of potential ib the condenser, and devices operated by the discharge of the condenser when the local circuit is closed, as set forth.

4. An apparatus for utilizing radiant energy, comprising in combination, a condenser, one terminal of which is subjected to the action of rays or radiations, and the other of which is connected with the ground, a circuit and apparatus therein adapted to be operated by the discharge of the accumulated energy in the condenser, as set forth.

5. An apparatus for utilizing radiant energy, comprising in combination, a condenser, one terminal of which is subjected to the action of rays or radiations and the other of which is connected with the ground, a local circuit connected with the condenser-terminals, a circuit-controller therein and means adapted to be operated by the discharge of the condenser when the local circuit is closed, as set forth.

6. An apparatus for utilizing radiant energy, comprising in combination, a condenser, one terminal of which is subjected to the action of rays or radiations and the other of which is connected with the ground, a local circuit connected with the condenser-terminals, a circuit-controller therein adapted to be operated by a given rise of potential in the condenser, and devices operated by the discharge of the condenser when the local circuit is closed, as set forth.

7. An apparatus for utilizing radiant en-

ergy, comprising a condenser, having one terminal connected to earth and the other to an elevated conducting-plate, which is adapted to receive the rays from a distant source of radiant energy, a local circuit connected with the condenser-terminals, a receiver therein, and a circuit - controller therefor which is adapted to be operated by a given rise of potential in the condenser, as set forth.

NIKOLA TESLA.

Witnesses:
M. LAWSON DYER,
RICHARD DONOVAN

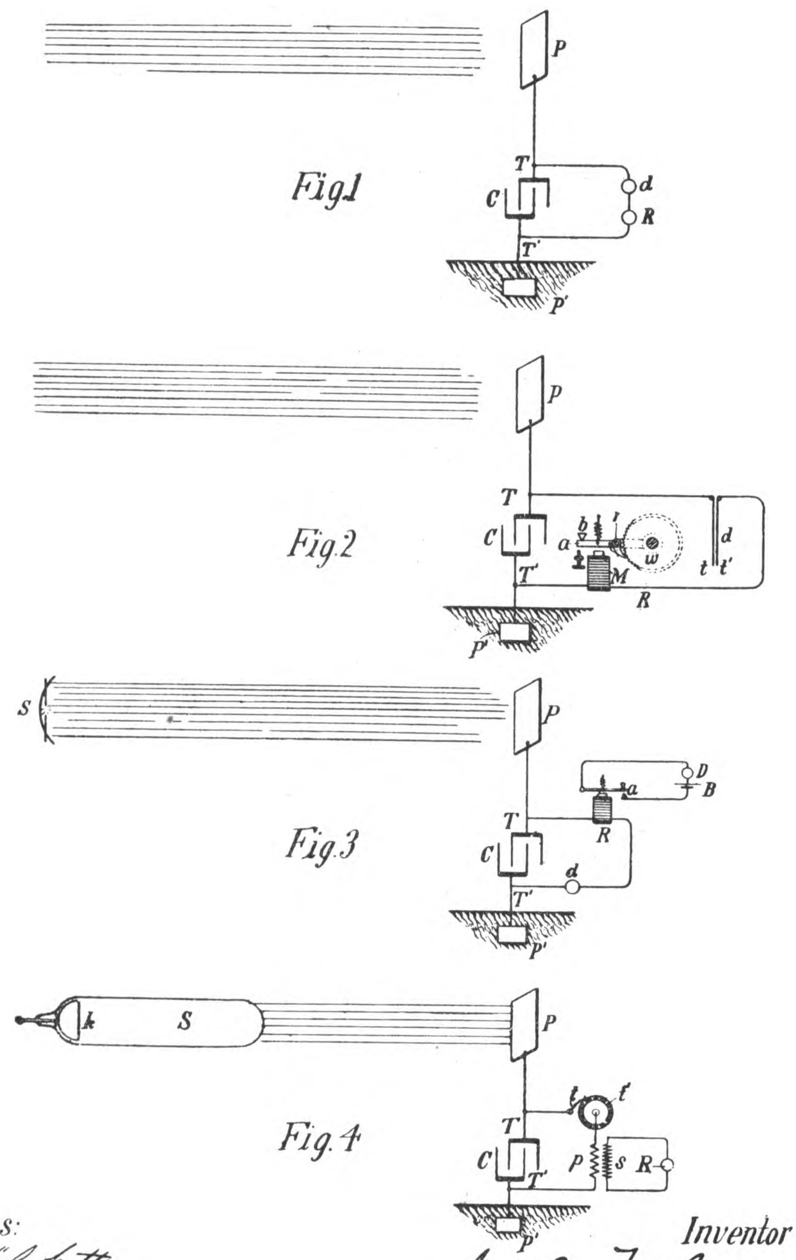
No. 685,957 Patented Nov. 5, 1901.

N. TESLA.

APPARATUS FOR THE UTILIZATION OF RADIANT ENERGY

(Application filed Mar. 21, 1901.)

(No Model.)



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UNITED STATES PATENT OFFICE.

NIKOLA TESLA, OF NEW YORK, N. Y.

METHOD OF UTILIZING RADIANT ENERGY.

SPECIFICATION forming part of Letters Patent No. 685,958, dated November 5, 1901.

Application filed March 21, 1901. Serial No. 52,154. (No model.)

To all whom it may concern:

Be it known that I, NIKOLA TESLA, a citizen of the United States, residing at the borough of Manhattan, in the city, county, and State of Now York, have invented certain new and useful Improvements in Methods of Utilizing Radiant Energy, of which the following is a specification, reference being had to the drawings accompanying and forming a part of the same.

It is well known that certain radiations—such as those of ultra-violet light, cathodic, Roentgen rays, or the like—possess the property of charging and discharging conductors of electricity, the discharge being particularly noticeable when the conductor upon which the rays impinge is negatively electrified. These radiations are generally considered to be ether vibrations of extremely small wave lengths, and in explanation of the phenomena noted it has been assumed by some authorities that they ionize or render conducting the atmosphere through which they are propagated. My own experiments and observations, however, lead me to conclusions more in accord with the theory heretofore advanced by me that sources of such radiant energy throw off with great velocity minute particles of matter which are strongly electrified, and therefore capable of charging an electrical conductor, or even if not so may at any rate discharge an electrified conductor either by carrying off bodily its charge or otherwise.

My present application is based upon a discovery which I have made that when rays or radiations of the above kind are permitted to fall upon an insulated conducting body connected to one of the terminals of a condenser, while the other terminal of the same is made by independent means to receive or to carry away electricity, a current flows into the condenser so long as the insulated body is exposed to the rays, and under the conditions hereinafter specified an indefinite accumulation of electrical energy in the condenser takes place. This energy after a suitable time interval, during which the rays are allowed to act, may manifest itself in a powerful discharge, which may be utilized for the operation or control of mechanical or electrical devices or rendered useful in many other ways.

In applying my discovery I provide a condenser, preferably of considerable electrostatic capacity, and connect one of its terminals to an insulated metal plate or other conducting body exposed to the rays or streams of radiant matter. It is very important, particularly in view of the fact that electrical energy is generally supplied at a very slow rate to the condenser, to construct the same with the greatest care. I use by preference the best quality of mica as dielectric, taking every possible precaution in insulating the armatures, so that the instrument may withstand great electrical pressures without leaking and may leave no perceptible electrification when discharging instantaneously. In practice I have found that the best results are obtained with condensers treated in the manner described in a patent granted to me February 23, 1897, No. 577,671. Obviously the above precautions should be the more rigorously observed the slower the rate of charging and the smaller the time interval during which the energy is allowed to accumulate in the condenser. The insulated plate or conducting body should present as large a surface as practicable to the rays or streams of matter, I having ascertained that the amount of energy conveyed to it per unit of time is under otherwise identical conditions proportionate to the area exposed, or nearly so. Furthermore, the surface should be clean and preferably highly polished or amalgamated. The second terminal or armature of the condenser may be connected to one of the poles of a battery or other source of electricity or to any conducting body or object whatever of such properties or so conditioned that by its means electricity of the required sign will be supplied to the terminal. A simple way of supplying positive or negative electricity to the terminal is to connect the same either to an insulated conductor, supported at some height in the atmosphere, or to a grounded conductor, the former, as is well known, furnishing positive and the latter negative electricity. As the rays or supposed streams of matter generally convey a positive charge to the first condenser-terminal, which is connected to the plate or conductor above mentioned, I usually connect the second terminal of the condenser to the ground, this being the most convenient way of obtaining negative electricity, dispensing with the necessity of providing an artificial source. In order to utilize for any useful purpose the energy accumulated in the condenser, I furthermore connect to the terminals of the same a circuit including an instrument or apparatus which it is desired to operate and another instrument or device for alternately closing and opening the circuit. This latter may be any form of circuit-controller, with fixed or movable parts or electrodes, which may be actuated either by the stored energy or by independent means.

The rays or radiations which are to be utilized for the operation of the apparatus above described in general terms may be derived from a natural source, as the sun, or may be artificially produced by such means, for example, as an arc-lamp, a Roentgen tube, and the like, and they may be employed for a great variety of useful purposes.

My discovery will be more fully understood from the following detailed description and annexed drawings, to which reference is now made, and in which—

Figure 1 is a diagram showing typical forms of the devices or elements as arranged and connected in applying the method for the operation of a mechanical contrivance or instrument solely by the energy stored; and Fig. 2 is a diagrammatical representation of a modified arrangement suitable for special purposes, with a circuit-controller actuated by independent means.

Referring to Fig. 1, C is the condenser, P the insulated plate or conducting body, which is exposed to the rays, and P' another plate or conductor, all being joined in series, as shown. The terminals T T' of the condenser are also connected to a circuit including a receiver R, which is to be operated, and a circuit-controlling device *d,* which in this case is composed of two very thin conducting-plates *t t'*, placed in close proximity and very mobile, either by reason of extreme flexibility or owing to the character of their support. To improve their action, they should be inclosed in a receptacle from which the air may be exhausted. The receiver R is shown as consisting of an electromagnet M, a movable armature *a*, a retractile spring *b*, and a ratchet-wheel *w*, provided with a spring-pawl *r*, which is pivoted to armature *a,* as illustrated. The apparatus being arranged as shown, it will be found that when the radiations of the sun or of any other source capable of producing the effects before described fall upon the plate P an accumulation of electrical energy in the condenser C will result. This phenomenon, I believe, is best explained as follows: The sun as well as other sources of radiant energy throw off minute particles of matter positively electrified, which, impinging upon the plate P, communicate an electrical charge to the same. The opposite terminal of the condenser being connected to the ground, which may be considered as a vast reservoir of negative electricity, a feeble current flows continuously into the condenser, and inasmuch as these supposed particles are of an inconceivably small radius or curvature, and consequently charged to a relatively very high potential, this charging of the condenser may continue, as I have found in practice, almost indefinitely, even to the point of rupturing the dielectric. Obviously whatever circuit-controller be employed it should operate to close the circuit in which it is included when the potential in the condenser has reached the desired magnitude. Thus in Fig. 2 when the electrical pressure at the terminals T T' rises to a certain predetermined value the plates *t t'*, attracting each other, close the circuit connected to the terminals. This permits a flow of current which energizes the magnet M, causing it to draw down the armature *a* and impart a partial rotation to the ratchet-wheel *w.* As the current ceases the armature is retracted by the spring *b* without, however, moving the wheel *w.* With the stoppage of the current the plates *t t'* cease to be attracted and separate, thus restoring the circuit to its original condition.

Many useful applications of this method of utilizing the radiations emanating from the sun or other source and many ways of carrying out the same will at once suggest themselves from the above description. By way of illustration a modified arrangement is shown in Fig. 2, in which the source S of radiant energy is a special form of Roentgen tube devised by me having but one terminal *k*, generally of aluminium, in the form of half a sphere with a plain polished surface on the front side, from which the streams are thrown off. It may be excited by attaching it to one of the terminals of any generator of sufficiently-high electromotive force; but whatever apparatus be used it is important that the tube be exhausted to a high degree, as otherwise it might prove entirely ineffective. The working or discharge circuit connected to the terminals T T' of the condenser includes in this case the primary *p* of a transformer and a circuit-controller comprising a fixed terminal or brush *t* and a movable terminal *t'* in the shape of a wheel with conducting and insulating segments which may be rotated at an arbitrary speed by any suitable means. In inductive relation to the primary wire or coil *p* is a secondary *s,* usually of a much greater number of turns, to the ends of which is connected a receiver R. The terminals of the condenser being connected as indicated, one to an insulated plate P and the other to a grounded plate P', when the tube S is excited rays or streams of matter are emitted from the same, which convey a positive charge to the plate P and condenser-terminal T, while terminal T' is continuously receiving negative electricity from the plate

P'. This, as before explained, results in an accumulation of electrical energy in the condenser, which goes on as long as the circuit including the primary *p* is interrupted. Whenever the circuit is closed, owing to the rotation of the terminal *t'*, the stored energy is discharged through the primary *p*, this giving rise in the secondary *s* to induced currents which operate the receiver R.

It is clear from what has been stated above that if the terminal T is connected to a plate supplying positive instead of negative electricity the rays should convey negative electricity to plate P. The source S may be any form of Roentgen or Lenard tube; but it is obvious from the theory of action that in order to be very effective the electrical impulses exciting it should be wholly or at least preponderantly of one sign. If ordinary symmetrical alternating currents are employed, provision should be made for allowing the rays to fall upon the plate P only during those periods when they are productive of the desired result. Evidently if the radiations of the source be stopped or intercepted or their intensity varied in any manner, as by periodically interrupting or rythmically varying the current exciting the source, there will be corresponding changes in the action upon the receiver R, and thus signals may be transmitted and many other useful effects produced. Furthermore, it will be understood that any form of circuit-closer which will respond to or be set in operation when a predetermined amount of energy is stored in the condenser may be used in lieu of the device specifically described with reference to Fig. 1, and also that the special details of construction and arrangement of the several parts of the apparatus may be very greatly varied without departure from the invention.

Having described my invention, what I claim is—

1. The method of utilizing radiant energy, which consists in charging one of the armatures of a condenser by rays or radiations, and the other armature by independent means, and discharging the condenser through a suitable receiver, as set forth.

2. The method of utilizing radiant energy, which consists in simultaneously charging a condenser by means of rays or radiations and an independent source of electrical energy, and discharging the condenser through a suitable receiver, as set forth.

3. The method of utilizing radiant energy, which consists in charging one of the armatures of a condenser by rays or radiations, and the other by independent means, controlling the action or effect of said rays or radiations and discharging the condenser through a suitable receiver, as set forth.

4. The method of utilizing radiant energy, which consists in charging one of the armatures of a condenser by rays or radiations and the other by independent means, varying the intensity of the said rays or radiations and periodically discharging the condenser through a suitable receiver, as set forth.

5. The method of utilizing radiant energy, which consists in directing upon an elevated conductor, connected to one of the armatures of a condenser, rays or radiations capable of positively electrifying the same, carrying off electricity from the other armature by connecting the same with the ground, and discharging the accumulated energy through a suitable receiver, as set forth.

6. The method of utilizing radiant energy, which consists in charging one of the armatures of a condenser by rays or radiations, and the other by independent means, and effecting by the automatic discharge of the accumulated energy the operation or control of a suitable receiver, as set forth.

NIKOLA TESLA

Witnesses:
M. LAWSON DYER,
RICHARD DONOVAN.

No. 685,958. Patented Nov. 5, 1901.

N. TESLA.

METHOD OF UTILIZING RADIANT ENERGY.

(Application filed Mar. 21, 1901.)

(No Model.)

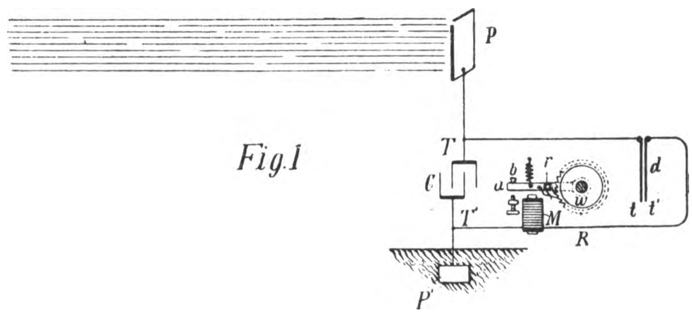

Fig.1

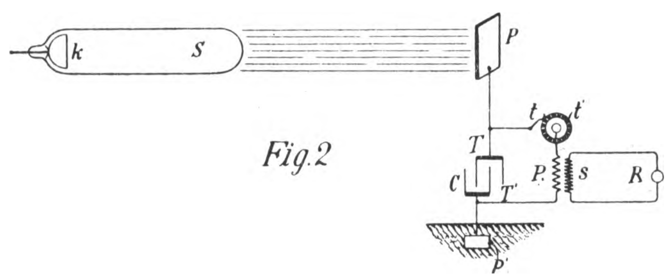

Fig.2

Witnesses:
Raphaël Netter
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Nikola Tesla, Inventor
by Kerr, Page & Cooper Att'ys

UNITED STATES PATENT OFFICE.

NIKOLA TESLA, OF NEW YORK, N. Y.

METHOD OF SIGNALING.

SPECIFICATION forming part of Letters Patent No. 723,188, dated March 17, 1908

Original application filed July 18, 1900, Serial No. 23,847. Divided and this application filed June 14, 1901, Serial No. 64,622. (No model.)

To all whom it may concern:

Be it known that I, NIKOLA TESLA, a citizen of the United States, residing in the borough of Manhattan, in the city, county, and State of New York, have invented certain new and useful Improvements in Methods of Signaling, of which the following is a specification, reference being had to the drawings accompanying and forming a part of the same.

In certain systems for transmitting intelligible messages or governing the movements and operations of distant automata electrical impulses or disturbances produced by suitable apparatus are conveyed through the natural media to a receiving-circuit capable of responding to the impulses, and thereby effecting the control of other appliances. Generally a special device, highly sensitive, is connected to the receiving-circuit, which in order to render it still more susceptible and to reduce the liability of its being affected by extraneous disturbances is carefully adjusted so as to be in tune with the transmitter. By a scientific design of the Bending and receiving circuits and other apparatus and skilful adjustment of the same these objects may be in a measure attained; but in long experience I have found that notwithstanding all constructive advantages and experimental resources this method is in many cases inadequate. Thus while I have succeeded in so operating selectively under certain favorable conditions more than one hundred receivers in most cases it is practicable to work successfully but a few, the number rapidly diminishing as, either owing to great distance or other causes, the energy available in the tuned circuits becomes smaller and the receivers necessarily more delicate. Evidently a circuit however well constructed and adjusted to respond exclusively to vibrations of one period is apt to be affected by higher harmonics and still more so by lower ones. When the oscillations are of a very high frequency, the number of the effective harmonics may be large and the receiver consequently easily disturbed by extraneous influences to such an extent that when very short waves, such as those produced by Hertzian spark apparatus, are used little advantage in this respect is to be derived from tuning the circuits. It being an imperative requirement in most practical applications of such systems of signaling or intelligence transmission that the signals or messages should be exclusive or private, it is highly desirable to do away with the above limitations, especially in view of the fact which I have observed that the influence of powerful electrical disturbances upon sensitive receivers extends even on land to distances of many hundreds of miles, and consequently, in accordance with theory still farther on sea. To overcome these drawbacks and to enable a great number of transmitting and receiving stations to be operated selectively and exclusively and without any danger of the signals or messages being disturbed, intercepted, or interfered with in any way is the object of my present invention.

Broadly stated, this invention consists in generating two or more kinds or classes of disturbances or impulses of distinctive character with respect to their effect upon a receiving-circuit and operating thereby a distant receiver which comprises two or more circuits, each of which is tuned to respond exclusively to the disturbances or impulses of one kind or class and so arranged that the operation of the receiver is dependent upon their conjoint or resultant action.

By employing only two kinds of disturbances or series of impulses instead of one, as has heretofore been done, to operate a receiver of this kind I have found that safety against the disturbing influences of other sources is increased to such an extent that I believe this number to be amply sufficient in most cases for rendering the exchange of signals or messages reliable and exclusive; but in exceptional instances a greater number may be used and a degree of safety against mutual and extraneous interference attained, such as is comparable to that afforded by a combination-lock. The liability of a receiver being affected by disturbances emanating from other sources, as well as that of the signals or messages being received by instruments for which they are not intended, may however, be reduced not only by an increased number of the cooperative disturbances or series of impulses, but also by judicious choice of the same and order in which they are made to act upon the receiver.

Evidently there are a great many ways of generating impulses or disturbances at any wave length, wave form, number or order of succession, or of any special character, such as will be capable of fulfilling the requirements above stated, and there are also many ways in which such impulses or disturbances may be made to cooperate and to cause the receiver to be actuated, and inasmuch as the skill and practical knowledge in these novel fields can only be acquired by long experience the degree of safety and perfection attained will necessarily depend upon the ability and resource of the expert who applies my invention; but in order to enable the same to be successfully practiced by any person possessed only of the more general knowledge and experience in these branches I shall describe the simplest plan of carrying it out which is at present known to me.

For a better understanding of the subject reference is now made to the accompanying drawings, in which—

Figures 1 and 2 represent diagrammatically an apparatus and circuit connections employed at the sending and receiving stations, respectively, for the practice of my invention; and Figs. 3, 4, and 5, modified means which may be employed in the practical application of the invention.

In Fig. 1, S' S^2 are two spirally-wound coils or conductors connected with their inner ends to preferably elevated terminals D' and D^2, respectively, and with their outer ends to an earth-plate E. These two coils, conductors, or systems D; S' E and D^2 S^2 E have different and suitably-chosen periods of vibration, and, as pointed out in other patents relating to my system of energy and intelligence transmission, their lengths should be such that the points of maximum pressure developed therein coincide with the elevated terminals D' D^2. By suitably-chosen periods of vibration such periods are meant as will secure the greatest safety against interference, both mutual and extraneous. The two systems may have electrical oscillations impressed upon them in any desired manner conveniently by energizing them through primaries P' and P^2, placed in proximity to them. Adjustable inductances L' and L^2 are preferably included in the primary circuits chiefly for the purpose of regulating the rates of the primary oscillations. In the drawings these primaries P' and P^2 surround the coils S' S^2 and are joined in series through the inductances L' L^2, conductor F, condensers C' and C^2, brush-holders B' and B^2, and a toothed disk D, which is connected to the conductor F and, if desired, also to the ground-plate E, as shown, two independent primary circuits being thus formed. The condensers C' and C^2 are of such capacity and the inductances L' L^2 are so adjusted that each primary is in close resonance with its secondary system, as I have explained in other patents granted to me. The brush-holders B' and B^2 are capable independently of angular and, if necessary, also of lateral adjustment, so that any desired order of succession or any difference of time interval between the discharges occurring in the two primary circuits may be obtained. The condensers being energized from a suitable source S, preferably of high potential, and the disk D being rotated, its projections or teeth *p p* coming at periodically-recurring intervals in very close proximity to or, as the case may be, in contact with conducting rods or brushes *n n* cause the condensers to be discharged in rapid succession through their respective circuits. In this manner the two secondary systems D' S' E and D^2 S^2 E are set in vibration and oscillate freely each at its proper rate for a certain period of time at every discharge. The two vibrations are impressed upon the ground through the plate E and spread to a distance reaching the receiving-station, which has two similar circuits or systems $e\ s'\ d'$ and $e\ s^2\ d^2$, arranged and connected in the same manner and tuned to the systems at the sending-station, so that each responds exclusively to one of the two vibrations produced by the transmitting apparatus. The same rules of adjustment are observed with respect to the receiving-circuits, care being furthermore taken that the tuning is effected when all the apparatus is connected to the circuits and placed in position, as any change may more or less modify the vibration. Each of the receiving-coils s' and s^2 is shunted by a local circuit containing, respectively, sensitive devices a' a^2, batteries b' b^2, adjustable resistances r' r^2, and sensitive relays R' R^2, all joined in series, as shown. The precise connections and arrangements of the various receiving instruments are largely immaterial and may be varied in many ways. The sensitive devices a' a^2 may be any of the well-known devices of this kind—as, for example, two conducting-terminals separated by a minute air-gap or a thin film of dielectric which is strained or weakened by a battery or other means to the point of breaking down and gives way to the slightest disturbing influence. Its return to the normal sensitive state may be secured by momentarily-interrupting the battery-circuits after each operation or otherwise. The relays R' R^2 have armatures l l^2, which are connected by a wire *w* and when attracted establish electrical contacts at c' and c^2, thus closing a circuit containing a battery b^3 and adjustable resistance r^3 and a relay R^3. From the above description it will be readily seen that the relay R^3 will be operated only when both contacts c' and c^2 are closed.

The apparatus at the sending-station may be controlled in any suitable manner—as, for instance, by momentarily closing the circuit of the source S, two different electrical vi-

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brations being emitted simultaneously or in rapid succession, as may be desired, at each closure of the circuit. The two receiving-circuits at the distant station, each tuned to respond to the vibrations produced by one of the elements of the transmitter, affect the sensitive devices *a'* and a^2 and cause the relays R' and R^2 to be operated and contacts *c'* and c^2 to be closed, thus actuating the receiver or relay R^3, which in turn establishes a contact c^3 and brings into action a device a^3 by means of a battery d^4 included in a local circuit, as shown. But evidently if through any extraneous disturbance only one of the circuits at the receiving-station is affected the relay R^3 will fail to respond. In this way a communication may be carried on with greatly-increased safety against interference and privacy of the messages may be secured. The receiving-station shown in Fig. 2 is supposed to be one requiring no return message; but if the use of the system is such that this is necessary then the two stations will be similarly equipped, and any well-known means, which it is not thought necessary to illustrate here, may be resorted to for enabling the apparatus at each station to be used in turn as transmitter and receiver. In like manner the operation of a receiver, as R^3, may be made dependent instead of upon two upon more than two such transmitting systems or circuits, and thus any desired degree of exclusiveness or privacy and safety against extraneous disturbances may be attained. The apparatus as illustrated in Figs. 1 and 2 permits, however, special results to be secured by the adjustment of the order of succession of the discharges of the primary circuits P' and P^2 or of the time intervals between such discharges. To illustrate: The action of the relays R' R^2 may be regulated either by adjusting the weights of the levers *l'* l^2, or the strength of the batteries *b'* b^2, or the resistances *r'* r^2, or in other well-known ways, so that when a certain order of succession or time interval between the discharges of the primary circuits P' and P^2 exists at the sending-station the levers *l'* and l^3 will close the contacts *c'* and c^2 at the same instant, and thus operate the relay R^3, but will fail to produce this result when the order of succession of or the time interval between the discharges in the primary circuits is another one. By these or similar means additional safety against disturbances from other sources may be attained and, on the other hand, the possibility afforded of effecting the operation of signaling by varying the order of succession of the discharges of the two circuits. Instead of closing and opening the circuit of the source S', as before indicated, for the purpose of sending distinct signals it may be convenient to merely alter the period of either of the transmitting-circuits arbitrarily, as by varying the inductance of the primaries.

Obviously there is no necessity for using transmitters with two or more distinct elements or circuits, as S' and S^2, since a succession of waves or impulses of different characteristics may be produced by an instrument having but one such circuit. A few of the many ways which will readily suggest themselves to the expert who applies my invention are illustrated in Figs. 3, 4, and 5. In Fig. 3 a transmitting system *e* s^3 d^3 is partly shunted by a rotating wheel or disk D^3, which may be similar to that illustrated in Fig. 1 and which cuts out periodically a portion of the coil or conductor s^3, or, if desired, bridges it by an adjustable condenser C^3, thus altering the vibration of the system *e* s^2 d^3 at suitable intervals and causing two distinct kinds or classes of impulses to be emitted in rapid succession by the sender. In Fig. 4 a simitar result is produced in the system *e* s^4 d^4 by periodically short-circuiting, through an induction-coil L^3 and a rotating disk D^4 with insulating and conducting segments, a circuit p^4 in inductive relation to said system. Again, in Fig. 5 three distinct vibrations are caused to be emitted by a system *e* s^5 d^5, this result being produced by inserting periodically a number of turns of an induction-coil L^4 in series with the oscillating system by means of a rotating disk B^5 with two projections p^5 p^5 and three rods or brushes n^5, placed at an angle of one hundred and twenty degrees relatively to each other. The three transmitting systems or circuits thus produced may be energized in the same manner as those of Fig. 1 or in any other convenient way. Corresponding to each of these cases the receiving-station may be provided with two or three circuits in an analogous manner to that illustrated in Fig. 2, it being understood, of course, that the different vibrations or disturbances emitted by the sender follow in such rapid succession upon each other that they are practically simultaneous so far as the operation of such relays as R' and R^2 is concerned. Evidently, however, it is not necessary to employ two or more receiving-circuits, but a single circuit may be used also at the receiving-station constructed and arranged like the transmitting-circuits or systems illustrated in Figs. 3, 4, and 5, in which case the corresponding disks, as D^3 D^4 D^5, at the sending will be driven in synchonism with those at the receiving stations as far as may be necessary to secure the desired result; but whatever the nature of the specific devices employed it will be seen that the fundamental idea in my invention is the operation of a receiver by the conjoint or resultant effect of two or more circuits each tuned to respond exclusively to waves, impulses, or vibrations of a certain kind or class produced either simultaneously or successively by a suitable transmitter.

It will be seen from a consideration of the nature of the method herein before described that the invention is applicable not only in the special manner described, in which the transmission of the impulses is effected through natural media, but for the transmission of energy for any purpose and whatever the medium through which the impulses are conveyed.

What I claim is–

1. The method of operating distant receivers which consists in producing and transmitting a plurality of kinds or classes of electrical impulses or disturbances, actuating by the impulses or disturbances of each kind or class one of a plurality of circuits tuned to respond to impulses of such kind or class and operating or controlling the operation of a receiver by the conjoint action of two or more of said circuits, as set forth.

2. The method of signaling, which consists in producing and transmitting a plurality of kinds or classes of electrical impulses or disturbances, developing by the impulses of each class a current in one of a plurality of receiving-circuits tuned to respond exclusively thereto and controlling by means of the conjoint action of such circuits a local circuit, as set forth.

3. The method of signaling which consists in producing a plurality of series of impulses or disturbances differing from each other in character and order of succession, exciting by the impulses of each series one of a plurality of receiving-circuits tuned to respond exclusively thereto and controlling by the conjoint action of such circuits a local circuit, as set forth.

4. The method of signaling which consists in producing a plurality of series of electrical impulses of different character, varying the time interval between the emission of such impulses, exciting by the impulses of each series one of a plurality of receiving-circuits tuned to respond exclusively thereto and controlling by the conjoint action of such circuits a local circuit, as set forth.

5. The method of transmitting electrical energy for conveying intelligible signals which consists in producing a plurality of electrical impulses of different character, developing by the impulses of each kind a current in one of a plurality of receiving-circuits tuned to respond exclusively thereto, controlling the action or effect of the transmitted impulses upon the receiving-circuits by varying the character of said impulses, and operating or controlling the operation of a receiver by the conjoint action of two or more of said receiving-circuits, as set forth.

6. The method of transmitting electrical energy which consists in producing a plurality of electrical waves or impulses of different periodicities, varying the order of transmission of the waves or impulses forming elements of the signal sent, according as one or another receiving-station is to be communicated with where (proper circuit-closing mechanism being provided at each receiving-station) the transmitted signal will be intelligible at and only at the intended receiving-station.

7. The method of transmitting intelligence, which consists in selecting and associating together in predetermined order of succession two or more electrically-generated impulses of different periodicity, forming elements of signals to be sent, and transmitting such selected impulses with reference to the conjoint action of both or all in the production of a signal at a distant point, substantially as set forth.

8. In a system of telegraphy, wherein signals or messages are sent by the use of a plurality of electrical impulses of different periodicities and in a predetermined order of succession, the method of ascertaining at any particular station the particular signal sent to that station, which consists in the selection, to form a signal, of certain transmitted impulses of different periodicities and of a predetermined order of succession to the exclusion of all others, as set forth.

9. The improvement in the art of transmitting electrical energy which consists in operating or controlling a receiving mechanism by a series or group of electrical impulses of different periodicities and of a predetermined order of succession.

10. In a system for the transmission of electrical energy, for sending signals or messages to any one of two or more receiving-stations, the method of transmitting the message with reference to the intelligible receipt thereof at the desired station, which consists in the transmission of electrical waves or impulses of different periodicities in varying order of transmittal by a separate order or grouping of transmittal for each receiving-station.

NIKOLA TESLA.

Witnesses:
M. LAWSON DYER,
BENJAMIN MILLER.

P-356

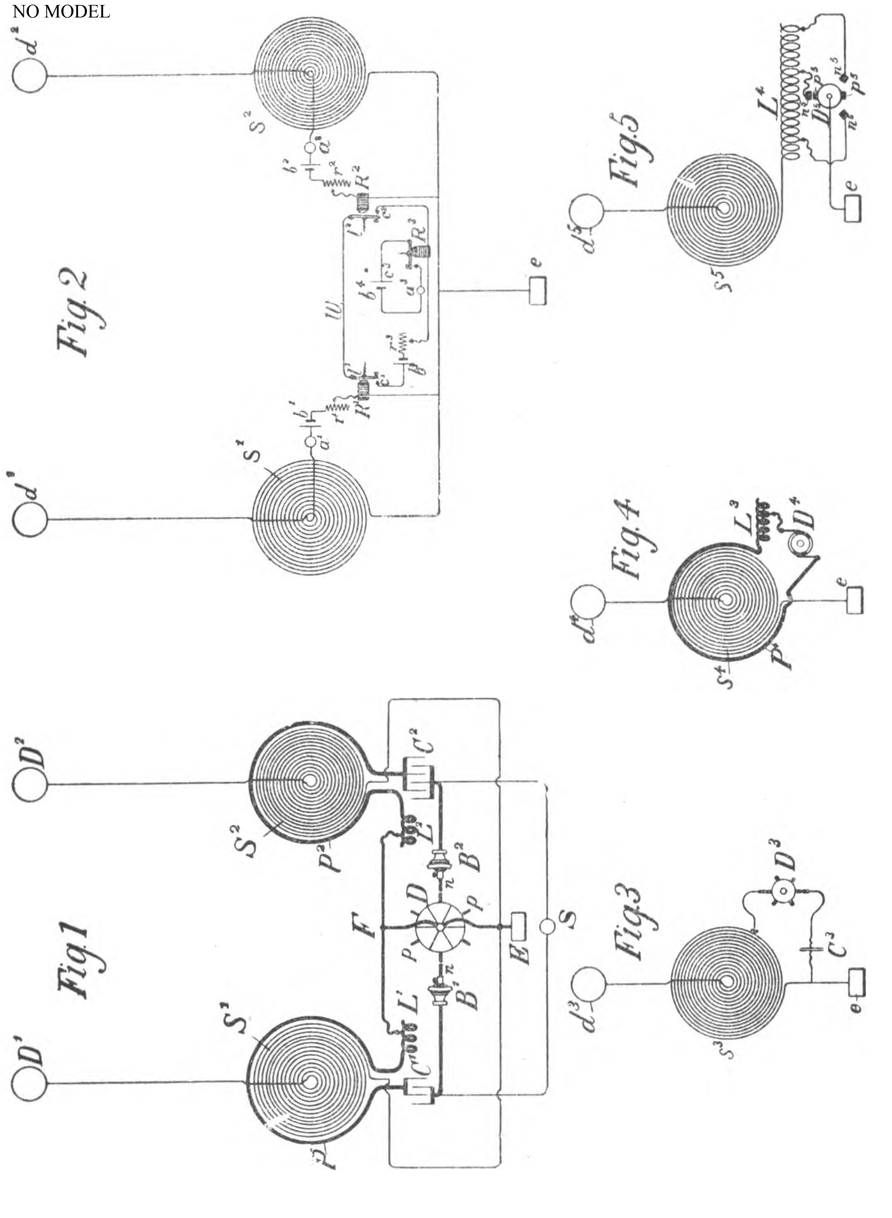
No. 723,188. PATENTED MAR. 17, 1903

N. TESLA.

METHOD OF SIGNALING.

APPLICATION FILED JUNE 14, 1901

NO MODEL



WITNESSES:
Benjamin Miller
Richard Donovan

INVENTOR.
Nikola Tesla
BY
Kerr, Page & Cooper
ATTORNEYS.

UNITED STATES PATENT OFFICE.

NIKOLA TESLA, OF NEW YORK, N. Y.

APPARATUS FOR TRANSMITTING ELECTRICAL ENERGY.

1,119,732. Specification of Letters Patent. Patented Dec. 1, 1914.

Application filed January 18, 1902, Serial No. 90,245. Renewed May 4, 1907. Serial No. 371,817.

To all whom it may concern:

Be it known that I, NIKOLA TESLA, a citizen of the United States, residing in the borough of Manhattan, in the city, county, and State of New York, have invented certain new and useful Improvements in Apparatus for Transmitting Electrical Energy, of which the following is a specification, reference being had to the drawing accompanying and forming a part of the same.

In endeavoring to adapt currents or discharges of very high tension to various valuable uses, as the distribution of energy through wires from central plants to distant places of consumption, or the transmission of powerful disturbances to great distances, through the natural or non-artificial media, I have encountered difficulties in confining considerable amounts of electricity to the conductors and preventing its leakage over their supports, or its escape into the ambient air, which always takes place when the electric surface density reaches a certain value.

The intensity of the effect of a transmitting circuit with a free or elevated terminal is proportionate to the quantity of electricity displaced, which is determined by the product of the capacity of the circuit, the pressure, and the frequency of the currents employed. To produce an electrical movement of the required magnitude it is desirable to charge the terminal as highly as possible, for while a great quantity of electricity may also be displaced by a large capacity charged to low pressure, there are disadvantages met with in many cases when the former is made too large. The chief of these are due to the fact that an increase of the capacity entails a lowering of the frequency of the impulses or discharges and a diminution of the energy of vibration. This will be understood when it is borne in mind, that a circuit with a large capacity behaves as a slack spring, whereas one with a small capacity acts like a stiff spring, vibrating more vigorously. Therefore, in order to attain the highest possible frequency, which for certain purposes is advantageous and, apart from that, to develop the greatest energy in such a transmitting circuit, I employ a terminal of relatively small capacity, which I charge to as high a pressure as practicable. To accomplish this result I have found it imperative to so construct the elevated conductor, that its outer surface, on which the electrical charge chiefly accumulates, has itself a large radius of curvature, or is composed of separate elements which, irrespective of their own radius of curvature, are arranged in close proximity to each other and so, that the outside ideal surface enveloping them is of a large radius. Evidently, the smaller the radius of curvature the greater, for a given electric displacement, will be the surface-density and, consequently, the lower the limiting pressure to which the terminal may be charged without electricity escaping into the air. Such a terminal I secure to an insulating support entering more or less into its interior, and I likewise connect the circuit to it inside or, generally, at points where the electric density is small. This plan of constructing and supporting a highly charged conductor I have found to be of great practical importance, and it may be usefully applied in many ways.

Referring to the accompanying drawing, the figure is a view in elevation and part section of an improved free terminal and circuit of large surface with supporting structure and generating apparatus.

The terminal D consists of a suitably shaped metallic frame, in this case a ring of nearly circular cross section, which is covered with half spherical metal plates P P, thus constituting a very large conducting surface, smooth on all places where the electric charge principally accumulates. The frame is carried by a strong platform expressly provided for safety appliances, instruments of observation, etc., which in turn rests on insulating supports F F. These should penetrate far into the hollow space formed by the terminal, and if the electric density at the points where they are bolted to the frame is still considerable, they may be specially protected by conducting hoods as H.

A part of the improvements which form the subject of this specification, the transmitting circuit, in its general features, is identical with that described and claimed in my original Patents Nos. 645,576 and 649,621. The circuit comprises a coil A which is in close inductive relation with a primary C, and one end of which is connected to a ground-plate E, while its other end is led through a separate self induction coil B and a metallic cylinder B' to the terminal D.

The connection to the latter should always be made at, or near the center, in order to secure a symmetrical distribution of the current, as otherwise, when the frequency is very high and the flow of large volume, the performance of the apparatus might be impaired The primary C may be excited in any desired manner, from a suitable source of currents G, which may be an alternator or condenser, the important requirement being that the resonant condition is established, that is to say, that the terminal D is charged to the maximum pressure developed in the circuit, as I have specified in my original patents before referred to. The adjustments should be made with particular care when the transmitter is one of great power, not only on account of economy, but also in order to avoid danger. I have shown that it is practicable to produce in a resonating circuit as E A B B' D immense electrical activities, measured by tens and even hundreds of thousands of horse-power, and in such a case, if the points of maximum pressure should be shifted below the terminal D, along coil B, a ball of fire might break out and destroy the support F or anything else in the way. For the better appreciation of the nature of this danger it should be stated, that the destructive action may take place with inconceivable violence This will cease to be surprising when it is borne in mind, that the entire energy accumulated in the excited circuit, instead of requiring, as under normal working conditions, one quarter of the period or more for its transformation from static to kinetic form, may spend itself in an incomparably smaller interval of time, at a rate of many millions of horse power The accident is apt to occur when, the transmitting circuit being strongly excited, the impressed oscillations upon it are caused, in any manner more or less sudden, to be more rapid than the free oscillations. It, is therefore advisable to begin the adjustments with feeble and somewhat slower impressed oscillations, strengthening and quickening them gradually, until the apparatus has been brought under perfect control To increase the safety. I provide on a convenient place, preferably on terminal D, one or more elements or plates either of somewhat smaller radius of curvature or protruding more or less beyond the others (in which case they may be of larger radius of curvature) so that, should the pressure rise to a value, beyond which it is not desired to go, the powerful discharge may dart out there and lose itself harmlessly in the air. Such a plate, performing a function similar to that of a safety valve on a high pressure reservoir, is indicated at V.

Still further extending the principles underlying my invention, special reference is made to coil B and conductor B' The latter is in the form of a cylinder with smooth or polished surface of a radius much larger than that of the half spherical elements P P, and widens out at the bottom into a hood H, which should be slotted to avoid loss by eddy currents and the purpose of which will be clear from the fore going. The coil B is wound on a frame or drum D' of insulating material, with its turns close together I have discovered that when so wound the effect of the small radius of curvature of the wire itself is overcome and the coil behaves as a conductor of large radius of curvature, corresponding to that of the drum. This feature is of considerable practical importance and is applicable not only in this special instance, but generally. For example, such plates at P P of terminal D, though preferably of large radius of curvature, need not be necessarily so, for provided only that the individual plates or elements of a high potential conductor or terminal are arranged in proximity to each other and with their outer boundaries along an ideal symmetrical enveloping surface of a large radius of curvature, the advantages of the invention will be more or less fully realized. The lower end of the coil B—which, if desired, may be extended up to the terminal D—should be somewhat below the uppermost turn of coil A. This, I find, lessens the tendency of the charge to break out from the wire connecting both and to pass along the support F'.

Having described my invention, I claim—

1. As a means for producing great electrical activities a resonant circuit having its outer conducting boundaries, which are charged to a high potential, arranged in surfaces of large radii of curvature so as to prevent leakage of the oscillating charge, substantially as set forth.

2. In apparatus for the transmission of electrical energy a circuit connected to ground and to an elevated terminal and having its outer conducting boundaries, which are subject to high tension, arranged in surfaces of large radii of curvature substantially as, and for the purpose described.

3 In a plant for the transmission of electrical energy without wires, in combination with a primary or exciting circuit a secondary connected to ground and to an elevated terminal and having its outer conducting boundaries, which are charged to a high potential, arranged in surfaces of large radii of curvature for the purpose of preventing leakage and loss of energy, substantially as set forth.

4. As a means for transmitting electrical energy to a distance through the natural media a grounded resonant circuit, comprising a part upon which oscillations are impressed and another for raising the ten-

sion, having its outer conducting boundaries on which a high tension charge accumulates arranged in surfaces of large radii of curvature, substantially as described.

5. The means for producing excessive electric potentials consisting of a primary exciting circuit and a resonant secondary having its outer conducting elements which are subject to high tension arranged in proximity to each other and in surfaces of large radii of curvature so as to prevent leakage of the charge and attendant lowering of potential, substantially as described.

6. A circuit comprising a part upon which oscillations are impressed and another part for raising the tension by resonance, the latter part being supported on places of low electric density and having its outermost conducting boundaries arranged ip surfaces of large radii of curvature, as set forth.

7. In apparatus for the transmission of electrical energy without wires a grounded circuit the outer conducting elements of which have a great aggregate area and are arranged in surfaces of large radii of curvature so as to permit the storing of a high charge at a small electric density and prevent loss through leakage, substantially as described.

8. A wireless transmitter comprising in combination a source of oscillations as a condenser, a primary exciting circuit and a secondary grounded and elevated conductor the outer conducting boundaries of which are in proximity to each other and arranged in surfaces of large radii of curvature, substantially as described.

9. In apparatus for the transmission of electrical energy without wires an elevated conductor or antenna having its outer high potential conducting or capacity elements arranged in proximity to each other and in surfaces of large radii of curvature so as to overcome the effect of the small radius of curvature of the individual elements and leakage of the charge, as set forth.

10. A grounded resonant transmitting circuit having its outer conducting boundaries arranged in surfaces of large radii of curvature in combination with an elevated terminal of great surface supported at points of low electric density, substantially as described.

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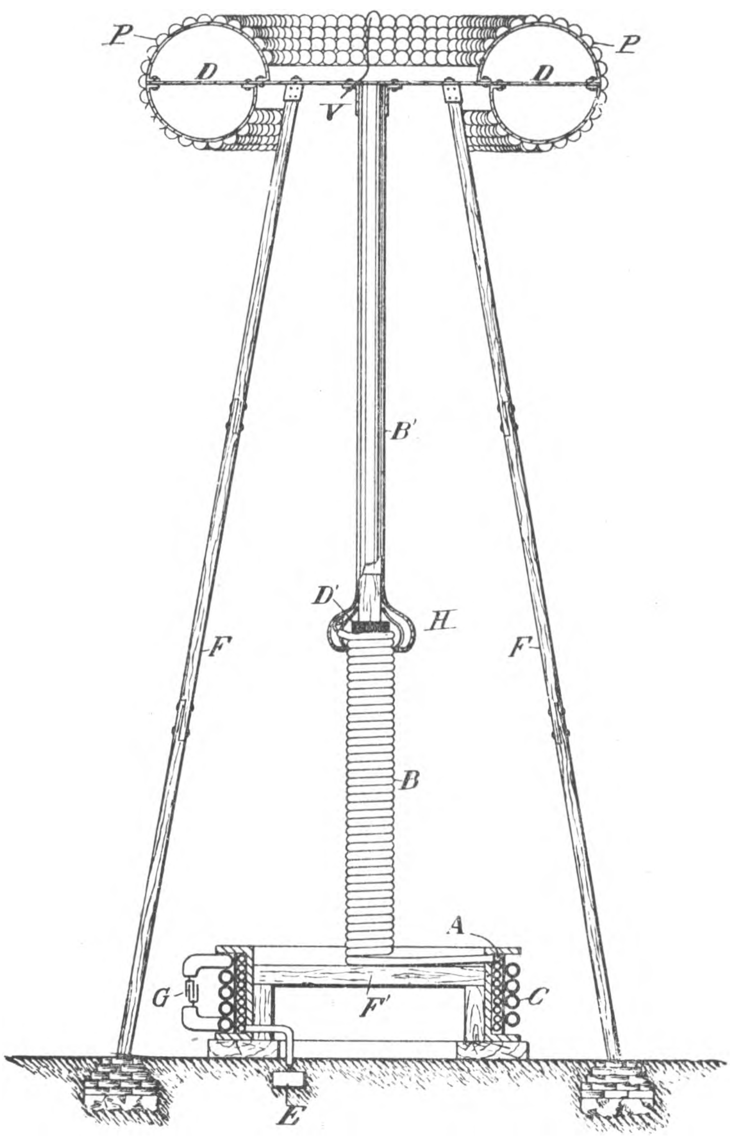
APPARATUS FOR TRANSMITTING ELECTRICAL ENERGY.

APPLICATION FILED JAN. 18. 1902, RENEWED MAY 4, 1907.

1.119,732. Patented Dec. 1, 1914



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VI

TELEMECHANICS

UNITED STATES PATENT OFFICE

NIKOLA TESLA, OF NEW YORK, N. Y.

METHOD OF AND APPARATUS FOR CONTROLLING MECHANISM OF MOVING VESSELS OF VEHICLES

SPECIFICATION forming part of Letters Patent No. 613,899, dated November 8, 1898.

Application filed July 1, 1898, Serial No. 634,934. (No model.)

To all whom it may concern:

Be it known that I, NIKOLA TESLA, a citizen of the United States, residing at New York, in the county and State of New York, have invented certain new and useful improvements in methods of and apparatus for controlling from a distance the operation of the propelling-engines, the steering apparatus, and other mechanism carried by moving bodies or floating vessels, of which the following is a specification, reference being had to the drawings accompanying and forming part of the same.

The problem for which the invention forming the subject of my present application affords a complete and practicable solution is that of controlling from a given point the operation of the propelling-engines, the steering apparatus, and other mechanism carried by a moving object, such as a boat or any floating vessel, whereby the movements and course of such body or vessel may be directed and controlled from a distance and any device carried by the same brought into action at any desired time. So far as I am aware the only attempts to solve this problem which have heretofore met with any measure of success have been made in connection with a certain class of vessels the machinery of which was governed by electric currents conveyed to the controlling apparatus through a flexible conductor; but this system is subject to such obvious limitations as are imposed by the length, weight, and strength of the conductor which can be practically used, by the difficulty of maintaining with safety a high speed of the vessel or changing the direction of movement of the same with the desired rapidity, by the necessity for effecting the control from a point which is practically fixed, and by many well-understood drawbacks inseparably connected with such a system. The plan which I have perfected involves none of these objections, for I am enabled by the use of my invention to employ any means of propulsion, to impart to the moving body or vessel the highest possible speed, to control the operation of its machinery and to direct its movements from either a fixed point or from a body moving and changing its direction however rapidly, and to maintain this control over great distances without any artificial connections between the vessel and the apparatus governing its movements and without such restrictions as these must necessarily impose.

In a broad sense, then, my invention differs from all of those systems which provide for the control of the mechanism carried by a moving object and governing its motion in that I require no intermediate wires, cables, or other form of electrical or mechanical connection with the object save the natural media in space. I accomplish, nevertheless, similar results and in a much more practicable manner by producing waves, impulses, or radiations which are received through the earth, water, or atmosphere by suitable apparatus on the moving body and cause the desired actions so long as the body remains within the active region or effective range of such currents, waves, impulses, or radiations.

The many and difficult requirements of the object here contemplated, involving peculiar means for transmit ting to a considerable distance an influence capable of causing in a positive and reliable manner these actions, necessitated the designing of devices and apparatus of a novel kind in order to utilize to the best advantage various facts or results, which, either through my own investigations or those of others, have been rendered practically available.

As to that part of ray invention which involves the production of suitable waves or variations and the conveying of the same to a remote receiving apparatus capable of being operated or controlled by their influence, it may be carried out in various ways, which are at the present time more or lees understood. For example, I may pass through a conducting-path, preferably inclosing a large area, a rapidly-varying current and by electromagnetic induction of the same affect a circuit carried by the moving body. In this case the action at a given distance will be the stronger the larger the area inclosed by the conductor and the greater the rate of change of the current. If the latter were generated in the ordinary ways, the rate of change, and consequently the distance at which the action would be practically available for the present purpose, would be very small; but by adopting such means as I have devised—that is, either by passing through the conducting-path currents of a specially-designed high-frequency alternator or, better still, those of a strongly-charged condenser—a very high rate of change may be obtained and the effective range of the influence thus extended over a vast area, and by carefully adjusting the circuit on the moving body so as to be in exact electromagnetic synchronism with the primary disturbances this influence may be utilised at great distances.

Another way to carry out my invention is to direct the currents or discharges of a high-frequency machine or condenser through a circuit one terminal of which is connected directly or inductively with the ground and the other to a body, preferably of large surface and at an elevation. In this case if the circuit on the moving body be similarly arranged or connected differences of potential on the terminals of the circuit either by conduction or electrostatic induction are produced and the same object is attained. Again, to secure the best action the receiving-circuit should be adjusted so as to be in electromagnetic synchronism with the primary source, as before; but in this instance it will be understood by those skilled in the art that if the number of vibrations per unit of time be the same the circuit should now have a length of conductor only one-half of that used in the former case.

Still another way is to pass the currents simply through the ground by connecting both the terminals of the source of high-frequency currents to earth at different and remote points and to utilize the currents spreading through the ground for affecting a receiving-circuit properly placed and adjusted. Again, in this instance if only one of the terminals of the receiving-circuit be connected to the ground, the other terminal being insulated, the adjustment as to synchronism with the source will require that under otherwise equal conditions the length of wire be half of that which would be used if both the terminals be connected or, generally, if the circuit be in the form of a closed loop or coil. Obviously also in the latter case the relative position of the receiving and transmitting circuits is of importance, whereas if the circuit be of the former kind—that is, open—the relative position of the circuits is, as a rule, of little or no consequence.

Finally, I may avail myself, in carrying out my invention, of electrical oscillations which do not follow any particular conducting-path, but propagate in straight lines through space, of rays, waves, pulses, or disturbances of any kind capable of bringing the mechanism of the moving body into action from a distance and at the will of the operator by their effect upon suitable controlling devices.

In the following detailed description I shall confine myself to an explanation of that method and apparatus only which I have found to be the most practical and effectual; but obviously my invention in its broad features is not limited to the special mode and appliances which I have devised and shall here describe.

In any event—that is to say, whichever of the above or similar plans I may adopt—and particularly when the influence exerted from a distance upon the receiving-circuit be too small to directly and reliably affect and actuate the controlling apparatus I employ auxiliary sensitive relays or, generally speaking, means capable of being brought into action by the feeblest influences in order to effect the control of the movements of the distant body with the least possible expenditure of energy and at the greatest practicable distance, thus extending the range and usefulness of my invention.

A great variety of electrical and other devices more or less suitable for the purpose of detecting and utilizing feeble actions are now well known to scientific men and artisans and need not be all enumerated here. Confining myself merely to the electrical as the most practicable of such means and referring only to those which, while not the most sensitive, are perhaps more readily available from the more general knowledge which exists regarding them, I may state that a contrivance may be used which has long been known and used as a lightning-arrester in connection with telephone-switchboards for operating annunciators and like devices, comprising a battery the poles of which are connected to two conducting-terminals separated by a minute thickness of dielectric. The electromotive force of the battery should be such as to strain the thin dielectric layer very nearly to the point of breaking down in order to increase the sensitiveness. When an electrical disturbance reaches a circuit so arranged and adjusted, additional strain is put upon the insulating-film, which gives way and allows the passage of a current which can be utilized to operate any form of circuit-controlling apparatus.

Again, another contrivance capable of being utilized in detecting feeble electrical effects consists of two conducting plates or terminals which have, preferably, wires of some length attached to them and are bridged by a mass of minute particles of metal or other conducting material. Normally these particles lying loose do not connect the metal plates; but under the influence of an electrical disturbance produced at a distance, evidently owing to electrostatic attraction, they are pressed firmly against each other, thus establishing a good electrical connection between the two terminals. This change of state may be made use of in a number of ways for the above purpose.

Still another modified device, which may be said to embody the features of both the former, is obtained by connecting the two conducting plates or terminals above referred to permanently with the poles of a battery which should be of very constant electromotive force. In this arrangement a distant electrical disturbance produces a twofold effect on the conducting particles and insulating-films between them. The former are brought nearer to each other in consequence of the sudden increase of electrostatic attraction, and the latter, owing to this, as well as by being reduced in thickness or in number, are subjected to a much greater strain, which they are unable to withstand.

It will be obviously noted from the preceding that whichever of these or similar contrivances be used the sensitiveness and, what is often still more important, the reliability of operation is very materially increased by a close adjustment of the periods of vibration of the transmitting and receiving-circuits, and, although such adjustment is in many cases unnecessary for the successful carrying out of my invention, I nevertheless make it a rule to bestow upon this feature the greatest possible care, not only because of the above-mentioned advantages, which are secured by the observance of the most favorable conditions in this respect, but also and chiefly with the object of preventing the receiving-circuit from being affected by waves or disturbances emanating from sources not under the control of the operator. The narrower the range of vibrations which are still capable of perceptibly affecting the receiving-circuit the safer will the latter be against extraneous disturbances. To secure the best result, it is necessary, as is well known to experts, to construct the receiving-circuit or that part of the same in which the vibration chiefly occurs so that it will have the highest possible self-induction and at the same time the least possible resistance. In this manner I have demonstrated the practicability of providing a great number of such receiving-circuits—fifty or a hundred, or more—each of which may be called up or brought into action whenever desired without the others being interfered with. This result makes it possible for one operator to direct simultaneously the movements of a number of bodies as well as to control the action of a number of devices located on the same body, each of which may have a distinct duty to fulfil. In the following description, however, I shall show a still further development in this direction—namely, how, by making use of merely one receiving-circuit, a great variety of devices may be actuated and any number of different functions performed at the will and command of the distant operator.

It should be stated in advance in regard to the sensitive devices above mentioned, which may be broadly considered as belonging to one class, inasmuch as the operation of all of them involves the breaking down of a minute thickness of highly-strained dielectric, that it is necessary to make some provision for automatically restoring to the dielectric its original unimpaired insulating qualities in order to enable the device to be used in successive operations. This is usually accomplished by a gentle tapping or vibration of the electrodes or particles or continuous rotation of the same; but in long experience with many forms of these devices I have found that such procedures, while suitable in simple and comparatively unimportant operations, as ordinary signaling, when it is merely required that the succeeding effects produced in the receiving-circuit should differ in regard to their relative duration only, in which case it is of little or no consequence if some of the individual effects be altered or incomplete or even entirely missed, do not yield satisfactory results in many instances, when it may be very important that the effects produced should all be exactly such as desired and that none should fail. To illustrate, let it be supposed that an official directing the movements of a vessel in the manner described should find it necessary to bring into action a special device on the latter or to perform a particular operation, perhaps of vital moment, at an instant's notice and possibly when, by design or accident, the vessel itself or any mark indicating its presence is hidden from his view. In this instance a failure or defective action of any part of the apparatus might have disastrous consequences and such cases in which the sure and timely working of the machinery is of paramount importance may often present themselves in practice, and this consideration has impressed me with the necessity of doing away with the defects in the present devices and procedures and of producing an apparatus which while being sensitive will also be most reliable and positive in its action. In the arrangement hereinafter described these defects are overcome in a most satisfactory manner, enabling thousands of successive operations, in all respects alike, being performed by the controlling apparatus without a single irregularity or miss being recorded. For a better understanding of these and other details of the invention as I now carry them out I would refer to the accompanying drawings, in which—

Figure 1 is a plan view of a vessel and mechanism within the same. Fig. 2 is a longitudinal section of the same, showing the interior mechanism in side elevation. Fig. 3 is a plan view, partially diagrammatical, of the vessel, apparatus, and circuit connections of the same. Fig. 4 is a plan view, on an enlarged scale, of a portion of the controlling mechanism. Fig. 5 is an end view of the same. Fig. 6 shows the same mechanism in side elevation. Fig. 7 is a side view of a detail of the mechanism. Fig. 8 is a central sectional view, on a larger scale, of a sensitive device forming part of the receiving-circuit. Fig. 9 is a diagrammatic illustration of the system in its preferred form. Fig. 10 is a view of the various mechanisms employed, but on a larger scale, and leaving out or indicating conventionally certain parts of well-understood character.

Referring to Figs. 1 and 2, A designates any type of vessel or vehicle which is capable of being propelled and directed, such as a boat, a balloon, or a carriage. It may be designed to carry in a suitable compartment B objects of any kind, according to the nature of the uses to which it is to be applied. The vessel—in this instance a boat—is provided with suitable propelling machinery, which is shown as comprising a screw-propeller C, secured to the shaft of an electromagnetic motor D, which derives its power from storage batteries E E E E. In addition to the propelling engine or motor the boat carries also a small steering-motor F, the shaft of which is extended beyond its bearings and provided with a worm which meshes with a toothed wheel G. This latter is fixed to a sleeve *b*, freely movable on a vertical rod H, and is rotated in one or the other direction, according to the direction of rotation of the motor F.

The sleeve *b* on rod H is in gear, through the cog-wheels H' and H", with a spindle G, mounted in vertical bearings at the stem of the boat and carrying the rudder F'.

The apparatus by means of which the operation of both the propelling and steering mechanisms is controlled involves, primarily, a receiving-circuit, which for reasons before stated is preferably both adjusted and rendered sensitive to the influence of waves or impulses emanating from a remote source, the adjustment being so that the period of oscillation of the circuit is either the same as that of the source or a harmonic thereof.

The receiving-circuit proper (diagrammatically shown in figs. 3 and 10) comprises a terminal E', conductor C', a sensitive device A', and a conductor A", leading to the ground conveniently through a connection to the metal keel B' of the vessel. The terminal E' should present a large conducting-surface and should be supported as high as practicable on a standard D', which is shown as broken in Fig. 2; but such provisions are not always necessary. It is important to insulate very well the conductor C' in whatever manner it be supported.

The circuit or path just referred to forms also a part of a local circuit, which latter includes a relay-magnet *a* and a battery *a*', the electromotive force of which is, as before explained, so determined that although the dielectric layers in the sensitive device A' are subjected to a great strain, yet normally they withstand the strain and no appreciable current flows through the local circuit; but when an electrical disturbance reaches the circuit the dielectric films are broken down, the resistance of the device A' is suddenly and greatly diminished, and a current traverses the relay-magnet A.

The particular sensitive device employed is shown in general views and in detail in Figs. 4, 6, 7, and 8. It consists of a metal cylinder *c*, with insulating-heads *c*', through which passes a central metallic rod *c*". A small quantity of grains *d* of conducting material, such as an oxidized metal, is placed in the cylinder. A metallic strip *d*', secured to an insulated post *d*", bears against the side of the cylinder *c*, connecting it with the conductor C', forming one part of the circuit. The central rod *c*" is connected to the frame of the instrument and so to the other part of the circuit through the forked metal arm *e*, the ends of which are fastened with two nuts to the projecting ends of the rod, by which means the cylinder *c* is supported.

In order to interrupt the flow of battery-current which is started through the action of the sensitive device A', special means are provided, which are as follows: The armature *e*' of the magnet *a*, when attracted by the latter, closes a circuit containing a battery *b*' and magnet *f*. The armature-lever *f*' of this magnet is fixed to a rock-shaft *f*", to which is secured an anchor-escapement *g*, which controls the movements of a spindle *g*', driven by a clock-train K. The spindle *g*' has fixed to it a disk *g*" with four pins *b*", so that for each oscillation of the escapement *g* the spindle *g*' is turned through one-quarter of a revolution. One of the spindles in the clock-train, as *h*, is geared so as to make one-half of a revolution for each quarter-revolution of spindle *g*'. The end of the former spindle extends through the side of the frame and carries an eccentric cylinder *h*', which passes through a slot in a lever *h*", pivoted to the side of the frame. The forked arm *e*, which supports the cylinder *c*, is pivoted to the end of eccentric *h*', and the eccentric and said arm are connected by a spiral spring *l*. Two pins *i*' *i*' extend out from the lever *h*", and one of these is always in the path of a projection on arm *e*. They operate to prevent the turning of cylinder *c* with the spindle *h* and the eccentric. It will be evident that a half-revolution of the spindle *h* will wind up the spring *i* and at the same time raise or lower the lever *h*", and these parts are so arranged that just before the half-revolution of the spindle is completed the pin *i*', in engagement with projection or stop-pin *p*, is withdrawn from its path, and the cylinder *c*, obeying the force of the spring *i*, is suddenly turned end for end, its motion being checked by the other pin *i*'. The adjustment relatively to armature *f*' of magnet *f* is furthermore so made that the pin *i*' is withdrawn at the moment when the armature has nearly reached its extreme position in its approach toward the magnet—that is, when the lever *l*, which carries the armature *f*', almost touches the lower one of the two stops *s s*, Fig. 5—which limits its motion in both directions.

The arrangement just described has been the result of long experimenting with the object of overcoming certain defects in devices of this kind, to which reference has been made before. These defects I have found to be due to many causes, as the unequal size, weight, and shape of the grains, the unequal pressure which results from this and from the manner in which the grains are usually agitated, the lack of uniformity in the conductivity of the surface of the particles owing to the varying thickness of the superficial oxidized layer, the varying condition of the gas or atmosphere in which the particles are immersed, and to certain deficiencies, well known to experts, of the transmitting apparatus as heretofore employed, which are in a large measure reduced by the use of my improved high-frequency coils. To do away with the defects in the sensitive device, I prepare the particles so that they will be in all respects is nearly alike as possible. They are manufactured by a special tool, insuring their equality in size, weight, and shape, and are then uniformly oxidized by placing them for a given time in an acid solution of predetermined strength. This secures equal conductivity of their surfaces and stops their further deterioration, thus preventing a change in the character of the gas in the space in which they are inclosed. I prefer not to rarefy the atmosphere within the sensitive device, as this has the effect of rendering the former less constant in regard to its dielectric properties, but merely secure an air-tight inclosure of the particles and rigorous absence of moisture, which is fatal to satisfactory working.

The normal position of the cylinder *c* is vertical, and when turned in the manner described the grains in it are simply shifted from one end to the other; but inasmuch as they always fall through the same space and are subjected to the same agitation they are brought after each operation of the relay to precisely the same electrical condition and offer the same resistance to the flow of the battery-current until another impulse from afar reaches the receiving-circuit.

The relay-magnet *a* should be of such character as to respond to a very weak current and yet be positive in its action. To insure the retraction of its armature *e'* after the current has been established through the magnet *f* and interrupted by the inversion of the sensitive device *c*, a light rod *k* is supported in guides on the frame in position to be lifted by an extension *k'* of the armature-lever *l* and to raise slightly the armature *e.* As a feeble current may normally flow through the sensitive device and the relay-magnet *a,* which would be sufficient to hold though not draw the armature down, it is well to observe this precaution.

The operation of the relay-magnet *a* and the consequent operation of the electromagnet *f,* as above described, are utilized to control the operation of the propelling-engine and the steering apparatus in the following manner: On the spindle *g'*, which carries the escapement-disk *g''* , Figs. 4 and 6, is a cylinder *j* of insulating material with a conducting plate or head at each end. From these two heads, respectively, contact plates or segments *j' j''* extend on diametrically opposite sides of the cylinder. The plate *j''* is in electrical connection with the frame of the instrument through the head from which it extends, while insulted strips or brushes J J' bear upon the free end or head of the cylinder and the periphery of the same, respectively. Three terminals are thus provided, one always in connection with plate *j'*, the other always in connection with the plate *j''* , and the third adapted to rest on the strips *j'* and *j''* in succession or upon the intermediate insulating-spaces, according to the position in which the commutator is brought by the clock-train and the anchor-escapement *g.*

K' K'', Figs. 1, 3, and 10, are two relay-magnets conveniently placed in the rear of the propelling-engine. One terminal of a battery *k''* is connected to one end of each of the relay-coils, the opposite terminal to the brush *J'*, and the opposite ends of the relay-coils to the brush J and to the frame of the instrument, respectively. As a consequence of this arrangement either the relay K' or K'' will be energized as the brush J' bears upon the plate *j'* or *j''* , respectively, or both relays will be inactive while the brush J' bears upon an insulating-space between the plates *j'* and *j''* . While one relay, as K', is energized, its armature closes a circuit through the motor F, which is rotated in a direction to throw the rudder to port. On the other hand, when relay K'' is active another circuit through the motor F is closed, which reverses its direction of rotation and shifts the rudder to starboard. These circuits, however, are at the same time utilized for other purposes, and their course is, in part, through apparatus which I shall describe before tracing their course.

The fixed rod H carries an insulating disk or head L, Fig. 2, to the under side of which are secured six brushes, 1, 2, 3, 4, 5, and 6, Fig. 3. The sleeve *b,* which surrounds the rod and is turned by the steering-motor F, carries a disk L', upon the upper face of which are two concentric circles of conducting contact-plates. Brushes 1, 2, 3, and 4 bear upon the inner circle of contacts, while the brushes 5 and 6 bear upon the outer circle of contacts. The outer circle of contacts comprises two long plates 7 and 8 on opposite sides of the disk and a series of shorter plates 9, 10, 11, 12, 13, and 14 in the front and rear. Flexible conductors *l' l''* connect the plates 7 and 8 with the terminals of the propelling-motor D, and the poles of the main battery E are connected to the brushes 5 and 6, respectively, so that while the rudder is straight or turned up to a certain angle to either side the current is conveyed through the brushes 5 and 6 and segments 7 and 8 to the propelling-motor D. The steering-motor F is also driven by current taken from the main battery E in the following manner: A conductor 15 from one pole of the battery leads to one of the commutator-brushes, and from the other brush runs a conductor 16 to one of the contacts of each relay K' K". When one of these relays, as K", is active, it continues this circuit through a wire 19 through one field-coil or set of coils on the motor F and thence to the brush 1. In a similar manner when the other relay K' is active the circuit is continued from wire 18 through a wire 20, the second or reversing set of field-coils, and to brush 2.

Both brushes 1 and 2 at all times when the rudder is not turned more than about forty-five degrees to one side are in contact with a long conducting-plate 21, and one brush in any position of the rudder is always in contact with said plate, and the latter is connected by a flexible conductor 22 with the opposite pole of the main battery. Hence the motor F may always be caused to rotate in one direction whatever may be the position of the rudder, and may be caused to rotate in either direction whenever the position of the rudder is less than a predetermined angle, conveniently forty-five degrees from the center position. In order, however, to prevent the rudder from being turned too far in either direction, the isolated plate 23 is used. Any movement of the rudder beyond a predetermined limit brings this plate under one or the other of the brushes 1 2 and breaks the circuit of motor. F, so that the rudder can be driven no farther in that direction, but, as will be understood, the apparatus is in condition to turn the rudder over to the other side. In like manner the circuit of the propelling-motor D is controlled through brushes 5 and 6 and the segments on the outer circle of contacts of head L. If the short segments on either side of the circle are insulated, the motor D will be stopped whenever one of the brushes 5 or 6 passes onto one of them from the larger segments 7 8.

It is important to add that on all contact-points where a break occurs provision should be made to overcome the sparking and prevent the oscillation of electrical charges in the circuits, as such sparks and oscillations may affect the sensitive device. It is this consideration chiefly which makes it advisable to use the two relays K' K", which otherwise might be dispensed with. They should be also placed as far as practicable from the sensitive device in order to guard the latter against any action of strong varying currents.

In addition to the mechanism described the vessel may carry any other devices or apparatus as might be required for accomplishing any special object of more or less importance. By way of illustration a small motor *m* is shown, Figs. 1 and 3, which conveniently serves for a number of purposes. This motor is shown connected in series with the armature of the steering-motor F, so that whenever either one of the circuits of the latter is closed through relays K' K" the motor *m* is likewise rotated, but in all eases in the same direction. Its rotation is opposed by a spring *m'*, so that in normal operation, owing to the fact that the circuits of motor F are closed but a short time, the lever *m"*, which is fastened to one of the wheels of clockwork M, with which the armature of the motor is geared, will move but a short distance and upon cessation of the current return to a stop P; but if the circuits of the motor F are closed and opened rapidly in succession, which operation leaves the rudder unaffected, then the lever *m"* is moved to a greater angle, coming in contact with a metal plate *n*, and finally, if desired, with a post *n'*. Upon the lever *m"* coming in contact with plate *n* the current of the main battery passes either through one or other or both of the lights supported on standards *q q,* according to the position of brushes 3 and 4 relatively to the insulating-segment 23; but since the head L, carrying the segments, is geared to the rudder the position of the latter is in a general way determined by observing the lights. Both of the lights may be colored, and by flashing them up whenever desired the operator may guide at night the vessel in its course. For such purposes also the standards *r r* are provided, which should be painted in lively colors, so as to be visible by day at great distances. By opening and closing the circuits of motor F a greater number of times, preferably determined beforehand, the lever *m"* is brought in contact with post *n'*, thus closing the circuit of the main battery through a device *o* and bringing the latter into action at the moment desired. By similar contrivances or such as will readily suggest themselves to mechanicians any number of different devices may be operated.

Referring now to Fig. 9, which illustrates diagrammatically the system as practiced when directing the movements of a boat, in this figure S designates any source of electrical disturbance or oscillations the generation of which is controlled by a suitable switch contained in box T. The handle of the switch is movable in one direction only and stops on four points *t t' u u'*, so that as the handle passes from stop to stop oscillations are produced by the source during a very short lime interval. There are thus produced four disturbances during one revolution and the receiving-circuit is affected four times; but it will be understood from the foregoing description of the controlling devices on the vessel that the rudder will be moved twice, once to right and once to left. Now I preferably place the handle of the switch so that when it is arrested on points *t t'*—that is, to the right or left of the operator—he is reminded that the vessel is being deflected to the right or left from its course, by which means the control is facilitated. The normal positions of the handle are therefore at *u u'* when the rudder is not acted upon, and it remains on the points *u u'* only so long as necessary. Since, as before stated, the working of the apparatus is very sure, the operator is enabled to perform any such operations as provision is made for without even seeing the vessel.

The manner of using the apparatus and the operation of the several instrumentalities comprising the same is in detail as follows: Normally the plate L' is turned so that brush 2 rests upon the insulated segment 23 and brush 6 upon one of the insulated short segments in the rear of the circle. Under these conditions the rudder will be turned to starboard and the circuit of motor D interrupted between brushes 5 and 6. At the same time only one of the circuits of motor F—that controlled by relay K'—is capable of being closed, since brush 2, which connects with the other, is out of contact with the long segment 21. Assuming now that it is desired to start the vessel and direct it to a given point, the handle T is turned from its normal position on point *u'* to the point *t* on the switch-box. This sends out an electrical disturbance, which, passing through the receiving-circuit on the vessel, affects the sensitive device A' and starts the flow of current through the local circuit, including said device, the relay *a*, and the battery *a'*. This, as has been previously explained, turns the cylinder *j* and causes the brush J' to pass from insulation onto the contact *j'*. The battery *k"* is thus closed through relay K", and the latter closes that circuit of the motor F which, starting from plate 22, which is permanently connected with one pole of the main battery, is completed through the brush 1, the field of motor F, wire 19, the armature of relay K", wire 16, the motor *m*, the brushes and commutator of motor F, and wire 15 to the opposite terminal of the battery E. Motor F is thus set in operation to shift the rudder to port; but the movement of plate L' which follows brings the brush 6 back onto segment 8 and closes the circuit of the propelling-motor which starts the vessel. The motor F is permitted to run until the rudder has been turned sufficiently to steer the vessel in the desired direction, when the handle T is turned to the point *u*. This produces another action of the relay *a* and brush J' is shifted onto insulation and both relays K' and K" are inactive. The rudder remains in the position to which it has been shifted by the motor F. If it be then desired to shift it to starboard, or in the opposite direction to that in which it was last moved, the handle T is simply turned to point *t'* and allowed to remain there until the motor F, which is now operated by relay K', the circuit of which is closed by strip J' coming into contact with plate *j"* , has done its work. The movement of handle T to the next point throws out both relays K' and K", and the next movement causes a shifting of the rudder to port, and so on. Suppose, however, that after the rudder has been set at any angle to its middle position it be desired to shift it still farther in the name direction. In such case the handle is moved quickly over two points, so that the circuit which would move the rudder in the opposite direction is closed for too short a time interval to produce an appreciable effect and is allowed to rest on the third point until the rudder is shifted to the desired position, when the handle is moved to the next point, which again throws onto both relays K' and K". It will be understood that if the handle be held for a sufficiently long time upon either point *t* or *t'* the motor F will simply turn the plate L' in one direction or the other until the circuits of motors D and F are broken. It is furthermore evident that one relay K' or K" will always be operative to start the motor F.

As previously explained, the longest period of operation of which the motor F is capable under ordinary conditions of use does not permit the motor *m* to shift the arm *m'* into contact with the plate *n*; but if the handle T be turned with a certain rapidity a series of current impulses will be directed through motor *m*; but as these tend to rotate the motor F in opposite directions they do not sensibly affect the latter, but act to rotate the motor *m* against the force of the coiled spring.

The invention which I have described will prove useful in many ways. Vessels or vehicles of any suitable kind may be used, as life, despatch, or pilot boats or the like, or for carrying letters, packages, provisions, instruments, objects, or materials of any description, for establishing communication with inaccessible regions and exploring the conditions existing in the same, for killing or capturing whales or other animals of the sea, and for many other scientific, engineering, or commercial purposes; but the greatest value of my invention will result from its effect upon warfare and armaments, for by reason of its certain and unlimited destructiveness it will tend to bring about and maintain permanent peace among nations.

Having now described my invention; what I claim is—

1. The improvement in the art of controlling the movements and operation of a vessel or vehicle herein described, which consists in producing waves or disturbances which are conveyed to the vessel by the natural media, actuating thereby suitable apparatus on the vessel and effecting the control of the propelling-engine, the steering and other mechanism by the operation of the said apparatus, as set forth.

2. The improvement in the art of controlling the movements add operation of a vessel or vehicle, herein described, which consists in establishing a region of waves or disturbances, and actuating by their influence exerted at a distance the devices on such vessel or vehicle, which control the propelling, steering and other mechanism thereon, as set forth.

3. The improvement in the art of controlling the movements and operation of a vessel

or vehicle, herein described, which consists in establishing a region of electrical waves or disturbances, and actuating by their influence, exerted at a distance, the devices on said vessel or vehicle, which control the propelling, steering and other mechanism thereon, as set forth.

4. The improvement in the art of controlling the movements and operation of a vessel or vehicle, herein described, which consists in providing on the vessel a circuit controlling the propelling, steering and other mechanism, adjusting or rendering such circuit sensitive, to waves or disturbances of a definite character, establishing a region of such waves or disturbances, and rendering by their means the controlling-circuit active or inactive, as set forth.

5. The combination with a source of electrical waves or disturbances of a moving vessel or vehicle, and mechanism thereon for propelling, steering or operating the same, and a controlling apparatus adapted to be actuated by the influence of the said waves or disturbances at a distance from the source, as set forth.

6. The combination with a source of electrical waves or disturbances of a moving vessel or vehicle, mechanism for propelling, steering or operating the same, a circuit and means therein for controlling said mechanism, and means for rendering said circuit active or inactive through the influence of the said waves or disturbances exerted at a distance from the source, as set forth.

7. The combination with a source of electrical waves or disturbances and means for starting and stopping the same, of a vessel or vehicle, propelling and steering mechanism carried thereby, a circuit containing or connected with means for controlling the operation of said mechanism and adjusted or rendered sensitive to the waves or disturbances of the source, as set forth.

8. The combination with a source of electrical waves or disturbances, and means for starting and stopping the operation of the same, of a vessel or vehicle, propelling and steering mechanism carried thereby, local circuits controlling said mechanisms, a circuit sensitive to the waves or disturbances of the source and means therein adapted to control the said local circuits, as and for the purpose set forth.

9. The sensitive device herein described comprising in construction a receptacle containing a material such as particles of oxidized metal forming a part of the circuit, and means for turning the same end for end when the material has been rendered active by the passage through it of an electric discharge, as set forth

10. The sensitive device herein described, comprising in combination a receptacle containing a material such as particles of oxidized metal forming a part of an electric circuit, an electromagnet in said circuit, and devices controlled thereby for turning the receptacle end for end when said magnet is energized, as set forth.

11. The sensitive device herein described, comprising in combination a receptacle containing a material such as particles of oxidized metal forming part of an electric circuit, a motor for rotating the receptacle, an electromagnet in circuit with the material, and an escapement controlled by said magnet and adapted to permit a half-revolution of the receptacle when the said magnet is energized, as set forth.

12. The combination with a movable body or vehicle, of a propelling-motor, a steering-motor and electrical contacts carried by a moving portion of the steering mechanism, and adapted in certain positions of the latter to interrupt the circuit of the propelling-motor, a local circuit and means connected therewith for controlling the steering-motor, and a circuit controlling the local circuit and means for rendering said controlling-circuit sensitive to the influence of electric waves or disturbances exerted at a distance from their source, at set forth.

13. The combination with the steering-motor, a local circuit for directing current through the same in opposite directions, a controlling-circuit rendered sensitive to the influence of electric waves or disturbances exerted at a distance from their source, a motor in circuit with the steering-motor but adapted to run always in the same direction, and a local circuit or circuits controlled by said motor, as set forth.

NIKOLA TESLA.

Witnesses:
RAPHAËL NETTER,
GEORGE SCHERFF.

P-371

No. 613,809 Patented Nov. 8, 1898.

N. TESLA.

METHOD OF AND APPARATUS FOR CONTROLLING MECHANISM OF MOVING VESSELS OR VEHICLES.

(Application filed July 1, 1808.)

(No Model.) 5 Sheets—Sheet 1.

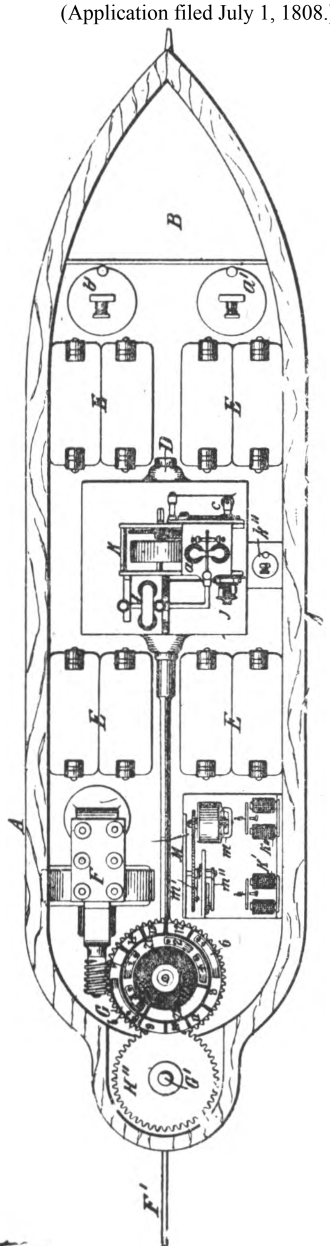

Fig. 1

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No. 613,809 Patented Nov. 8, 1898

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METHOD OF AND APPARATUS FOR CONTROLLING MECHANISM OF MOVING VESSELS OR VEHICLES.

(Application filed July 1, 1898.)

(No Model.) 5 Sheets—Sheet 2.

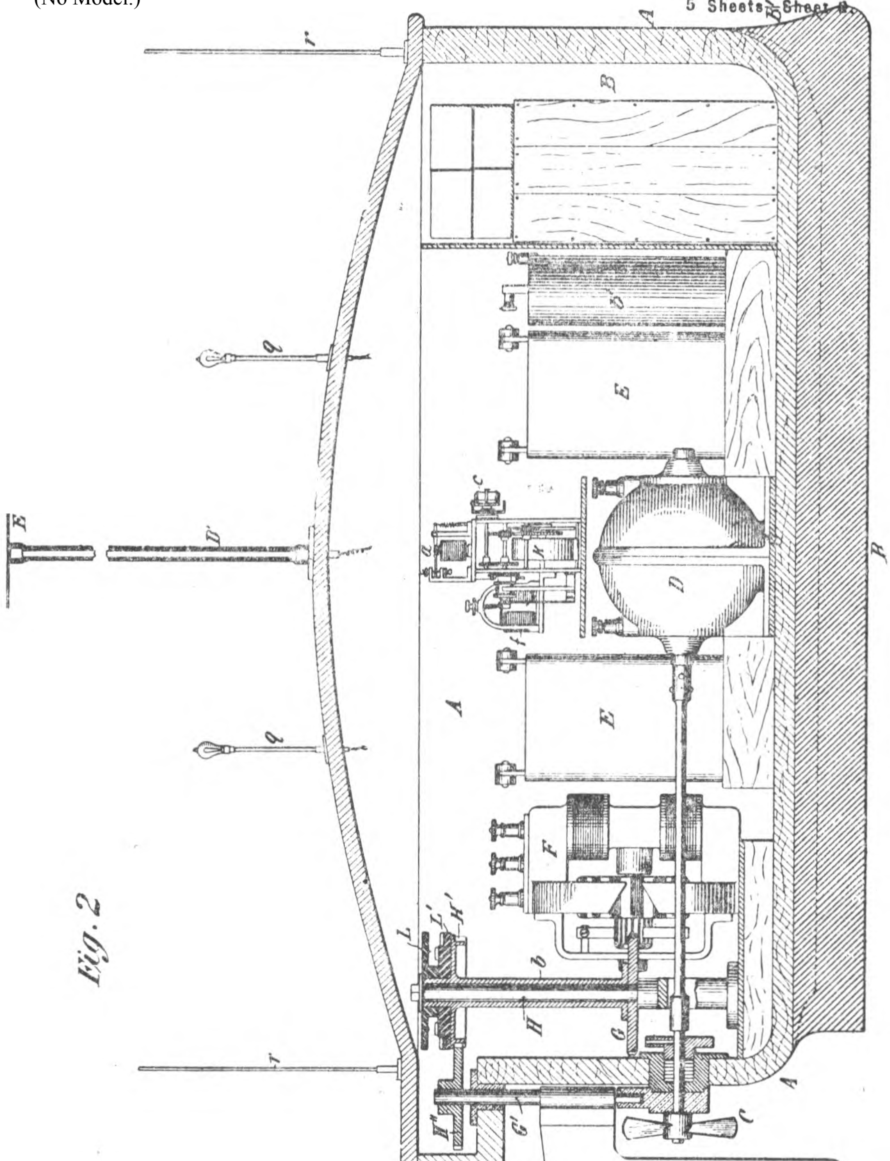

Fig. 2

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METHOD OF AND APPARATUS FOR CONTROLLING MECHANISM OF MOVING VESSELS OR VEHICLES.

(Application filed July 1, 1898.)

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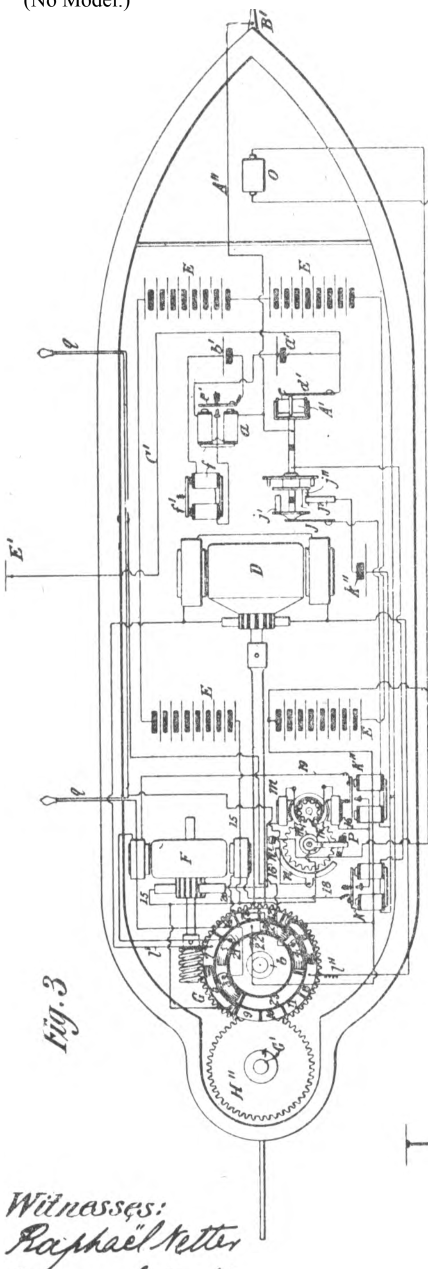

Fig. 3

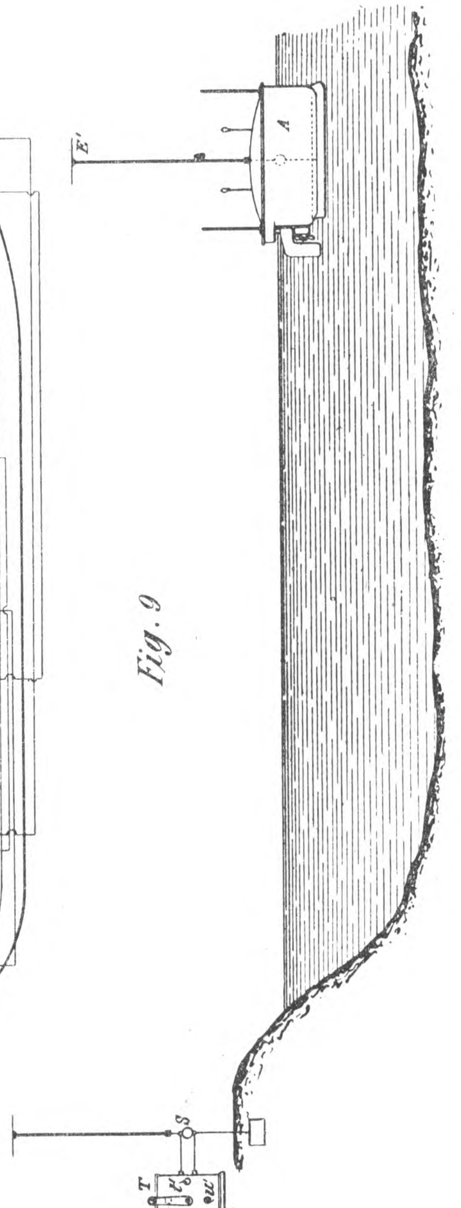

Fig. 9

Witnesses:
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P-374

No. 613.809 Patented Nov. 8. 1898.

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METHOD OF AND APPARATUS FOR CONTROLLING MECHANISM OF MOVING VESSELS OR VEHICLES.

(Application filed July 1, 1898.)

(No Model.) 5 Sheets—Sheet 4.

Fig. 5

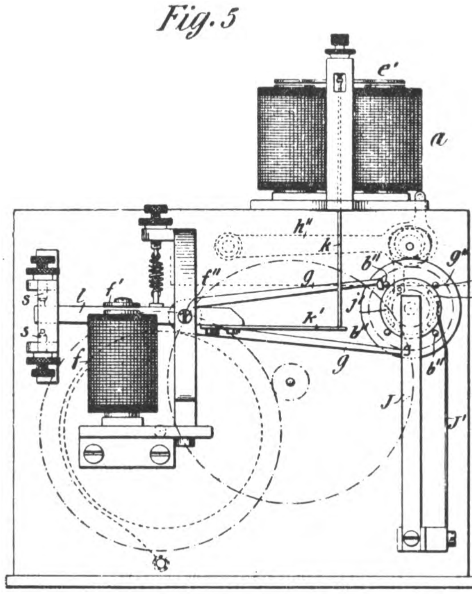


Fig. 6

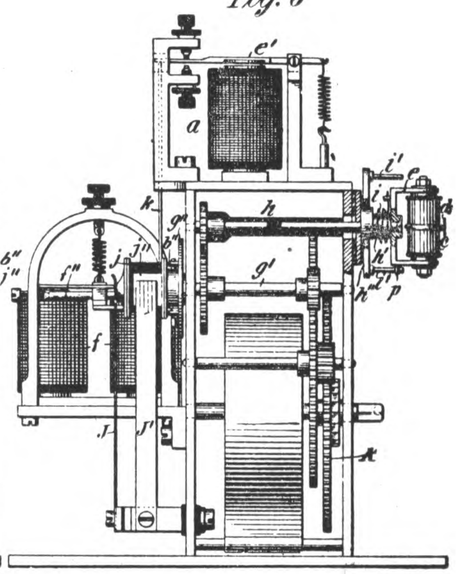


Fig. 4

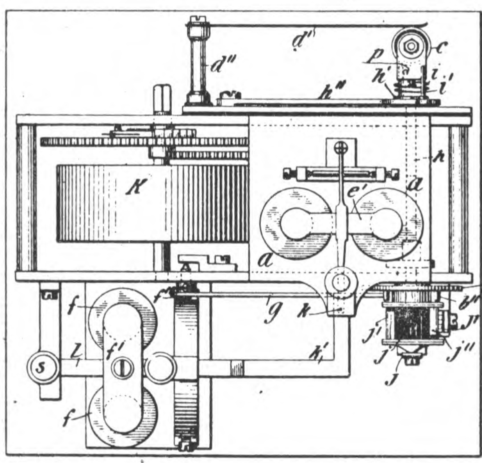


Fig. 8

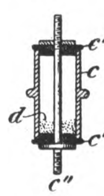
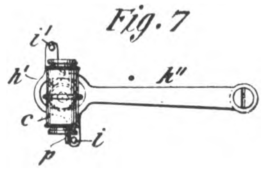


Fig. 7



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Inventor:
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No. 613,809. Patented Nov. 8, 1898

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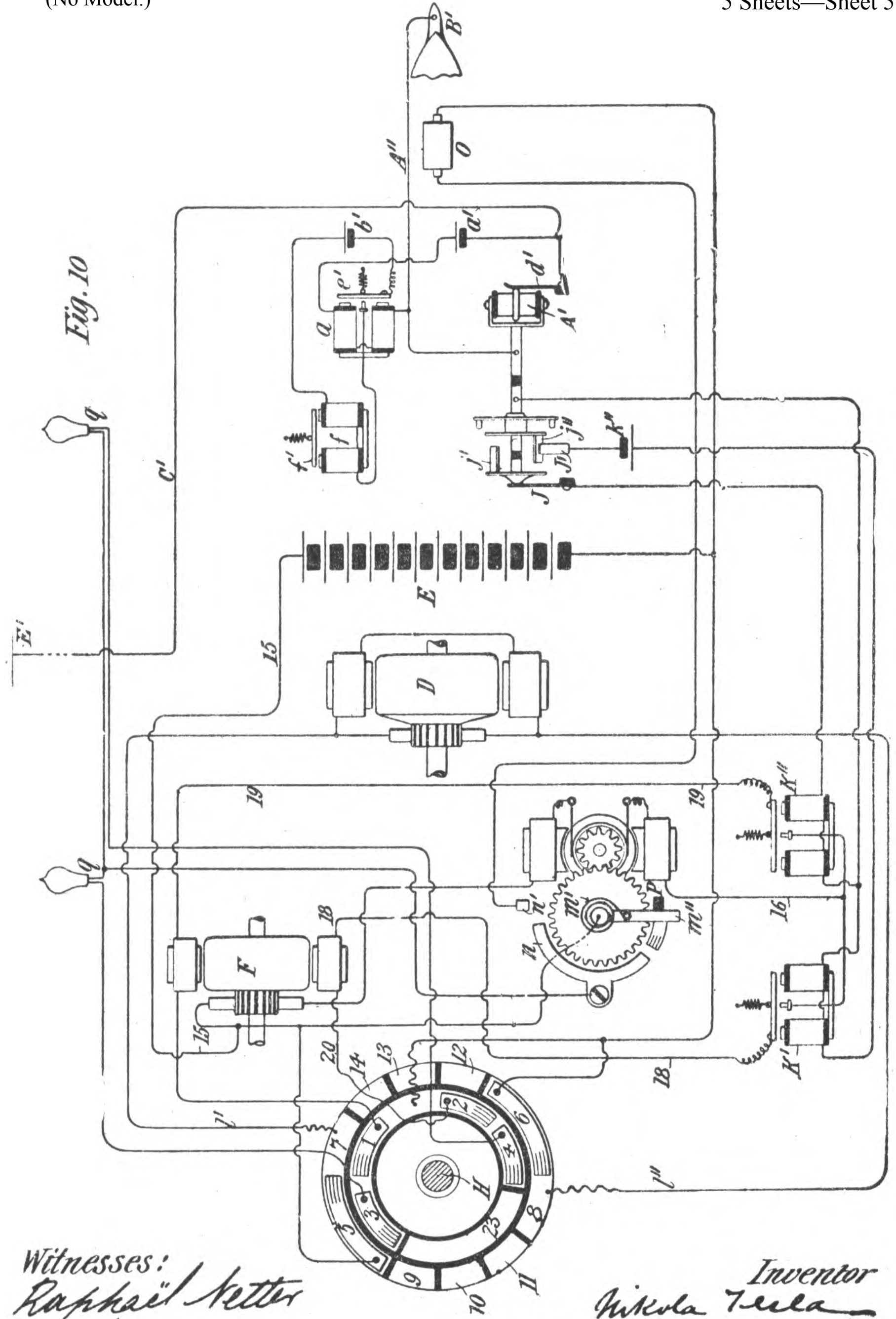
METHOD OF AND APPARATUS FOR CONTROLLING MECHANISM OF MOVING VESSELS OR VEHICLES

(Application filed July 1, 1898.)

(No Model.) 5 Sheets—Sheet 5.

Fig. 10



Witnesses:
Raphaël Netter
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Inventor
Nikola Tesla
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attys.

VII
TURBINES AND SIMILAR APPARATUS

UNITED STATES PATENT OFFICE.

NIKOLA TESLA, OF NEW YORK, N. Y.

FLUID PROPULSION.

1,061,142. Specification of Letters Patent. Patented May 6, 1913.

Application filed October 21, 1909. Serial No 523,832.

To all whom it may concern:

Be it known that I, NIKOLA TESLA, a citizen of the United States, residing at New York, in the county and State of New York, have invented certain new and useful Improvements in Fluid Propulsion, of which the following is a full, clear, and exact description.

In the practical application of mechanical power based on the use of a fluid as the vehicle of energy, it has been demonstrated that, in order to attain the highest economy, the changes in velocity and direction of movement of the fluid should be as gradual as possible. In the present forms of such apparatus more or less sudden changes, shocks and vibrations are unavoidable. Besides, the employment of the usual devices for imparting energy to a fluid, as pistons, paddles, vanes and blades, necessarily introduces numerous defects and limitations and adds to the complication, cost of production and maintenance of the machine.

The object of my present invention is to overcome these deficiencies in apparatus designed for the propulsion of fluids and to effect thereby the transmission and transformation of mechanical energy through the agency of fluids in a more perfect manner, and by means simpler and more economical than those heretofore employed. I accomplish this by causing the propelled fluid to move in natural paths or stream lines of least resistance, free from constraint and disturbance such as occasioned by vanes or kindred devices, and to change its velocity and direction of movement by imperceptible degrees, thus avoiding the losses due to sudden variations while the fluid is receiving energy.

It is well known that a fluid possesses, among others, two salient properties: adhesion and viscosity. Owing to these a body propelled through such a medium encounters a peculiar impediment known as "lateral" or "skin resistance" which is twofold: one arising from the shock of the fluid against the asperities of the solid substance, the other from internal forces opposing molecular separation. As an inevitable consequence, a certain amount of the fluid is dragged along by the moving body. Conversely, if the body be placed in a fluid in motion, for the same reasons, it is impelled in the direction of movement. These effects, in themselves, are of daily observation, but I believe that I am the first to apply them in a practical and economical manner for imparting energy to or deriving it from a fluid.

The subject of this application is an invention pertaining to the art of imparting energy to fluids, and I shall now proceed to describe its nature and the principles of construction of the apparatus which I have devised for carrying it out by reference to the accompanying drawings which illustrate an operative and efficient embodiment of the same.

Figure 1 is a partial end view, and Fig. 2 is a vertical cross section of a pump or compressor constructed and adapted to be operated in accordance with my invention.

In these drawings the device illustrated contains a runner composed of a plurality of flat rigid disks 1 of a suitable diameter, keyed to a shaft 2, and held in position by a threaded nut 3, a shoulder 4 and washers 5, of the requisite thickness. Each disk has a number of central openings 6, the solid portions between which form spokes 7, preferably curved, as shown, for the purpose of reducing the loss of energy due to the impact of the fluid. The runner is mounted in a two part volute casing 8, having stuffing boxes 9, and inlets 10 leading to its central portion. In addition a gradually widening and rounding outlet 11 is provided, formed with a flange for connection to a pipe as usual. The casing 8 rests upon a base 12, shown only in part, and supporting the bearings for the shaft 2, which, being of ordinary construction, are omitted from the drawings.

An understanding of the principle embodied in this device will be gained from the following description of its mode of operation. Power being applied to the shaft and the runner set in rotation in the direction of the solid arrow the fluid by reason of its properties of adherence and viscosity, upon, entering through the inlets 10 and coming in contact with the disks 1 is taken hold of by the same and subjected to two forces, one acting tangentially in the direction of rotation, and the other radially outward. The combined effect of these tangential and centrifugal forces is to propel the fluid with continuously increasing velocity in a spiral path until it teaches the outlet 11 from which it is ejected. This spiral movement, free and undisturbed and essentially dependent on the properties of the fluid, permitting it to adjust itself to natural paths or stream lines and to change its velocity and direction by insensible degrees, is characteristic of this method of propulsion and advantageous in its application. While traversing the chamber inclosing the runner, the particles of the fluid may complete one or more turns, or but a part of one turn. In any given case their path can be closely calculated and graphically represented, but fairly accurate estimate of turns can be obtained simply by determining the number of revolutions required to renew the fluid passing through the chamber and multiplying it by the ratio between the mean speed of the fluid and that of the disks. I have found that the quantity of fluid propelled in this manner is, other conditions being equal, approximately proportionate to the active surface of the runner and to its effective speed. For this reason, the performance of such machines augments at an exceedingly high rate with the increase of their size and speed of revolution.

The dimensions of the device as a whole, and the spacing of the disks in any given machine will be determined by the conditions and requirements of special cases. It may be stated that the intervening distance should be the greater, the larger the diameter of the disks, the longer the spiral path of the fluid and the greater its viscosity. In general, the spacing should be such that the entire mass of the fluid, before leaving the runner, is accelerated to a nearly uniform velocity, not much below that of the periphery of the disks under normal working conditions and almost equal to it when the outlet is closed and the particles move in concentric circles. It may also be pointed out that such a pump can be made without openings and spokes in the runner, as by using one or more solid disks, each it its own casing, in which form the machine will be eminently adapted for sewage, dredging and the like, when the water is charged with foreign bodies and spokes or vanes especially objectionable.

Another application of this principle which I have discovered to be not only feasible, but thoroughly practicable and efficient, is the utilization of machines such as above described for the compression or rarefaction of air, or gases in general. In such cases it will be found that most of the general considerations obtaining in the case of liquids, properly interpreted, hold true. When, irrespective of the character of the fluid, considerable pressures are desired, staging or compounding may be resorted to in the usual way the individual runners being, preferably, mounted on the same shaft. It should be added that the same end may be attained with one single runner by suitable deflection of the fluid through rotative or stationary passages.

The principles underlying the invention are capable of embodiment also in that field of mechanical engineering which is concerned in the use of fluids as motive agents, for while in some respects the actions in the latter case are directly opposite to those met with in the propulsion of fluids, the fundamental laws applicable in the two cases are the same. In other words, the operation above described is reversible, for if water or air under pressure be admitted to the opening 11 the runner is set in rotation in the direction of the dotted arrow by reason of the peculiar properties of the fluid which traveling in a spiral path and with continuously diminishing velocity, reaches the orifices 6 and 10 through which it is discharged.

When apparatus of the general character above described is employed for the transmission of power, however, certain departures from structural similarity between transmitter and receiver may be necessary for securing the best result. I have, therefore, included that part of my invention which is directly applicable to the use of fluids as motive agents in a separate application filed January 17, 1911, Serial No. 603,049. It may be here pointed out, however, as is evident from the above considerations, that when transmitting power from one shaft to another by such machines, any desired ratio between the speeds of rotation may be obtained by proper selection of the diameters of the disks, or by suitably staging the transmitter, the receiver, or both. But it may be stated that in one respect, at least, the two machines are essentially different. In the pump, the radial or static pressure, due to centrifugal force, is added to the tangential or dynamic, thus increasing the effective head and assisting in the expulsion of the fluid. In the motor, on the contrary, the first named pressure, being opposed to that of supply, reduces the effective head and velocity of radial flow toward the center. Again, in the propelled machine a great torque is always desirable, this calling for an increased number of disks and smaller distance of separation, while in the propelling machine, for numerous economic reasons, the rotary effort should be the smallest and the speed the greatest practicable. Many other considerations, which will naturally suggest themselves, may affect the design and construction, but the preceding is thought to contain all necessary information in this regard.

It will be understood that the principles of construction and operation above set forth, are capable of embodiment in machines of the most widely different forms, and adapted for the greatest variety of purposes. Ill the above, I have sought to describe and explain only the general and typical applications of the principle which I believe I am the first to realize and turn to useful account.

I do not claim in this application the method herein described of imparting energy to a fluid, having made that discovery the subject of a copending application Serial No. 735,914.

What I claim is:

1. A machine for propelling or imparting energy to fluids comprising in combination a plurality of spaced disks rotatably mounted and having plane surfaces, an inclosing casing, ports or inlet at the central portion of said casing and through which the fluid is adapted to be introduced to the axial portions of the disks, and ports of outlet at the peripheral portion of the casing through which the fluid, when the machine is driven by power, is adapted to be expelled, as set forth.

2. A machine for propelling or imparting energy to fluids, comprising in combination a volute casing provided with ports of inlet and outlet at its central and peripheral portions, respectively, and a runner mounted within the casing and composed of spaced disks with plane surfaces having openings adjacent to the axis of rotation.

3. A rotary pump, comprising in combination a plurality of spaced disks with plane surfaces mounted on a rotatable shaft and provided with openings adjacent thereto, a volute casing inclosing the said disks, means for admitting a fluid into that portion of the casing which contains the shaft and an outlet extending tangentially from the peripheral portion of said casing.

In testimony whereof I affix my signature in the presence of two subscribing witnesses.

NIKOLA TESLA.

Witnesses:

M. LAWSON DYER,

DRURY W. COOPER.

P-382

N. TESLA.
FLUID PROPULSION.

APPLICATION FILED OCT. 21, 1909.

1,061,142. Patented May 6, 1913.

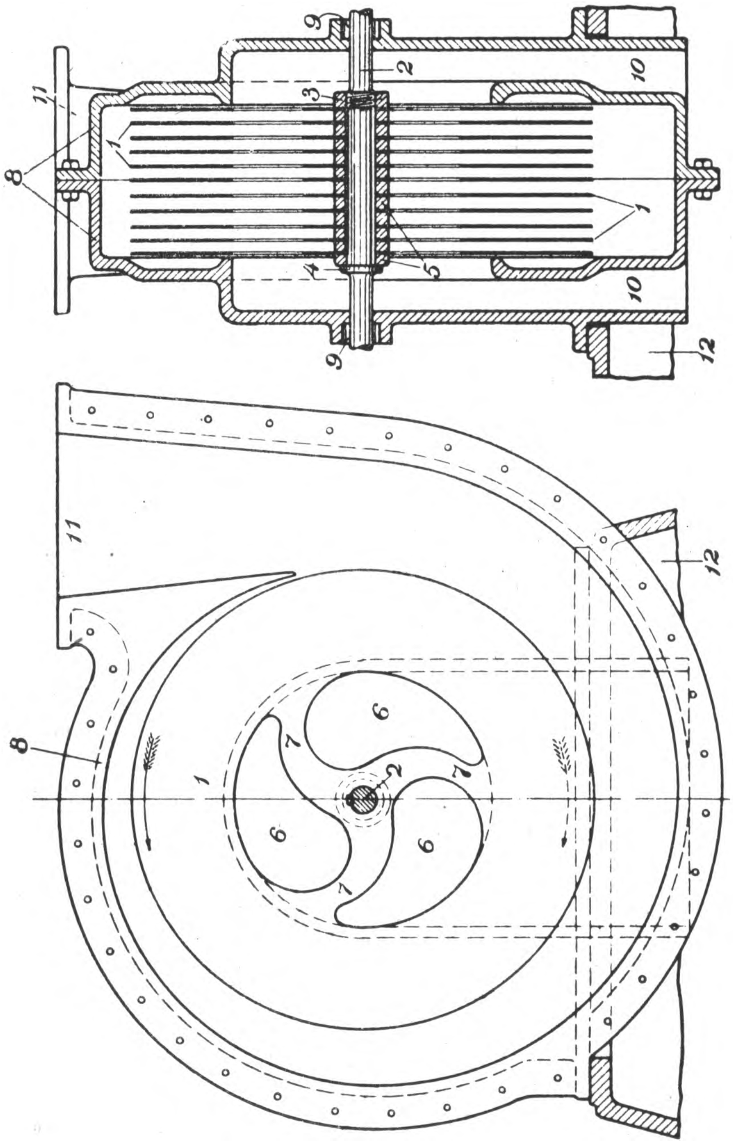

Fig 2

Fig 1

Witnesses
R. Diaz Buitrago
D. J. Dunham

Nikola Tesla,
Inventor

By his Attorneys
Kerr, Page, Cooper & Hayward

UNITED STATES PATENT OFFICE.

NIKOLA TESLA, OF NEW YORK, N. Y.

TURBINE.

1,061,206. Specification of Letters Patent. Patented May 6, 1913.

Original application filed October 21, 1909, Serial No. 623,832. Divided and this application filed January 17, 1911. Serial No. 603,049.

To all whom it may concern:

Be it known that I, NIKOLA TESLA, a citizen of the United States, residing at New York, in the county and State of New York, have invented certain new and useful Improvements in Rotary Engines and Turbines, of which the following is a full, clear, and exact description.

In the practical application of mechanical power, based on the use of fluid as the vehicle of energy, it has been demonstrated that, in order to attain the highest economy, the changes in the velocity and direction of movement of the fluid should be as gradual as possible. In the forms of apparatus heretofore devised or proposed, more or less sudden changes, shocks and vibrations are unavoidable. Besides, the employment of the usual devices for imparting to, or deriving energy from a fluid, such as pistons, paddles, vanes and blades, necessarily introduces numerous defects and limitations and adds to the complication, cost of production and maintenance of the machines.

The object of my invention is to overcome these deficiencies and to effect the transmission and transformation of mechanical energy through the agency of fluids in a more perfect manner and by means simpler and more economical than those heretofore employed. I accomplish this by causing the propelling fluid to move in natural paths or stream lines of least resistance, free from constraint and disturbance such as occasioned by vanes or kindred devices, and to change its velocity and direction of movement by imperceptible degrees, thus avoiding the losses due to sudden variations while the fluid is imparting energy.

It is well known that a fluid possesses, among others, two salient properties, adhesion and viscosity. Owing to these a solid body propelled through such a medium encounters a peculiar impediment known as "lateral" or "skin resistance," which is twofold, one arising from the shock of the fluid against the asperities of the solid substance, the other from internal forces opposing molecular separation. As an inevitable consequence a certain amount of the fluid is dragged along by the moving body. Conversely, if the body be placed in a fluid in motion, for the same reasons, it is impelled in the direction of movement. These effects, in themselves, are of daily observation, but I believe that I am the first to apply them in a practical and economical manner in the propulsion of fluids or in their use as motive agents.

In an application filed by me October 21st, 1909, Serial Number 523,832 of which this case is a division, I have illustrated the principles underlying my discovery as embodied in apparatus designed for the propulsion of fluids. The same principles, however, are capable of embodiment also in that field of mechanical engineering which is concerned in the use of fluids as motive agents, for while in certain respects the operations in the latter case are directly opposite to those met with in the propulsion of fluids, and the means employed may differ in some features, the fundamental laws applicable in the two cases are the same. In other words, the operation is reversible, for if water or air under pressure be admitted to the opening constituting the outlet of a pump or blower as described, the runner is set in rotation by reason of the peculiar properties of the fluid which, in its movement through the device imparts its energy thereto.

The present application, which is a division of that referred to, is specially intended to describe and claim my discovery above set forth, so far as it bears on the use of fluids as motive agents, as distinguished from the applications of the same to the propulsion or compression of fluids.

In the drawings, therefore, I have illustrated only the form of apparatus designed for the thermo-dynamic conversion of energy, a field in which the applications of the principle have the greatest practical value.

Figure 1 is a partial end view, and Fig. 2 a vertical cross-section of a rotary engine or turbine, constructed and adapted to be operated in accordance with the principles of my invention.

The apparatus comprises a runner composed of a plurality of flat rigid disks 13 of suitable diameter, keyed to a shaft 16, and held in position thereon by a threaded nut 11, a shoulder 12, and intermediate washers 17. The disks have openings 14 adjacent to the shaft and spokes 15, which may be substantially straight. For the sake of clearness, but a few disks, with comparatively wide intervening spaces, are illustrated.

The runner is mounted in a casing comprising two end castings 19. which contain the bearings for the shaft 16, indicated but not shown in detail; stuffing boxes 21 and outlets 20. The end castings are united by a central ring 22, which is bored out to a circle of a slightly larger diameter than that of the disks, and has flanged extensions 23, and inlets 25, into which finished ports or nozzles 25 are inserted. Circular grooves 26 and labyrinth packing 27 are provided on the sides of the runner. Supply pipes 28, with valves 29, are connected to the flanged extensions of the central ring, one of the valves being normally closed.

For a more ready and complete understanding of the principle of operation it is of advantage to consider first the actions that take place when the device is used for the propulsion of fluids for which purpose let it be assumed that power is applied to the shaft and the runner set in rotation say in a clockwise direction. Neglecting, for the moment, those features of construction that make for or against the efficiency of the device as a pump, as distinguished from a motor, a fluid, by reason of its properties of adherence and viscosity, upon entering through the inlets 20, and coming in contact with the disks 13, is taken hold of by the latter and subjected to two forces, one acting tangentially in the direction of rotation, and the other radially outward. The combined effect of these tangential and centrifugal forces is to propel the fluid with continuously increasing velocity in a spiral path until it reaches a suitable peripheral outlet from which it is ejected. This spiral movement, free and undisturbed and essentially dependent on the properties of the fluid, permitting it to adjust itself to natural paths or stream lines and to change its velocity and direction by insensible degrees, is a characteristic and essential feature of this principle of operation.

While traversing the chamber inclosing the runner, the particles of the fluid may complete one or more turns, or but a part of one turn, the path followed being capable of close calculation and graphic representation, but fairly accurate estimates of turns can be obtained simply by determining the number of revolutions required to renew the fluid passing through the chamber and multiplying it by the ratio between the mean speed of the fluid and that of the disks. I have found that the quantity of fluid propelled in this manner, is, other conditions being equal, approximately proportionate to the active surface of the runner and to its effective speed. For this reason, the performance of such machines augments at an exceedingly high rate with the increase of their size and speed of revolution.

The dimensions of the device as a whole, and the spacing of the disks in any given machine will be determined by the conditions and requirements of special cases. It may be stated that the intervening distance should should be the greater, the larger the diameter of the disks, the longer the spiral path of the fluid and the greater its viscosity. In general, the spacing should be such that the entire mass of the fluid, before leaving the runner, is accelerated to a nearly uniform velocity, not much below that of the periphery of the disks under normal working conditions, and almost equal to it when the outlet is closed and the particles move in concentric circles.

Considering now the converse of the above described operation and assuming that fluid under pressure be allowed to pass through the valve at the side of the solid arrow, the runner will be set in rotation in a clockwise direction, the fluid traveling in a spiral path and with continuously diminishing velocity until it reaches the orifices 14 and 20, through which it is discharged. If the runner be allowed to turn freely, in nearly frictionless bearings, its rim will attain a speed closely approximating the maximum of that of the adjacent fluid and the spiral path of the particles will be comparatively long, consisting of many almost circular turns. If load is put on and the runner slowed down, the motion of the fluid is retarded, the turns are reduced, and the path is shortened.

Owing to a number of causes affecting the performance, it is difficult to frame a precise rule which would be generally applicable, but it may be stated that within certain limits, and other conditions being the same, the torque is directly proportionate to the square of the velocity of the fluid relatively to the runner and to the effective area of the disks and, inversely, to the distance separating them. The machine will, generally, perform its maximum work when the effective speed of the runner is one-half of that of the fluid; but to attain the highest economy, the relative speed or slip, for any given performance, should be as small as possible. This condition may be to any desired degree approximated by increasing the active area of and reducing the space between the disks.

When apparatus of the kind described is employed for the transmission of power certain departures from similarity between transmitter and receiver are necessary for securing the best results. It is evident that, when transmitting power from one shaft to another by such machines, any desired ratio between the speeds of rotation may be obtained by a proper selection of the diameters of the disks, or by suitably staging the transmitter, the receiver or both. But it may be pointed out that in one respect, at least, the two machines are essentially different. In the pump, the radial or static pressure, due to centrifugal force, is added to the tangential or dynamic, thus increasing the effective head and assisting in the expulsion of the fluid. In the motor, on the contrary, the first named pressure, being opposed to that of supply, reduces the effective head and the velocity of radial flow toward the center. Again, in the propelled machine a great torque is always desirable, this calling for an increased number of disks and smaller distance of separation, while in the propelling machine, for numerous economic reasons, the rotary effort should be the smallest and the speed the greatest practicable. Many other considerations, which will naturally suggest themselves, may affect the design and construction, but the preceding is thought to contain all necessary information in this regard.

In order to bring out a distinctive feature, assume, in the first place, that the motive medium is admitted to the disk chamber through a port, that is a channel which it traverses with nearly uniform velocity. In this case, the machine will operate as a rotary engine, the fluid continuously expanding on its tortuous path to the central outlet. The expansion takes place chiefly along the spiral path, for the spread inward is opposed by the centrifugal force due to the velocity of whirl and by the great resistance to radial exhaust. It is to be observed that the resistance to the passage of the fluid between the plates is, approximately, proportionate to the square of the relative speed, which is maximum in the direction toward the center and equal to the full tangential velocity of the fluid. The path of least resistance, necessarily taken in obedience to a universal law of motion is, virtually, also that of least relative velocity. Next, assume that the fluid is admitted to the disk chamber not through a port, but a diverging nozzle, a device converting wholly or in part, the expansive into velocity-energy. The machine will then work rather like a turbine, absorbing the energy of kinetic momentum of the particles as they whirl, with continuously decreasing speed, to the exhaust.

The above description of the operation, I may add, is suggested by experience and observation, and is advanced merely for the purpose of explanation. The undeniable fact is that the machine does operate, both expansively and impulsively. When the expansion in the nozzles is complete, or nearly so, the fluid pressure in the peripheral clearance space is small; as the nozzle is made less divergent and its section enlarged, the pressure rises, finally approximating that of the supply. But the transition from purely impulsive to expansive action may not be continuous throughout, on account of critical states and conditions and comparatively great variations of pressure may be caused by small changes of nozzle velocity.

In the preceding it has been assumed that the pressure of supply is constant or continuous, but it will be understood that the operation will be, essentially the same if the pressure be fluctuating or intermittent, as that due to explosions occurring in more or less rapid succession.

A very desirable feature, characteristic of machines constructed and operated in accordance with this invention, is their capability of reversal of rotation. Fig. 1, while illustrative of a special case, may be regarded as typical in this respect. If the right hand valve be shut off and the fluid supplied through the second pipe, the runner is rotated in the direction of the dotted arrow, the operation, and also the performance remaining the same as before, the central ring being bored to a circle with this purpose in view. The same result may be obtained in many other ways by specially designed valves, ports or nozzles for reversing the flow, the description of which is omitted here in the interest of simplicity and clearness. For the same reasons but one operative port or nozzle is illustrated which might be adapted to a volute but does not fit best a circular bore. It will be understood that a number of suitable inlets may be provided around the periphery of the runner to improve the action and that the construction of the machine may be modified in many ways.

Still another valuable and probably unique quality of such motors or prime movers may be described. By proper construction and observance of working conditions the centrifugal pressure, opposing the passage of the fluid, may, as already indicated, be made nearly equal to the pressure of supply when the machine is running idle. If the inlet section be large, small changes in the speed of revolution will produce great differences in flow which are further enhanced by the concomitant variations in the length of the spiral path. A self-regulating machine is thus obtained bearing a striking resemblance to a direct-current electric motor in this respect that, with great differences of impressed pressure in a wide open channel the flow of the fluid through the same is prevented by virtue of rotation. Since the centrifugal head increases as the square of the revolutions, or even more rapidly, and with modern high grade steel great peripheral velocities are practicable, it is possible to attain that condition in a single stage machine, more readily if the runner be of large diameter. Obviously this problem is facilitated by compounding, as will be understood by those skilled in the art. Irrespective of its bearing on economy, this tendency which is, to a degree, common to motors of the above description, is of special advantage in the operation of large units, as it affords a safeguard against running away and destruction. Besides these, such a prime mover possesses many other advantages, both constructive and operative. It is simple, light and compact, subject to but little wear, cheap and exceptionally easy to manufacture as small clearances and accurate milling work are not essential to good performance. In operation it is reliable, there being no valves, sliding contacts or troublesome vanes. It is almost free of windage, largely independent of nozzle efficiency and suitable for high as well as for low fluid velocities and speeds of revolution.

It will be understood that the principles of construction and operation above generally set forth, are capable of embodiment in machines of the most widely different forms, and adapted for the greatest variety of purposes. In my present specification I have sought to describe and explain only the general and typical applications of the principle which I believe I am the first to realize and turn to useful account.

What I claim is:

1. A machine adapted to be propelled by a fluid consisting in the combination with a casing having inlet and outlet ports at the peripheral and central portions, respectively, of a rotor having plane spaced surfaces between which the fluid may flow in natural spirals and by adhesive and viscous action impart its energy of movement to the rotor, as described.

2. A machine adapted to be propelled by a fluid, comprising a rotor composed of a plurality of plane spaced disks mounted on a shaft and open at or near the same, an inclosing casing with a peripheral inlet or inlets, in the plane of the disks, and an outlet or outlets in its central portion, as described.

3. A rotary engine adapted to be propelled by adhesive and viscous action of a continuously expanding fluid comprising in combination a casing forming a chamber, an inlet or inlets tangential to the periphery of the same, and an outlet or outlets in its central portion, with a rotor composed of spaced disks mounted on a shaft, and open at or near the same, as described.

4. A machine adapted to be propelled by fluid, consisting in the combination of a plurality of disks mounted on a shaft and open at or near the same, and an inclosing casing with ports or passages of inlet and outlet at the peripheral and central portions, respectively, the disks being spaced to form passages through which the fluid may flow, under the combined influence of radial and tangential forces, in a natural spiral path from the periphery toward the axis or the disks, and impart its energy of movement to the same by its adhesive and viscous action thereon, as set forth.

5. A machine adapted to be propelled by a fluid comprising in combination a plurality of spaced disks rotatably mounted and having plane surfaces, an inclosing casing and ports or passages of inlet and outlet adjacent to the periphery and center of the disks, respectively, as set forth.

6. A machine adapted to be propelled by a fluid comprising in combination a runner composed of a plurality of disks having plane surfaces and mounted at intervals on a central shaft, and formed with openings near their centers, and means for admitting the propelling fluid into the spaces between the disks at the periphery and discharging it at the center of the same, as set forth.

7. A thermo-dynamic converter, comprising in combination a series of rotatably mounted spaced disks with plane surfaces, an inclosing casing, inlet ports at the peripheral portion and outlet ports leading from the central portion of the same, as set forth.

8. A thermo-dynamic converter, comprising in combination a series of rotatably mounted spaced disks with plane surfaces and having openings adjacent to their central portions, an inclosing casing, inlet ports in the peripheral portion, and outlet ports leading from the central portion of the same, as set forth.

In testimony whereof I affix my signature in the presence of two subscribing witnesses

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P-387

N. TESLA.
TURBINE.
APPLICATION FILED JAN. 17, 1911.

1,061,206. Patented May 6, 1913.

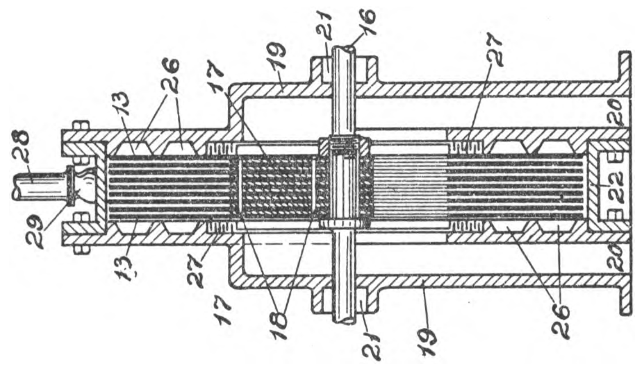

Fig. 2.

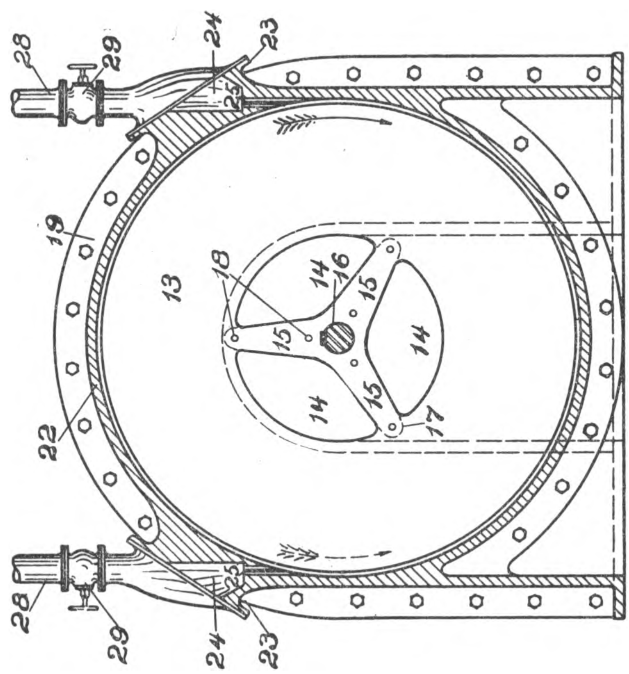

Fig. 1.

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UNITED STATES PATENT OFFICE.

NIKOLA TESLA, OF NEW YORK, N. Y., ASSIGNOR TO WALTHAM WATCH COMPANY, OF WALTHAM, MASSACHUSETTS, A CORPORATION OF MASSACHUSETTS.

SPEED-INDICATOR.

1,209,359. Specification of Letters Patent. Patented Dec. 19, 1916.

Application filed May 29, 1914. Serial No. 841,726.

To all whom it may concern:

Be it known that I. NIKOLA TESLA, a citizen of the United States, residing at New York, in the county and State of New York, have invented certain new and useful Improvements in Speed-Indicators, of which the following is a full, clear, and exact description.

In the provision of speed indicators, that give direct readings of rate of motion,—for example shaft speeds in terms of revolutions per minute or vehicle speeds in miles per hour—it is obviously important that the instrument be simple, inexpensive and durable, and that its indications be correct throughout a wide range of speed. Likewise it is very desirable that its operation shall be subject to little or no appreciable deviation from accuracy under normal or expected extraneous changes, such as those of atmospheric density, temperature, or magnetic influence, in order that the structure may be free from any complications incident to the employment of specific means compensating for such varying conditions.

My present invention supplies a speed measuring appliance amply satisfying commercial demands as above stated, in a structure wherein the adhesion and viscosity of a gaseous medium, preferably air, is utilized for torque-transmission between the driving and driven members.

More particularly, my invention provides a rotatable primary and a mechanically resistant or biased pivoted secondary element, cooperating through an intervening fluid medium to produce, inherently, without the use of compensating instrumentalities, angular displacements of the secondary element in linear proportion to the rate of rotation of the primary, so that the reading scale may be uniformly graduated. This latter advantage is secured through the application of novel principles, discovered by me. which will be presently elucidated.

In investigating the effects of fluids in motion upon rotative systems I have observed that under certain conditions to be hereafter defined, the drag or turning effort exerted by the fluid is exactly proportionate to its velocity relative to the system. This I have found to be true of gaseous and liquid media, with the distinction however, that the limits within which the law holds good are narrower for the latter, especially so when the specific gravity or the viscosity of the liquid is great.

Having determined the conditions under which the law of proportionality of torque to speed (rather than to the square of the speed or to some higher exponential function of the same) holds good, I have applied my discoveries in the production of new devices—essentially indicators of speed but having wider fields of use—which are, in many aspects, superior to other forms of speedometers.

Specifically I have devised rate-of-motion indicators which comprise driving and driven members with confronting, closely-adjacent. noncontacting, smooth, annular surfaces of large area, coacting in the transmission of torque through the viscosity, and adhesion of interposed thin films of air,—mechanical structures offering numerous constructive and operative advantages. Furthermore, by properly designing and coordinating the essential elements of such instruments I have secured substantial linear proportionality between the deflections of the indicating or secondary element and the rate of rotation of the driving or primary member.

The conditions more or less indispensable for this most perfect embodiment of my invention—that is to say, embodiment in a speed indicator approximating rigorous linear proportionality of deflection to speed—are:

1. The arrangement should be such that the exchange of fluid acting on the system is effectively prevented or minimized. If new fluid were permitted to pass freely between the elements there would be. as in a pump, with the rise and fall of velocity, corresponding changes of quantity and the torque would not vary directly as the speed, but as an exponential function of the same. Broadly speaking, such provision as is commonly made in hydraulic brakes for free circulation of fluid with respect to the rotative system, with the attendant acceleration and retardation of the flow, will generally produce a torque varying as the square of the speed, subject however, in practice, to influences which may cause it to change according to still higher powers. For this reason confinement of the fluid intervening between the primary and secondary elements of the system so that such active, torque-

transmitting medium may remain resident, and not be constantly renewed, is vital to complete attainment of the desired linear proportionality.

2. The spaces or channels inclosing the active medium should be as narrow as practicable, although within limits this is relative, the range of effective separation increasing with the diameter of the juxtaposed rotative surfaces. My observations have established that when the spacing is so wide as to accommodate local spiral circulation in the resident fluid between the confronting areas, marked departures from rigorous proportionality of torque to speed occur. Therefore in small instruments with primary members of but few inches diameter, it is desirable that the channels should be as narrow as is mechanically feasible with due regard to the importance of maintaining the noncontacting relation of the rotative parts.

3. The velocity of the fluid relative to the system should be as small as the circumstances of the case will permit. When a gas such as air is the active medium, it may be 100 feet per second or even more, but with liquids speeds of that order cannot be used without detriment.

4. The bodies exposed to the action of the fluid should be symmetrically shaped and with smooth surfaces, devoid of corners or projections which give rise to destructive eddies that are particularly hurtful.

5. The system should be so shaped and disposed that no part of the moving fluid except that contained in the spaces or channels can effect materially the torque. If this rule is not observed the accuracy of the instrument may be impaired to an appreciable degree, for even though torque transmission between the confronting surfaces is proportional, there may yet be a component of the rotary effort (through the fluid coacting with the external surfaces) proportional to an exponential function of the speed. Hence it is desirable that by a closely investing casing, or other means, the torque-transmitting effect of fluid outside of the channels between the rotative parts be minimized.

6. In general the flow of the medium should be calm and entirely free from all turbulent action As soon as there is a break of continuity the law above stated is violated and the indications of the device cease to be rigorously precise.

These requirements can be readily fulfilled and the above discoveries applied to a great many valuable uses, as for indicating the speed of rotation or translation, respectively, of a shaft, or a vehicle, such as an automobile, locomotive, boat or aerial vessel; for determining the velocity of a fluid in motion; for measuring the quantity of flow in steam, air, gas, water or oil supply; for ascertaining the frequency of mechanical and electrical impulses or oscillations; for determining physical constants; and for numerous other purposes of scientific and practical importance.

The nature and object of the invention will be clearly understood from the succeeding description with reference to the accompanying drawings in which:

Figure 1 represents a vertical cross section of a speed indicator or hand tachometer embodying the above principles; Fig. 2 is a horizontal view of the instrument disclosing part of the scale, and Figs. 3 and 4 are diagrammatic illustrations showing modified constructions of the main parts in a similar device.

Referring to Fig. 1, 1 is a pulley-shaped metal disk from three to four inches in diameter constituting the freely-rotatable primary element. It is fastened to a drive shaft 2 which is turned to fit a hole in the central hub 3 of the casting 4. A ball bearing 5 set in a recess of the former, serves to take up the thrust against the shoulder 6 of the shaft and insures free running of the same. In close proximity to the disk 1 is the thin shell 7 in the form of a cup, this being the secondary element of the system. It is made of stiff and light material, as hard aluminum, and is fixed to a spindle 8, supported in nearly frictionless bearings or pivots 9 and 10. As before remarked the spacing between the two elements, (1 and 7), should best be as small as manufacturing conditions may make feasible. By way of example, a separation,—in an instrument of the diameter suggested,—of say .015" to .025" will be found effective for working purposes and also within a reasonable range of inexpensive mechanical attainment. Still smaller spacing is, however, theoretically desirable. One of the bearings aforesaid is screwed into the end of the shaft 2 and the other into a plug 11 in a slotted tubular extension 12 of a casting 13. The running bearing in the shaft, though not of perceptible influence on the indications, may be replaced by a stationary support behind and close to shell 7, as at 8. A torsional spring 14 is provided, for biasing the pivoted element 7, having its ends held in collars 15 and 16, which can be clamped, as by the set screws shown, the one to the spindle 8 and the other to the plug 11. The bearings 9 and 10 are capable of longitudinal adjustment and can be locked in any position by check nuts 17, and 18, but this refinement is generally unnecessary. The castings 4 and 13, in the construction specifically shown, when screwed together form a casing that closely invests the rotative system. This casing forms one available means for preventing communication of torque from the primary element 1 to the secondary member 7 through the medium contacting with the external surfaces of both, to any extent sufficient for materially modifying the torque due to the films between the elements, but other means to this end may be substituted. The chamber inclosed within the casting should be airtight for highest accuracy in order that the density of the contained medium may remain constant, although in the vast majority of cases where air is used as the active agent, the slight effects of ordinary changes of temperature and density of the external atmosphere can be ignored, as they are in a measure neutralized by the concomitant variations in the resilience of the torsional spring and as they do not seriously affect the proportionality of deflections observed. However, when great precision is essential, a seal 19 of suitable packing, paste or amalgam may be employed. Obviously the working parts may be contained in a separate, perfectly tight reservoir filled with fluid of any desired character, the rotating member or disk 1 being driven by a magnet outside. This expedient has been adopted in numerous instances and is quite familiar. The casting 4 has a window or opening 20. closed by a piece of transparent substance, such as celluloid, for enabling the readings to be made on the scale which is engraved upon or glued to the rim of the indication-controlling element or shell 7. The shaft 2 is armed with a steel or rubber tip 21, and a handle 22 of fiber or other material is fastened to the central hub of casting: 13, completing the hand tachometer.

Fig. 2 in which like numbers designate corresponding parts is self-explanatory.

Attention may be called to the pointed index 23 placed in the opening 20 and marking. when the instrument is not in use, zero on the scale. The latter can be readily put in proper position by turning the collar 16 to the desired angle.

As described the device is adapted for use in the manner of an ordinary hand tachometer. In taking the revolutions of a shaft, the tip 21 is placed firmly into the central cavity of the former, as usual, with the result of entraining the disk 1 and bringing it to full speed by friction. The active medium, preferably air, in the narrow channels between the rotating and pivoted members, by virtue of its adhesion and viscosity. is set in circular motion by the primary element, and, giving up the momentum imparted to it on the light secondary shell 7, causes the latter to turn until the torque exerted is balanced by the retractile force of spring 14. Care should be taken to employ a spring the resistance of which increases linearly with displacement. So that the deflections are exactly proportionate to the torsional effect, as otherwise the indications will not be true to scale, even though the instrument be prefect in other respects. In order that the torque should vary rigorously as the speed, the fluid particles in the minute channels between the rotating and pivoted members should move in circles and not in spirals, as necessarily would be the case in a device in which pumping action could take place, and either by making both the primary and secondary elements effectively imperforate to prevent central admission of air, or otherwise so constructed and conditioned that air may not freely pass front center to periphery between the elements of the moving system unchanging residence of a definite body, of the active medium within the system is insured. Where pumping action,—that is to say. acceleration or retardation of fluid movement other than circularly with the primary element,—takes place the deflections increase more rapidly than the speed. It follows that centrifugal force, which is the essential active principle in pumping, must be negligible to avoid compression of the air at the periphery which might result in a sensibly increased torque. To appreciate this, it should be borne in mind that the resistance of a circular strip of the active area would, under such conditions, be proportionate to the fourth power of the diameter so that a slight compression and attendant increase of density of the medium in the peripheral portion would cause a noticeable departure from rigorous proportionality. Experience has demonstrated that when the space is very narrow, as is indispensable for the fullest attainment of the desired proportionality, the centrifugal effect of the active fluid, be it gaseous or liquid, is so small as to be unobservable. The inference is that the actions in the narrow space between the rotative members are capillary or molecular and wholly different in principle from those taking place in a pumping device in which the fluid masses are alternately retarded and accelerated. The scale, which, as will be apparent from the preceding, is uniform in an instrument best embodying my invention, may be so graduated that each degree corresponds to a certain number of revolutions per unit of time, and for convenience, (in shaft-speed indicators as herein shown), the constant is made a round number, as 100. The establishment of this relation through the adjustment of the torsional spring is facilitated by varying the distance between the parts 1 and 7. thus modifying the torque and consequently the deflection, (the torque varying inversely as the distance) while always keeping within the range throughout which linear proportionality is attainable. In calibrating it is necessary to make but one observation comparative with some positive standard and to plot the balance of the scale accordingly. The conditions above set forth being realized, the reading will be accurately proportionate to the speed and the constant will be correct through the whole range contemplated in the design. Therein lies a very important advantage bearing on manufacture and introduction of devices of this character over those now in use which are based on an empirical scale, tedious to prepare, and unreliable. When desired. the instrument may be rendered dead beat through magnetic or mechanical damping, but by making the torque very great, and the inertia of the secondary element very small, such objectionable complication may be avoided. With a given separation the turning effort is proportionate to the product of the velocity of rotation, the density of the fluid and the aggregate area of the active surfaces, hence by increasing either of these factors the torsion can be augmented at will. It obviously follows that the pull exerted on a circular disk will be as the third power of the diameter and one way of attaining the object is to use a large plate. Other and better ways are illustrated in Figs. 3 and 4 in which the rotating and pivoted elements are composed of interleaved disks or cylinders. The first arrangement permits an indefinite increase of the torque, the second commends itself through the facility of adjustment of the force by varying the active area.

For many reasons it is decidedly advantageous to employ air as the agent in an instrument intended for popular purposes, especially those involving rough use and inexpert handling, since thereby the cost of manufacture may be kept low, the need for ensealing minimized and susceptibility of the parts to easy disassembling and replacement attained. It is, therefore, desirable that the annular confronting surface of the elements,—whether of disk or cylindrical form,—be sufficiently extensive for securing ample torque to make the instrument approximately dead beat and to minimize the percentage of error due to mechanical imperfections.

The foregoing description contains, I believe, all the information necessary for enabling an expert to carry my invention into successful practice. When using the indicator in the manner of an ordinary vehicle speedometer, as in an automobile, the shaft 2 is rigidly or flexibly geared to the driving axle or other suitable part and readings are made in miles per hour, as is customary. As will be apparent many other valuable uses may be served, since the primary element may be connected in suitable electrical or mechanical manner with any rotating part, the speed of which may be translated through a linearly proportionate constant into the desired terms of time and quantity, and the reading scale may be calibrated in such terms. It will also be evident that by accurate workmanship, following the teachings of my invention, instruments at once simple, rugged, and scientifically accurate may be constructed for a very wide range of uses in either huge or tiny sizes; and, since the commercial requirements of accuracy in many fields gives a reasonable range of permissive error, manufacturing considerations may lead to deviations from strict observance of some of the conditions that I have indicated as best attaining a rigorous proportionality of reading. The provision of simple mechanical elements, cooperating primarily only through the viscosity and adhesiveness of the air films intervening therebetween and substantially free from need for ensealing and from error caused by changes of extraneous conditions, especially temperature, affords striking commercial advantages unattainable in any form of speedometer of which I am aware. Therefore while I have described in detail for the purpose of full disclosure a specific and highly advantageous embodiment of my invention, it will be understood that wide variations in the mechanical development thereof may be made without departure from its spirit within the scope of the appended claims.

What I claim is:

1. In combination, fixed supporting means, disconnected alined driving and driven shafts rotatably mounted in said supporting means, relatively thin spaced rigid pieces of material rigidly connected to and arranged coaxially about said driven shaft with broad surfaces opposite each other, and other relatively thin spaced rigid pieces of material rigidly connected to and arranged coaxially with the driving shaft, and being alternated with the first-mentioned pieces between them and having their broad surfaces adjacent to and spaced from the broad surfaces of said other pieces, said pieces all arranged in air, through which torque is frictionally transmitted from the second-mentioned pieces to those first-mentioned.

2. In combination, in a speedometer, disconnected alined driving and driven shafts, a fixed support, said shafts being mounted in said support, a coiled spring having one end secured to said fixed support and the other end secured to said driven shaft, relatively thin spaced rigid pieces of material rigidly connected to and arranged coaxially about said driven shaft with their broad surfaces opposite each other, other relatively thin spaced rigid pieces of material rigidly connected to and arranged coaxially with the driving shaft, and being alternated between said first-mentioned pieces and spaced therefrom, and an air body filling

the spaces between said pieces and constituting the torque-transmitting friction medium therebetween.

3. In combination, in a speedometer, disconnected alined driving and driven shafts, a frame having hearings for said shafts, a coiled spring whose inner end is secured to said driven shaft and having its outer end secured to said frame, spaced rigid pieces of material rigidly connected to and arranged about said driven shaft, and other spaced rigid pieces of material rigidly connected to and arranged about said driving shaft, the former pieces being alternated between the latter pieces in spaced relation with their broad surfaces in close juxtaposition, and with the interspaces between said spaced pieces forming a convoluted air-containing channel therebetween open to the surrounding air.

4. In combination, disconnected aligned driving and driven shafts, a fixed support, bearings therefore in said support, a coiled spring having one end secured to the driven shaft and its other end secured to said fixed support, a cup-shaped body secured to one end of said driving shaft coaxially, spaced rigid relatively thin plates secured to said body in parallel relation to each other, another cup-shaped body secured coaxially to said driven shaft and inclosing said plates at their outer edges in spaced relation thereto, other spaced rigid relatively thin plates secured to the second-mentioned body and extending between the first-mentioned plates in spaced relation thereto, and an air body filling the spaces between said pieces frictionally to transmit torque from the driving structure to the driven structure.

5. The combination with means for support and driving and driven shafts rotatably supported thereby, of means to transmit torque from the driving shaft to the driven shaft comprising opposed material-pieces respectively connected with the driving shaft and the driven shaft and arranged to present toward each other relatively-extensive, non-contacting, closely-adjacent surfaces, and a gaseous medium in which said pieces work, said gaseous medium serving frictionally to connect the said opposed material-pieces for transmission of torque from the driving shaft to the driven shaft.

6. In combination, driving and driven elements suitably supported and having confronted annuli always presenting to each other relatively-extensive, non-contacting, closely-adjacent surfaces, said surfaces disposed in a gaseous friction medium, whereby the driving member, by its rotation, induces rotary motion of the driven member through the drag of the gaseous medium intervening between said annuli.

7. In combination, driving and driven elements having in opposed, closely adjacent, non-contacting relation, relatively extensive friction surfaces, and an interposed gaseous body, through which the driving member frictionally drags the driven element.

8. In a speedometer, the combination with supporting means, separately-rotatable driving and driven shafts mounted therein, biasing means for the driven shaft, and means to indicate rotary displacement of the biased shaft in terms of speed, of pieces rotatively carried by said respective shafts, having relatively-extensive, non-contacting, closely-adjacent surfaces arranged to confront each other, and a gaseous medium intervening between said confronting surfaces to coact therewith frictionally to transmit torque from the driving shaft to the biased driven shaft.

9. In a speedometer, the combination of a primary element rotatable at varying speeds, having a plurality of spaced annuli, a biased secondary element, arranged for separate rotary movement and adapted and arranged to indicate speed variations by the extent of its displacement, said secondary element having a plurality of spaced, thin, light annuli, the annuli of said two elements interleaved in non-contacting, closely-adjacent relation always to present toward each other extensive friction surfaces, and an air body, through the films of which, intervening between said annuli, rotation of the primary element may induce speed-indicating displacement of the secondary element.

10. A speedometer wherein a primary, variable-speed element, and a biased, speed-indication-controlling secondary element, that are suitably supported for separate movement, have opposed extensive friction surfaces in non-contacting juxtaposition for frictional communication of power from the primary element to the secondary element through a gaseous medium that intervenes between said friction surfaces.

11. An air drag speedometer, wherein a primary, variable-speed element and a biased speed-indication-controlling secondary element, that are suitably mounted for separate rotary movement in an air-containing casing, have opposed, extensive friction-surfaces in non-contacting juxtaposition, for frictional communication of torque from the primary element to the secondary element through the medium of the casing-contained air.

12. In a speedometer, the combination of an air containing casing, a primary element and a secondary element mounted in said casing for separate movement, said elements having extensive surfaces exposed toward each other in closely contiguous but non-contacting relation for frictional communication of power to one from, the other through the intervening air, means resiliently to resist displacement of the second-

ary element, and means to indicate displacement of the secondary element in terms of speed.

13. In combination, in a speedometer, disconnected shafts respectively carrying driving and driven elements that have annuli affording continuous extensive friction surfaces in always confronting noncontacting closely-spaced relation, the driven element being light and biased by a light, spring, for ready response to torque transmitted frictionally by air, and the air film-spaces between the elements constituting an open tortuous channel; and an air containing casing inclosing the driving and driven elements, its contained air body forming the sole effective means of torque transmission between the elements.

14. In a speedometer, the combination of rotatable driving and driven elements having in opposed, closely-adjacent non-contacting relation, relatively extensive friction surfaces, means to bias the driven element, means to indicate rotary displacement of said driven element in terms of speed, a casing inclosing said elements and containing air, said contained air body extending in films between the friction surfaces, and forming the sole effective means of torque transmission between the driving and driven elements.

15. In combination, driving and driven elements having in opposed non-contacting relation relatively extensive friction surfaces so closely adjacent that through an interposed gaseous body the driving member frictionally drags the driven member with a torque linearly proportionate to the speed of the former.

16. A rate indicator wherein a freely-rotatable primary and a biased, indication-controlling secondary member, suitably supported for separate movement, have opposed, non-contacting surfaces in such close proximity that through an intervening viscous fluid medium torque is transmitted to the secondary member in linear proportion to the speed of the primary.

17. A rate indicator wherein a freely rotatable primary and a biased, indication-controlling secondary element, suitably supported for separate movement are operatively linked through an intervening viscous and adhesive air body, said elements having opposed, extensive non-contacting surfaces so closely adjacent that the torque transmitted to the secondary element through said air body is substantially in linear proportion to the speed of the primary element.

18. In a speed indicator the combination of two rotatively movable driving and driven members having opposed non-contacting extensive surfaces confining between them a practically constant body of torque-transmitting fluid medium, said surfaces being so closely proximate that the torque transmitted from the driving to the driven member is substantially proportional to the rate of rotation of the former.

19. A speed indicator comprising, in combination, a rotatable body, a second angularly movable body, means to resist displacement of the latter proportionately to the torque applied thereto, and a fluid medium interposed between them, said bodies having opposed annular surfaces in such close proximity that pumping of the medium therebetween is prevented and the deflections of the second body are made proportionate to the speed of the other.

20. A speed indicator, comprising, in combination, a rotatable, variable speed primary element, and a light, pivoted, torsionally-resisted, indication-controlling secondary element, suitably mounted for separate movement and operatively linked with the former through an interposed gaseous medium, said elements having opposed, annular non-contacting surfaces so extensive and closely proximate that the whirling medium exerts a strong and steady turning effort upon the secondary element, substantially in linear proportion to the speed of the primary.

21. The combination, in a rate indicator, of a freely rotatable primary and a torsionally-resisted indication controlling secondary member mounted for separate movement, with their opposed non-contacting symmetrical surfaces confining therebetween a resident fluid body and arranged in such close proximity that the fluid, entrained in circles by the rotating primary exerts a torque on the secondary member in substantially linear proportion to the speed of the former.

22. In combination, in a speed-indicator, a rotatable primary element, a biased secondary element, a fluid body between and around them, said elements having opposed non-contacting extensive surfaces in such close proximity that the resident fluid body therebetween transmits torque to the secondary in substantially linear proportion to the speed of the primary element, and means for minimizing the rotary effort transmitted through the fluid around the elements.

23. A rate indicator comprising a structure confining a substantially unchanging body of fluid and including an extensive annular surface of a freely rotatable member, arranged to impart circular motion to the fluid, and a confronting annular surface of an indication-controlling angularly-displaceable member, arranged to take up momentum of the fluid, said surfaces being so closely proximate that the torque transmitted through the fluid is proportional to the speed of the rotatable member.

24. A speed indicator comprising two elements mounted for separate movement in a fluid medium, one of the elements being freely rotatable at varying speeds, and the other pivoted and biased against angular displacement, said elements having opposed non-contacting extensive symmetrical surfaces in such close proximity that torque is transmitted through the intervening fluid body in substantially linear proportion to the speed of the primary element, and a member surrounding said elements and minimizing the flow of the fluid along the exterior surfaces of said secondary element.

25. In a device of the character described, the combination of a rotatable primary element, a spring-biased secondary element, a casing surrounding the same and a fluid body filling the casing, said elements having opposed non-contacting annular surfaces in such close proximity that the rotary effort exerted through the fluid body on the secondary element is proportionate to the speed of the primary element, some parts of said casing being so closely proximate to said elements as to minimize torque-transmitting flow of the fluid along the exterior surfaces of the secondary element.

26. An air drag speedometer wherein a rotatable primary variable-speed element and a biased pivoted secondary element, mounted for separate movement in an air-containing casing, have opposed extensive smooth annular surfaces in such close juxtaposition that torque is transmitted through the air intervening between said surfaces in substantially linear proportion to the speed of the rotatable primary element.

27. A speed indicator comprising a closed fluid-filled casing, primary and secondary elements mounted therein, the one for rotation and the other for torsionally resisted angular displacement, said elements having opposed non-contacting extensive annular surfaces forming therebetween a smooth intervening channel wherein confined fluid may move in circles under the influence of the primary member, and between them and the interior surfaces of the casing surrounding channels wherein fluid contiguous to the secondary element may receive circular movement from the primary element, said surfaces being so closely proximate that torque transmission through the fluid is linearly proportionate to the speed of the primary element.

28. The combination, in a speed indicator, of a closed casing, a fluid body and two rotatively-movable members therein, means for rotating, one of the members, means for resisting displacement of the other, and means controlled by the last named member for reading its displacement in terms of speed, said two members having opposed, non-contacting imperforate annular surfaces in such close proximity as to confine therebetween a film of fluid through which torque is transmitted to the resistant member in linear proportionality to the speed of the rotatable member.

29. The combination with a closed fluid containing casing, of a plurality of symmetrical bodies with smooth surfaces rotatably mounted therein, means for torsionally restraining some of said bodies, and means for rotating the others, said bodies being placed with their surfaces in such close proximity to each other and to the walls of the casing that the rotating bodies will cause an even and undisturbed circular motion of the fluid and transmit torque to the torsionally restrained bodies in proportion to the speed of the others.

30. In a speed measuring instrument, the combination of driving and driven members having in opposed closely adjacent non-contacting relation relatively extensive smooth friction surfaces, and an interposed gaseous body through which the driving member frictionally drags the driven member.

31. A tachometer comprising, in combination, a rotatably mounted shaft, a smooth annular body fixed thereto, a similar pivoted body, a torsion spring for the latter, indicating means movable with said pivoted body, and an air-containing casing, said bodies having their annular surfaces in such close, non-contacting proximity that the intervening air transmits torque to the pivoted body in substantially linear proportion to the speed of the rotatable body.

32. A tachometer comprising, in combination, a rotatably mounted shaft, a primary element carried thereby, a pivoted secondary element, a torsion spring therefor permitting its angular displacement substantially in proportion to the torque, indicating means operated by the pivoted element and graduated with substantial uniformity, and a fluid-containing casing closely investing part of said rotative system, the opposed surfaces of the elements being so closely proximate to each other and to part of the casing that the fluid transmitted torque causing deflections of the pivoted body is substantially proportionate to the speed of the primary element.

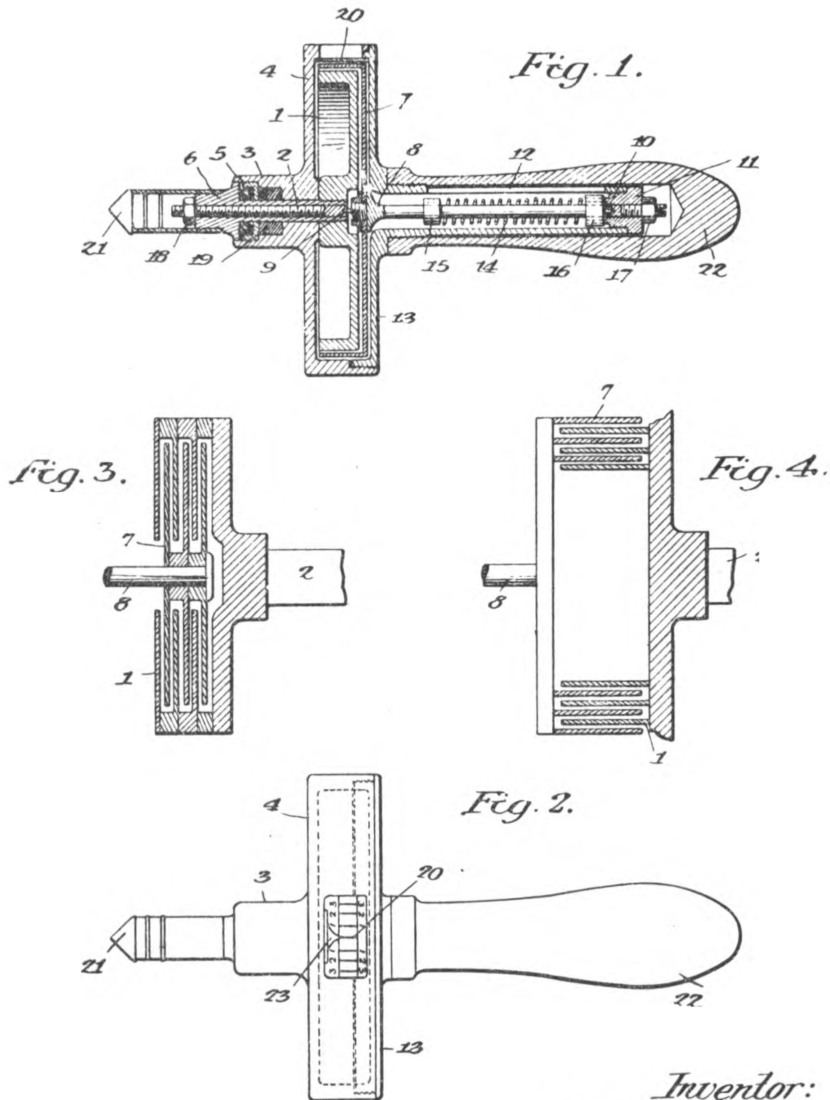
In testimony whereof I affix my signature in the presence of two subscribing witnesses.

NIKOLA TESLA.

Witnesses:
M. LAWSON DYER,
THOMAS J. BYRNE.

N. TESLA
SPEED INDICATOR
APPLICATION FILED MAY 29, 1914.

1,209,359. Patented Dec. 19, 1916.



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UNITED STATES PATENT OFFICE.

NIKOLA TESLA, OF NEW YORK, N. Y., ASSIGNOR TO WALTHAM WATCH COMPANY, OF WALTHAM, MASSACHUSETTS, A CORPORATION OF MASSACHUSETTS.

FREQUENCY METER.

1,402,025. Specification of Letters Patent. Patented Jan. 3, 1922.

Application filed December 18, 1919. Serial No. 137,689.

To all whom it may concern:

Be it known that I, NIKOLA TESLA, a citizen of the United States, residing at New York, in the county and State of New York, have invented certain new and useful Improvements in Frequency Meters, of which the following is a full, clear, and exact description.

In many instances in practice it is very desirable and important to ascertain the frequency of periodic currents or electric oscillations and therefrom the speed of rotation or reciprocation of the generating or controlling apparatus.

The devices commonly used at present for this purpose and designated "frequency meters" generally consist of reeds or bars tuned to respond to impulses of definite periods, or a direct current dynamo coupled to the alternating generator or frequency controller and connected with an instrument, of voltmeter construction, graduated to indicate the instantaneous frequency of the current. Both of these forms are objectionable from many points of view, being subject to various limitations of practical availability and to disturbing influences, all so well known to experts as to dispense with the necessity of enlarging upon them on this occasion.

My invention has for its object to provide a frequency meter of great accuracy, structural simplicity, wide range of use, and low cost, all adequate to meet the pressing demand for a commercial and scientifically satisfactory instrument of improved form.

In the drawings, wherein I have illustrated a single embodiment of my invention for purposes of disclosure,—

Fig. 1 is a central vertical section through the frequency meter, with diagrammatic extension to indicate an available manner of connecting it to a two-phase generator;

Fig. 2 is an end view;

Fig. 3 is a side elevation with the cover in section, and Fig. 4 is a side elevation of the instrument from its reading side.

It will be understood that the specific construction of instruments embodying my invention may be modified in many ways according to the demands of the electrical or mechanical environment in which it is to be used, and while I shall describe in detail a specific construction, illustrated in the drawing, it is without intent to limit my invention in its broader aspects to matters of detail.

5 represents diagrammatically a two-phase generator, typifying the machine controlling the frequency to be measured, and having suitable connection by wires 6 with the synchronous-motor element of the frequency meter, indicated as a whole by 7. The motor, 8, will of course have field poles and armature bars appropriate to the character of the current supplied from the generator 5, the motor being of the split-phase, two-phase, or other type, as needed. A frame 10, having lugs 11, or other means of support, provides a cup-formed shell 12 with a top wall 13 furnished with a central bearing tube 14 and with suitable supporting means, as 15, for the stationary field structure 16. A cap 17, screw threaded at 18, and suitably packed, hermetically seals one side of the motor casing into which the connecting wires are led through any suitable sealing and insulating bushings 19.

For accuracy and promptness of response to frequency-variations, the armature structure 21, as a whole, with its attachments should be of very light weight and so equipped that its work is minimized. Hence it is important both that the construction of the armature element be designed with reference to smallness and consequent lightness of parts, and that its frequency-indicating equipment be of a character imposing the lightest load on the armature. Specifically, the armature laminæ 22 are carried on a light disk 23, fixed to the vertical shaft 24, that is supported by ball bearings 25 and 26, in tube 14, and, above the wall 13, carries the driving member of the indicator device 28. This appliance comprises, as its primary element, 29, a non-magnetic disk 30, of brass, say, having annular spaced, concentric walls 31, and as its secondary element, 32, a pivoted part including very light, annular walls 33 interleaved with the walls 31 and affording extensive smooth friction surfaces, very closely adjacent to, but not contacting with, the kindred surfaces of the primary member so that through the thin films of fluid, preferably air, intervening between them, torque may be transmitted from the primary to the secondary element in substantially linear proportion to the speed of the primary, Posts 35, mounted in the top wall of the frame, support a bridge piece 36 that carries a bearing yoke 37, affording upper and lower jewel bearings 38 and 39, the former contained in a bushing 40 threaded for adjustment in the yoke and set by a nut 41, such bearings receiving the spindle 42 from which extends, rigidly, the arm 43 carrying the annular walls of the secondary element. A spiral spring 44, fixed at one end to the shaft 42 and at its other end clamped adjustably in the split stud 45 on bracket 37, permits rotary displacement of the secondary element, substantially in linear proportion to the force applied. A scale 48, printed on or otherwise affixed to the outermost wall of the secondary element, is graduated in units of frequency and its indication point is determined by a fixed pointer 49 that is fixed at the edge of a transparent sealed window 50 of the casing shell 51 of cup formation, that is secured in sealed relation to the wall 13 as by packed screws 52 engaging bosses 53 on the bridge piece 36 so to complete the hermetic enclosure of the chamber containing the indicating elements. Such hermetic closure is not necessary in many instances but may be desirable.

In my copending application Serial No. 841,726 filed May 29th, 1914, Patent No. 1,209,359 I have set forth in detail certain laws the observance of which results in attainment of rigorous proportionality of deflections to speed in an "air drag" instrument, and all of such conditions may be observed to advantage in constructing the indication-giving element of the frequency meter

It will be noted that an instrument as herein described has many structural and operative advantages. The translating instrument, giving the frequency-reading, when constructed for use of air as the transmitting medium, may be of size to give ample torque, but if desired the ensealed mechanism may be operated in air or other, preferably inert, gases of more than atmospheric density for increase of the torque. The air drag instrument is substantially unaffected in accuracy by temperature changes, without special compensating mechanism, and is therefore practically insensible to the heating effect of the subjacent motor, and the double-chamber construction segregating the motor and translating device prevents the latter from being affected by air-currents engendered by the motor-operation. Furthermore, the indicator structure may be made immune to magnetic influence and eddy currents, however intense, by making its secondary element of appropriate non-shrinkable, insulating material, as compressed fiber, although in many instances the partition 13, acting as a shield for the indicator obviates the necessity for such provision. The small size, low cost and ease of maintenance, due to the simplicity of the construction are especially desirable.

What I claim is:

1. In a frequency meter, the combination of a synchronous motor, and a speed-responsive device, having a primary element connected to the armature shaft, and a pivoted torsionally-restrained secondary element, deflectable in substantially linear proportion to the speed of the primary and calibrated in terms of electrical frequency.

2. In a frequency meter, the combination of a synchronous motor and a speed-responsive device, said motor having an armature of light construction and said speed-responsive device comprising a primary element carried in rotation by said armature, and a torsionally-restrained secondary element, these elements having extensive confronting, closely adjacent friction surfaces, co-operating through interposed films of a fluid medium for displacement of said secondary element in substantially linear proportion to the speed of rotation of the primary element.

3. In a frequency meter, the combination of a synchronous motor and a speed-responsive device, the former having an armature of light construction and the latter comprising a primary element, carried in rotation by said armature, and a torsionally-restrained secondary element, these elements having extensive confronting, closely adjacent friction surfaces, cooperating through interposed films of air for displacement of said secondary element in substantially linear proportion to the speed of rotation of the primary element, said secondary bearing a scale calibrated in terms of frequency.

4. A frequency meter comprising, in combination, a synchronous induction motor, having a shell carrying the field, and a rotatable armature within the chamber of said shell having its shaft extended through said shell; and a speed-responsive device, comprising a closed casing, a non-magnctic primary element mounted upon said armature shaft, a separately mounted secondary element pivoted and torsionally restrained, said elements having opposed, closely adjacent non-contacting surfaces, co-operating through interposed films of a fluid medium through which torque is transmitted to the secondary in approximately linear proportion to the speed of the primary member, and a visible scale uniformly graduated in terms of frequency carried by the secondary member.

5. A frequency meter comprising a sealed, air-containing casing divided into two compartments, a shaft extending into both compartments, a synchronous motor in one compartment adapted to drive said shaft and an indicating device in the other, said device having a primary rotatable element con-

nected with the shaft, a separately mounted, indication-controlling element and a spring restraining the latter, said elements having extensive, confronting, closely adjacent, non-contacting surfaces cooperating through the interposed air films for displacement of the secondary, at all ordinary temperatures, approximately in linear proportion to the speed of the primary element.

6. In a frequency meter, the combination of a synchronous motor having an armature of light construction, a speed-responsive device comprising a primary element carried in rotation by the said armature and a torsionally-restrained secondary element, said elements having extensive confronting closely adjacent friction surfaces cooperating through interposed films of air for displacement of said secondary element in substantially linear proportion to the speed of rotation of the primary element, and a wall interposed between the armature of the motor and the speed-responsive device for shielding the latter from air disturbance caused by rotation of the former.

7. A frequency meter comprising a casing divided into two compartments, a shaft extending into both thereof, a synchronous motor in one compartment adapted to drive said shaft and a speed-responsive device in the other having a primary element connected for rotation with said shaft, a separately mounted, torsionally-restrained indicating element, said elements having extensive confronting, closely adjacent, non-contacting surfaces cooperating through interposed gaseous films for displacement of the secondary, approximately in linear proportion to the speed of the primary element.

8. In a frequency meter, the combination of a synchronous motor and a speed-responsive device, said motor having a light armature and a shaft, and said speed responsive device comprising a primary element of non-magnetic material carried by the armature shaft and a torsionally-restrained secondary element, these elements having extensive confronting, closely adjacent, non-contacting surfaces cooperating through interposed films of a fluid medium for displacement of the secondary element in approximately linear proportion to the speed of the primary element, and a containing structure ensealing the speed responsive device.

9. In a frequency meter, the combination of a synchronous motor having an armature of light construction, a speed-responsive device comprising a primary element carried in rotation by the said armature and a torsionally-restrained secondary element, said elements having extensive confronting, closely adjacent friction surfaces cooperating through interposed films of air for displacement of said secondary element in substantially linear proportion to the speed of rotation of the primary element, and means interposed between the armature of the motor and the speed-responsive device for shielding the latter from air disturbance caused by rotation of the former.

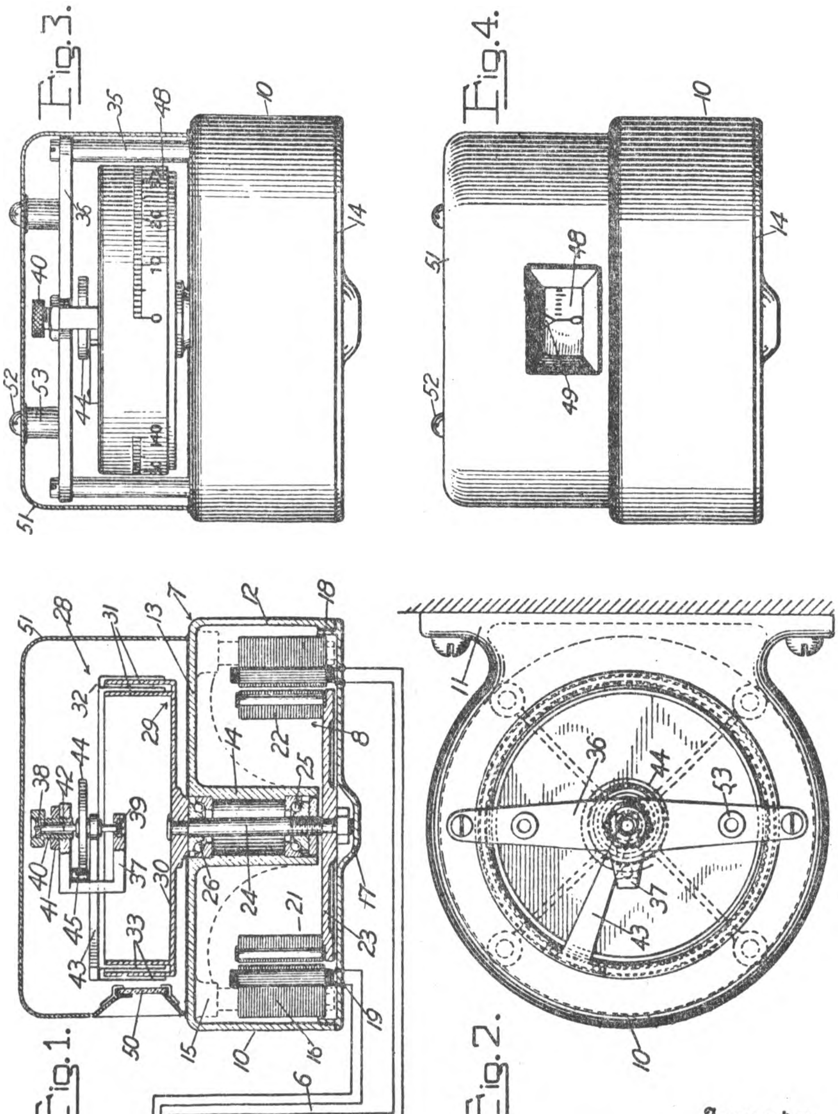
In testimony whereof I affix my signature.

NIKOLA TESLA.

P-399

N. TESLA.
FREQUENCY METER.
APPLICATION FILED DEC. 18, 1916

1,402,025. Patented Jan. 3, 1922.



Inventor
Nikola Tesla
By his Attorneys

UNITED STATES PATENT OFFICE.

NIKOLA TESLA, OF NEW YORK, N. Y., ASSIGNOR TO WALTHAM WATCH COMPANY, OF WALTHAM, MASSACHUSETTS, A CORPORATION OF MASSACHUSETTS.

SPEED-INDICATOR.

1,274,816. Specification of Letters Patent. Patented Aug. 6, 1918.

Application filed December 18, 1916. Serial No. 137,691.

To all whom it may concern:

Be it known that I, NIKOLA TESLA, a citizen of the United States, residing at New York, in the county and State of New York, have invented certain new and useful Improvements in Speed-Indicators, of which the following is a full, clear, and exact description.

Among the desiderata of speedometer construction are these: that the torque exerted upon the secondary, or indication-giving, element shall be linearly proportional to the speed of the primary member rather than to the square of the speed (as instanced in centrifugal speedometers); that the torsional effect at low speeds shall be strong and steady so that particular delicacy of construction may not be necessary and that minute causes of theoretical errors (such as bearing-friction, spring-inequalities and the like) may be negligible in effect; that the torque may be substantially unaffected by changes of extraneous conditions, as of temperature, atmospheric density and magnetic influence; that the instrument be inherently dead-beat and relatively insensible to mechanical vibration; and that ruggedness, simplicity and economy, for attendant durability, manufacturing facility and low cost, be attained. My present speedometer realizes these advantages and provides, also, an appliance that is suitable for great, as well as very small, velocities, exact in its readings, uniformly graduated as to scale, and unaffected by changes of temperature or pressure within as well as without.

In my Patent No. 1,209,359, dated December 19, 1918, I have described a new type of speed measuring instrument wherein the adhesion and viscosity of a gaseous medium, preferably air, is utilized for torque-transmission from a primary driving to a secondary pivoted and torsionally restrained member under conditions such that the rotary effort exerted upon the latter is linearly proportional to the rate of rotation of the former. The principles of that invention find place in my present construction. Such "air drag" speedometers have been found capable of meeting satisfactorily the commercial requirements for both large and small instruments respectively adapted to measure relatively high and low speeds, but nevertheless it is true that although such instruments, when built for high-speed indication, may be of sturdy construction, they must, when designed for low-speed measurement, be built with great precision and delicacy. This because the inertia of the secondary element must be kept extremely small for desirable promptness of response to very slow starting speeds and consequent feebleness of the turning effort. In some instances, therefore, it is highly desirable to employ a transmitting medium giving a much greater torque than air with concomitant extension of the low-range of accurate speed reading, quickness of response, practicable decrease of size of parts and lessening of sensitiveness to disturbances such as vibration of the instrument as a whole.

All of the stated objects I accomplish by employing as the torque-transmitting medium between the driving and driven elements a body of suitable liquid, (*e. g.*, mercury) under conditions (as set forth in my prior application referred to) proper to secure linear proportionality of deflections, and, further, by making provision automatically to compensate for the changes in the viscosity of the liquid that accompany variations of temperature. The latter equipment is unnecessary in my air-drag speedometer, but mercury and other liquids of relatively great density that might be employed for my present purposes have not the quality of approximate self-compensation for temperature changes that inheres in air, owing to the fact that the viscosity of such a liquid decreases rapidly as its temperature rises, and so to a successful "mercury-drag" instrument temperature compensation is requisite.

The underlying ideas of this invention can be carried out in various ways and are capable of many valuable uses, but for purposes of disclosure, specific reference to a form of speed indicator designed for use on an automobile is adequate.

As in the structure described in my stated prior application, I provide driving and driven members with confronting, closely-adjacent, non-contacting, smooth, annular friction surfaces, co-acting for transmission of torque through the viscosity and adhesion of interposed thin films of a suitable medium—in this case mercury—under conditions to prevent free exchange of fluid acting on the system, to prevent its local circulation and eddying, to maintain its flow calm and non-turbulent, and to secure as low velocity of the medium with respect to the system as the circumstances of the case may make desirable. These conditions all aid in the attainment of rigorous linear proportionality of deflection of the secondary to the speed of rotation of the primary element under given temperature conditions. Additionally, by suitable construction I make it possible to obtain a nearly perfect compensation for temperature changes so that the deflections may be rigorously proportionate to speed within limits of temperature variation wider than I believe likely to occur in the practical use of the instrument. I attain this compensatory result by providing thermo-responsive means to vary the effective area of the secondary element upon which the medium acts in approximately inverse proportion to temperature-effected changes of viscosity of the medium, and as a preferred specific means to this end, I dispose a body of the liquid beyond, but communicating with, the active portion of the liquid medium and of such quantity that, in effectively the same measure as viscosity and, consequently, the torque is diminished or increased with temperature changes, the active liquid-contacting area of the secondary member is enlarged or reduced owing to the expansion or contraction of the fluid.

In the drawing Figure 1 is a top view of a speedometer;

Fig. 2 is a central vertical section therethrough;

Fig. 3 shows a spring adjusting arrangement; and

Fig. 4 and Fig. 5 are diagrams explanatory of the compensating principle.

In Fig. 4 the primary or driving member is a cup 10 carried by a freely rotatable vertical shaft 11. Within it the cylinder-formed secondary member 12 is mounted on a spindle 13, journaled in jewels 14 and 15 of negligible friction, for pivotal displacement against the restraint of a spiral spring 16, connected at its ends respectively to fixed support 17 and spindle-collar 18, so that by pivotal displacement of the secondary cylinder against the resisting spring tension, the torsional effort exerted on the secondary member may be measured. The spring is such that its displacements are linearly proportionate to the force applied. The lower portion 19, of the cup-chamber is a reservoir filled with the liquid, 20, as mercury, and the liquid normally extends part way up the very narrow interspace 21 between the two elements to contact with less than the whole of their confronting friction surfaces. With mercury as the medium, in an instrument with a secondary cup of one inch diameter I find an interspace-width of 0.05 inch to be satisfactory.

It will now be seen that when shaft 11 is rotated the mercury in the cup is entrained and in turn produces a drag upon the pivoted member 12, the torsional effort being directly proportionate to the active area, viscosity of the fluid and the speed of rotation and, inversely, to the width of the interspace 21 or distance between the rotated and pivoted surfaces. If v be coefficient of viscosity, A the active area, s the speed and d the distance between the juxtaposed rotating and pivoted surfaces, all of the quantities being expressed in proper units, then the twisting force

$$F = \frac{vAs}{d} \text{ dynes.}$$

When, through changes in the external conditions or work performed on the fluid, the temperature of the same is raised, two effects, separate and distinct, are produced. In the first place, the viscosity is diminished according to a certain law, reducing correspondingly the torque, on the other hand, the fluid expands thereby enlarging the areas of the active, or liquid-contracting, surfaces of the elements with an attendant increase of rotary effort. Obviously, then, if it is possible so to relate these actions that they mutually annul each other upon any change of temperature, a complete compensation may be obtained. This result, I have ascertained, can be almost perfectly realized with a liquid, as mercury, by properly proportioning the volume of the chamber-contained, or compensating, component 20^c of the liquid and the component 20^a of the liquid in the interspace 21. With a view to simplifying this explanation, be it supposed that the force F is wholly due to the liquid component 20^a (the drag exerted on the bottom face of cylinder 12 being assumed to be negligible and the bearings to be frictionless). It will be evident that under these conditions the active area will increase as the volume of the fluid. Perfect compensation would require that upon a rise of temperature, the active area, and therefore the torsional effort, be augmented in the same ratio as viscosity is diminished. In other words, the percentage of decrease of viscosity divided by that of increase of area should be the same for all temperatures. Attention is called to the table below showing that, with mercury as the medium, the value of this fraction at ordinary temperatures is about, or not far from, 20.

Temperature C.	Volume of fluid.	Viscosity of fluid.	Percentage of increase of V.	Percentage of decrease of *v*.	Value of ratio.
T	V	v	a	b	$\frac{b}{a}$
−20	0.996364	0.018406	−0.3636	−8.2718	22.75
−15	0.997273	0.018038	−0.2727	−6.1029	22.38
−10	0.998182	0.017681	−0.1818	−4.0074	22.04
−5	0.999091	0.017335	−0.0909	−1.9722	21.70
0	1.000000	0.017000	0	0	21.35
5	1.000909	0.016663	0.0909	1.9107	21.02
10	1.001818	0.016361	0.1818	3.7603	20.68
15	1.002727	0.016057	0.2727	5.5505	20.35
20	1.003636	0.015762	0.3636	7.2706	20.00
25	1.004546	0.015477	0.4546	8.9564	19.70
30	1.005455	0.015202	0.5455	10.5750	19.38
35	1.006365	0.014937	0.6365	12.1410	19.07
40	1.007275	0.014680	0.7275	13.6470	18.75
45	1.008185	0.014433	0.8185	15.1031	18.45
50	1.009095	0.014194	0.9095	16.5073	18.15

This means to say that if the total volume of the liquid is twenty times that contained in the interspace between the elements, the two opposite effects, one increasing and the other reducing, the torque, will approximately balance. This fact is borne out by practical tests and measurements, which have demonstrated that by constructing for this volumetric ratio deflections very closely proportionate to the speed are obtained through a range of temperature variations far greater than ordinarily occurring. For commercial purposes it is quite sufficient to employ a ratio of approximately the stated value as the error involved in a small departure therefrom is inconsiderable. When necessary or desirable, greater precision can be obtained by taking into account four secondary effects, due to expansion or contraction of the walls, which slightly modify the torque; first, changes in the volume of the reservoir; second, in the distance between the opposed surfaces; third, in active area and, fourth, in velocity. Increase in the former two tend to diminish, the latter to augment, the viscous drag. A satisfactory ratio in a cylindrical type of instrument has been found to be about 24.

Fig. 5 illustrates a different arrangement, exemplifying the same principle of employing a reservoir-contained liquid body as the thermo-responsive means to compensate for viscosity changes of the active liquid. In this case a spindle-carried disk 12' serves as a secondary element, while the primary member consists of a hollow shell 10' with annular surfaces 23 confronting the disk surfaces and encompassed by an annular chamber 20', so that under rotation the mercury body fills the chamber and occupies peripheral portions of the interspaces 21 between the flat confronting surfaces. It is hardly necessary to remark that since there are two such interspaces 21, the calculation of capacity of the reservoir or chamber 20', beside considering the form of the device, must take account of the active mercury body in both interspaces.

In Figs. 1 to 3 a complete commercial instrument embodying my invention is shown. Specifically, 25 is a tube threaded at 26 and carrying at the top a casing head 27 the whole forming a housing for inclosure of the moving parts. The driving shaft 28 carries a cylindrical cup 29 in the bottom of which is screwed a plug 30, turned down as 31 for the purpose of providing the reservoir 32. The cup 29 is closed at its upper end by a tight fitting cover 33, having an upwardly extending shank 34, carrying a pinion 35 to drive suitable wheel work 36 of the odometer contained in the lower part of the head 27. This structure, providing the primary element, is rotatable in ball-bearings 37 and 38 fixed in tube 25 and adjustable by means of nuts 39.

The secondary element is made of a very thin metal cup 40, inverted and secured to slender spindle 41 mounted in jeweled bearings 42 and 43, respectively carried in a cavity of plug 30 and by a frame arm 43'. A running bearing 42 can usually be employed without detriment, but a fixed bearing may be used if desired. The weight of the secondary member with its movable attachments should be so determined that the upward thrust against jewel 43 is very slight. The torsional twist of secondary cup 40 is resisted by a spiral spring 44 lodged in a turned recess of a frame plate 45, having one of its ends connected to collar 46 fast on the spindle 41 and the other to a split ring 47 spring-gripping the wall of the recess in plate 45. By inserting pincers in holes 48 (Fig. 5) and contracting the ring it is freed sufficiently for adjustment to bring the spindle-carried indicator 49 to point to zero of the graduated scale 50 that, if all of the principles of my invention are best embodied, may be made uniformly graduated. The scale is carried on plate 45 and, together with the support 43', is held in place by a rim 53 that suitably carries the glass cover 52. The odometer may have any suitable number of indicating elements of different orders suitably geared, the two hands 54 and 55 sweeping over graduated dials 56 and 57, typifying any suitable construction.

It will be apparent that the high torque at low speed developed through the mercurial transmitting medium makes the instrument very effective as one for use on automobiles, and while it is true that with a heavy, fluid, as mercury, the range of velocity of the medium throughout which proportionality of torque to speed, under the described conditions, is rigorously linear falls below the range available where air is the medium, a construction presenting the friction surfaces of the elements in a cylinder-form as suggested in Figs. 2 and 4 permits of the use of a suitably constructed device with a small-diameter secondary to measure very high speeds without imparting to the medium a linear velocity beyond its stated range. For the successful use of mercury in the present described instrument (or other rotary devices) it is important that the mercury be pure, the surfaces contacting therewith smooth, clean and non-granular (preferably nickel-plated or made of non-corrosive, high grade steel) to minimize abrasion and keep the mercury clean, and that the linear velocity of the mercury be kept low, preferably below six feet per second, in order that it may not break up into minute droplets or apparently-powdered form.

What I claim is:

1. In combination, driving and driven elements, having opposed, closely-adjacent, non-contacting friction surfaces; a liquid body interposed between active areas thereof through which the driving element frictionally drags the driven one and thermo-responsive means for varying the active area of the secondary in approximately inverse proportion to the thermo-effected variations in viscosity of the liquid.

2. In a temperature-compensating speed indicator, the combination of variable speed primary and movement-restrained secondary elements that are suitably supported for separate movement and have opposed friction surfaces in close but non-contacting juxtaposition; an interposed liquid body contacting normally with active areas of said surfaces less than the whole thereof, and thermo-responsive means for varying the liquid-contacting areas of said elements approximately inversely to the thermo-effected variations of liquid viscosity.

3. In a temperature-compensating speed indicator, the combination of variable speed primary and movement-restrained secondary elements that are suitably supported for separate movement and have opposed closely-adjacent non-contacting friction surfaces; an interposed liquid body and thermo-responsive means for varying the active areas of said surfaces in predetermined proportion to thermally-effected changes or liquid viscosity.

4. In a temperature-compensating speed indicator, the combination of variable speed primary and movement-restrained secondary elements that are suitably supported for separate movement and have opposed closely-adjacent non-contacting friction surfaces; a liquid body partially filling the interspace between said surfaces, and thermo-responsive means for varying the liquid quantity within in said interspace in predetermined inverse ratio to thermo-effected changes of liquid viscosity.

5. The combination with driving and driven elements having opposed, closely-adjacent, non-contacting friction surfaces and an interposed liquid body contacting with active portions thereof, of a compensating liquid body communication with the said interposed or active one, and proportioned to vary the effective contact area of the active liquid approximately inversely to its temperature-effected viscosity changes.

6. The combination with freely movable driving and movement-resisted driven elements, having friction surfaces in opposed, closely-adjacent non-contacting relation, or means providing a reservoir, communicating with the interspace between said elements, and a liquid body having a reservoir-filling component and an active torque-transmitting component that normally, partly occupies said interspace, these components proportioned volumetrically for temperature-effected change of the contact area of the active component in approximately inverse ratio to the attendant changes of liquid viscosity.

7. In a temperature-compensating speed indicator, the combination of a freely rotatable cylindrical cup; a cylinder-formed member in the upper portion thereof, pivoted and spring-restrained; and a body of mercury filling the reservoir-portion of the cup below the pivoted member and extending partially in the narrow interspace between the cup and cylinder.

In testimony whereof I affix my signature.

NIKOLA TESLA.

P-404

N. TESLA.
SPEED INDICATOR.
APPLICATION FILED DEC. 18, 1916.

1,274,816. Patented Aug. 6, 1918.

Fig. 1.

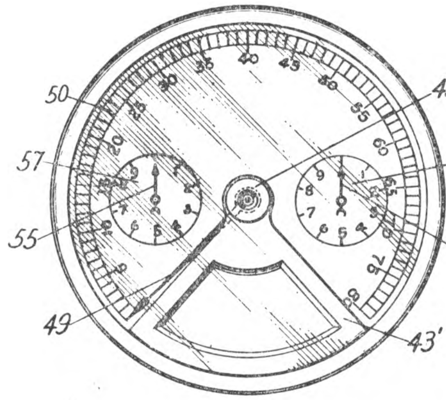


Fig. 3.

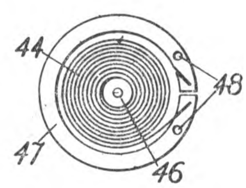


Fig. 2.

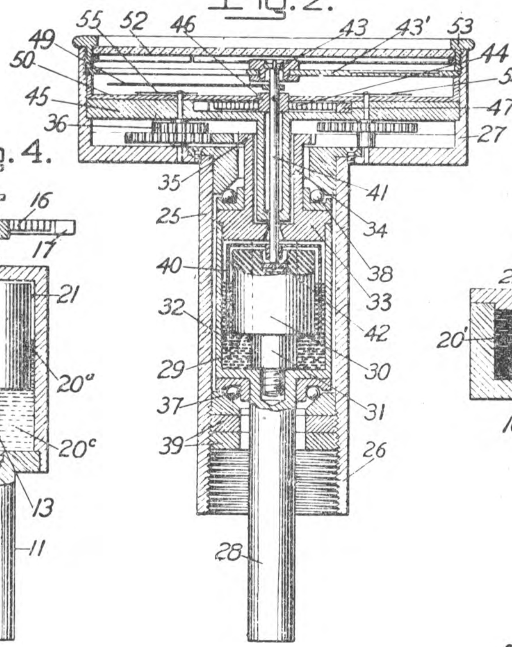


Fig. 4.

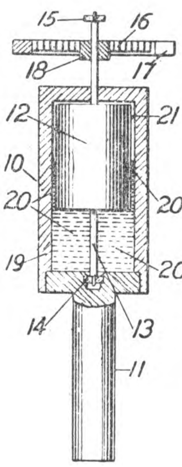
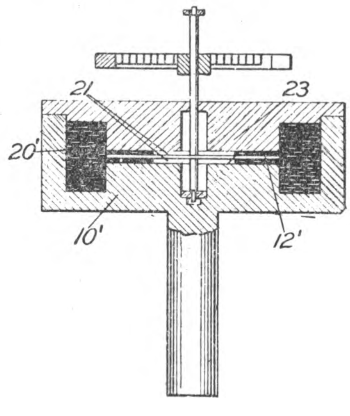


Fig. 5.



Inventor
Nikola Tesla
By his Attorneys-
Force Bain & May.

UNITED STATES PATENT OFFICE.

NIKOLA TESLA, OF NEW YORK, N. Y., ASSIGNOR TO WALTHAM WATCH COMPANY, OF WALTHAM, MASSACHUSETTS, A CORPORATION OF MASSACHUSETTS.

SHIP'S LOG.

1,314,718. Specification of Letters Patent. Patented Sept. 2, 1919.

Application filed December 18, 1916. Serial No. 137,690.

To all whom it may concern:

Be it known that I, NIKOLA TESLA, a citizen of the United States, residing at New York, in the county and State of New York, have invented certain new and useful Improvements in Ships' Logs, of which the following is a full, clear, and exact description.

My invention provides a ship's log of novel and advantageous construction and operation, designed to give instantaneous rate-readings, as in knots, or miles per hour. The customary log is trailed astern, twisting the flexible connector that drives a revolution-counter on the vessel, and many disadvantages of such arrangement are obvious.

In my instrument I combine very advantageously a propeller rotatable proportionately to vessel-speed and a speed indicator driven by it and reading directly in the desired terms, preferably upon a substantially uniformly-graduated scale.

In the drawings, Figure 1 diagrams the log in use;

Fig. 2 shows it in vertical section;

Fig. 3 illustrates speed-indicator parts with the casing broken away;

Fig. 4 is a section on line 4—4 of Fig. 3;

Fig. 5 is a section on line 5—5 of Fig. 2.

Fig. 6 shows in section a turbine form of propeller, and

Fig. 7 is a section on line 7—7 of Fig. 6.

To the vessel 10, preferably near its bow, is suitably affixed a tube or barrel, 11, with a threaded plug 12 closing its lower end, where the tube preferably dips below the level of the boat's keel. At the top—near the deck or other point of observation—the speed-indicator 13 is mounted, its casing 14, that carries all of the moving parts being detachably secured, as by screws 15, to the top-flange 16 of the barrel. A boss 17 on the underside of casing 14 supports the ball bearing 18 for the primary element of the indicator and a seal 19 for its flexible drive-shaft 20 that connects preferably through a slip-joint squared union, 21, to a propeller-driven part. The propeller may be of common form as shown in Fig. 2, at 22, with its shaft 23 horizontally mounted in the bracket 24 spanning the tubular passage 25 of a housing 26 that fits neatly in the barrel and is held in register with ports 27 and 28 by guide-ribs 29. Such a propeller drives the shaft 20 through bevel gears 30.

More advantageously in some respects, however, a turbine propeller of simple construction may be employed, as shown in Figs. 6 and 7. The rotor in this instance has a vertical shaft 23' and the wheel 22' is formed of thin, parallel, closely-spaced disks each having a central opening. The wheel is arranged in a cylindrical housing 26' that has inlet nozzles 31 and outlet ports 32 so disposed that the water enters the interspaces between the disks tangentially to rotate the wheel and finds escape through the ports 32 that communicate with the central orifices of the disks. This type of construction has many advantages due to its reliability and efficiency, but preferably it should be constructed to permit the disks and casing to be readily cleaned, casing 26' being made in two horizontal sections bolted together as at 33, each section having a detachable head 34.

A flexible and longitudinally elastic sleeve, 35, of coiled strip metal is fastened at opposite ends by threaded caps 36 and 37 to the boss 17 and to a threaded part on the propeller casing, so that the propeller mechanism is supported from the indicator casing for removal therewith.

By suitably constructing the submerged parts of bronze, enameling them, or otherwise making them substantially immune to corrosion, adequate durability is attained, and the facility of removal for cleaning, oiling, repairs, etc., makes the under-water parts easy to maintain in good order. The pliant shaft, slip-connected at one end and its stout protective sleeve, strong yet flexible and extensible frees the bearings from strain and makes the connection uniformly efficient under changes of conditions as to temperature, etc.

The speed indicator 13 preferably provides as its primary element 41 a multiple-walled cup, fast on shaft. 20, and as a secondary, or indication-giving, member a lightly-constructed pivoted, multiple-walled inverted cup structure 42, with the annular walls interleaved in closely adjacent non-contacting relation for transmission of turning effort from the one to the other through intervening films of the casing-contained fluid medium, as air, in approximately linear proportion to the speed of the primary. Specifically the secondary cups are dependent from an arm 43 projecting from spindle 44, having jewel bearings in yoke 45 carried by bridge-piece, 46, that spans the casing 14, and the dial 47, calibrated according to a suitable constant to read in knots, or miles per hour or other units of rate, is borne by the cup-structure below a fixed hand 48 visible through the sealed cover-glass 49. A coiled spring 50, connected at its ends respectively to the pivoted secondary element and to a fixed support, resists the pivotal displacement of the indication-giving member. The light secondary element, quickly and accurately responsive approximately directly proportionately to the speed of the propeller-driven primary member, and little affected by tremors, temperature changes and other extraneous influences, gives adequately accurate readings in the desired terms, showing instantaneously changes of the vessel's speed.

What I claim is:

1. In ship's log, a barrel having water flow openings near its bottom, a speed-indicator detachably secured to one end of the barrel, a flexible shaft for the speed-indicator, a propeller connected to the shaft-end, a housing for the propeller, registering with the water-flow openings, and a sleeve surrounding the shaft uniting the housing and casing, for extraction of the propeller-parts when the speed-indicator is removed from the barrel.

2. In a ship's log, a barrel, a speed indicator having a casing secured detachably to the upper or observation end of the barrel, a propeller having a housing and adapted to pass through the barrel, a flexible shaft slip-fitted to connect the propeller and speed indicator, and a flexible sleeve connecting the propeller-housing and indicator-casing.

3. In a ship's log, the combination of a barrel having waterflow openings near its bottom, a speed indicator having a casing detachably secured to one end of the barrel, a shaft for said speed indicator extending centrally through the barrel, a propeller for the shaft end, a housing for the propeller, said housing being smaller than the barrel, and a sleeve surrounding the shaft uniting said housing and said indicator casing for effecting extraction of the propeller parts when the speed indicator is removed from the barrel.

4. In a ship's log, a barrel, a speed indicator having a casing secured detachably to the upper end of the barrel, a propeller having a housing and adapted to pass through the barrel, there being registering openings near the bottom of the barrel and in said housing for water-flow to the propeller, a flexible shaft connecting said propeller and speed indicator and making axially slidable connection with one thereof, and a flexible and axially expansible sleeve connecting the propeller housing and the indicator casing for extraction of the propeller parts when the speed indicator is removed from the barrel.

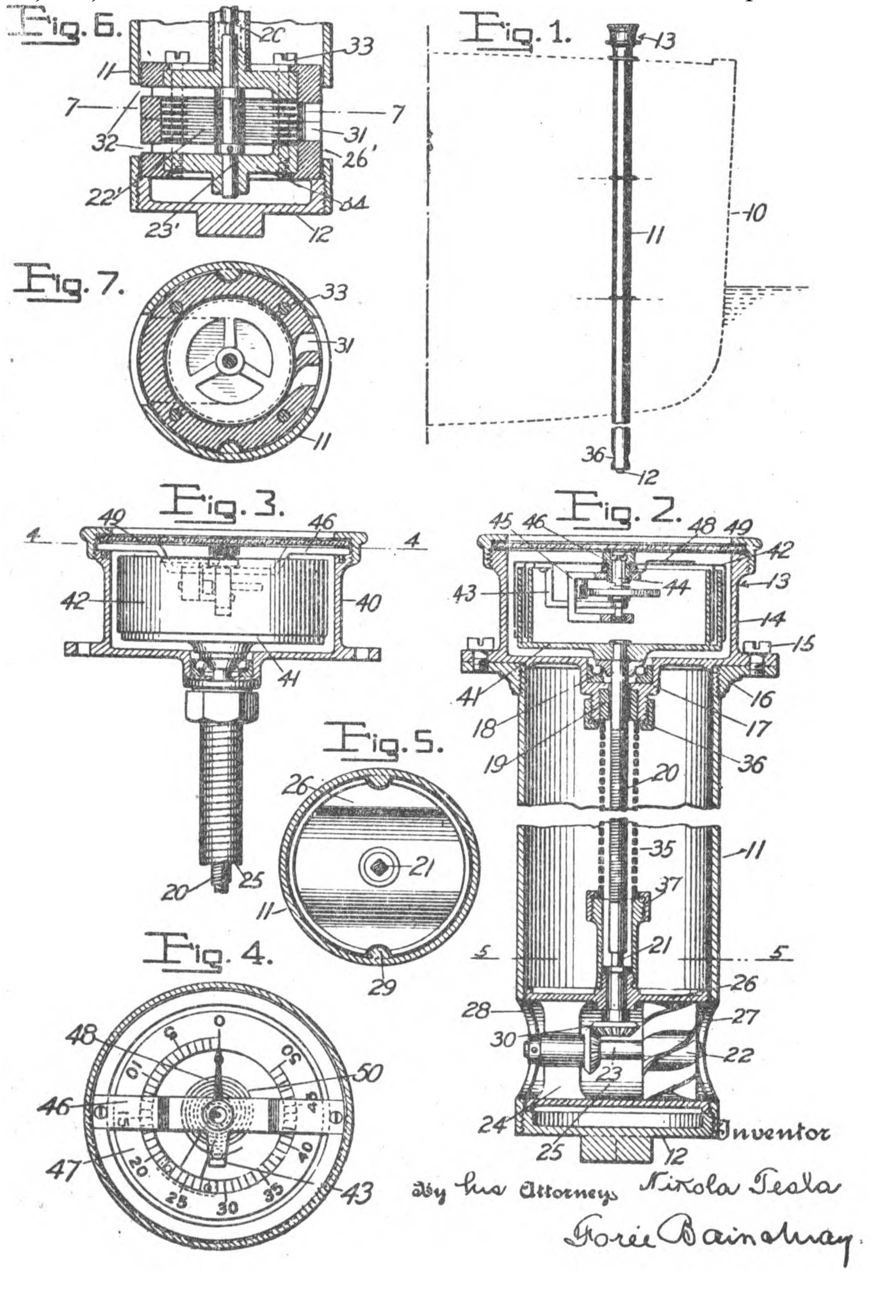
In testimony whereof I affix my signature.

NIKOLA TESLA.

N. TESLA.
SHIP'S LOG.

APPLICATION FILED DEC. 18, 1916.

1,314,718. Patented Sept. 2, 1919.



UNITED STATES PATENT OFFICE.

NIKOLA TESLA, OF NEW YORK, N. Y., ASSIGNOR TO WALTHAM WATCH COMPANY, OF WALTHAM, MASSACHUSETTS, A CORPORATION OF MASSACHUSETTS.

FLOW-METER.

1,365,547. Specification of Letters Patent. Patented Jan. 11, 1921.

Application filed December 18, 1916. Serial No. 137,688.

To all whom it may concern:

Be it known that I, NIKOLA TESLA, a citizen of the United States, residing at New York, in the county and State of New York, have invented certain new and useful Improvements in Flow-Meters, of which the following is a full, clear, and exact description.

My invention relates to meters for measurement of velocity or quantity of fluid flow. Its chief object is to provide a novel structure, simple, inexpensive and efficient, directly applicable to a conduit through which the fluid flows, and arranged to give instantaneous readings in terms of velocity, or quantity.

In the drawings I have shown a single embodiment of my invention in desirable form, and therein—

Figure 1 is a central, vertical section showing the device in use;

Fig. 2 is a plan detail of the indicating instrument with parts in section;

Fig. 3 is a horizontal section on line 3—3 of Fig. 1, and

Fig. 4 is an enlarged section on line 4—4 of Fig. 1.

Assuming that the flow of liquid 10 through a main 11 is to be measured as in gallons per hour, or feet per second, the main is tapped as at 12 and into the threaded orifice is screwed the body-casting of the flow-meter 13. This casting has a threaded waist 14, centrally apertured to receive the bearing bushing 15, the upper portion of the casting being formed as a shell 16 for incasing the indicating mechanism, and its lower portion prolonged as a tube 17, terminating in a head 18 to receive the flow-driven element. The latter, I prefer, shall be a turbine of the type commonly identified by my name. Illustrating simply its essential elements, the rotor, 19, is made up of centrally apertured parallel disks 20, closely spaced and mounted on a shaft, 21, extending through a shell 22 confined within the head 18 above the plug 23 that closes the bottom of the head and carries an adjustable step-bearing screw 24. Inlet nozzles 25, in the wall of head 18, direct the liquid to the disks tangentially to set the latter in rotation and the water finds escape through the outlet passages 26 of the shell 22 and ports 27 of the head 18. Preferably the length of tube 17 should be such as to dispose the turbine rotor approximately at the center of the main, and of course the turbine will rotate at a rate linearly proportional to the velocity of the fluid at that point, according to a practically-determined constant.

Turbine shaft 21 connects with shaft 30 of the indicator, that preferably is of minimal diameter for the work to be done and that passes through the long bushing 15 for direct connection with the indicator 31. The primary element, 32, of this indicator, directly mounted on said shaft 30, preferably comprises a cup having multiple vertical walls 33 in concentric arrangement, these being interleaved with inverted cup walls 34 of a secondary element 35, that is pivoted and torsionally restrained and that bears a movable element of the reading scale. Specifically, the secondary element may have its inverted cup walls made of very thin aluminum mounted on arm 36, affixed to the spindle 37 that runs in jewel bearings carried by a yoke 38, supported on a bridge piece 39 spanning the casing 16. A coiled spring 40, at one end fast to the spindle 37 and its other end adjustably secured in split stud 41, on bracket 38, resists displacement of the secondary element which carries on its top a reading scale 43, graduated in terms of gallons per hour, feet per minute, or other units of measurement. This dial moves below the stationary pointer 44 that is visible through the sight-glass 45, carried by the cover cap 46 and tightly sealed. By constructing the indicator in accordance with principles fully explained in my Patent No. 1,209,359 the primary element, acting through the viscous or adhesive properties of air or other fluid medium filling the casing, is caused to displace the scale-bearing member against the tension of its spring substantially in linear proportion to the speed of rotation of the primary element, and by observing the conditions requisite to make the torque bear a rigorously linear proportion to the speed, and making the spring to permit deflections proportionate directly to the turning effort, the scale may be graduated uniformly without the employment of any compensating mechanism to this end.

The pressure or density of the gaseous fluid medium in the casing 60 should not be subject to change under varying conditions of pressure within the main, or the readings might be seriously inaccurate; nor, obviously, should escape of the liquid from the main into the indicator casing be permitted. To seal the running bearing of shaft 30 adequately to withstand very considerable pressures, I make what I term a "mercury-lock" by the following provision: the shaft 30 is made of fine steel of great and uniform density and the bushing 15 is preferably of hard copper, these having diameters leaving a clearance of only a few thousandths of an inch,—much too small for the capillary admission of mercury. These surfaces are treated for amalgamation with mercury. The bearing-portion of the shaft 30 is thinly copper plated, and then both bearing surfaces are coated, in a quickening solution, with mercury, after which the mercury-filmed parts are assembled. In this way, as sought graphically and exaggeratedly to be represented in Fig. 4, the mercury body 50 is introduced into the very narrow clearance, and although it is a unitary seal in its resistance to the passage of air or water, it may practically be regarded as forming two mirror-surfaced films between the bushing 15 and the copper plating 51 on shaft 30. I have found such a mercury lock makes a very effective and enduring seal while permitting adequately free rotation of the shaft.

The combination of turbine rotor and air drag indicating mechanism as above described is especially advantageous in that the small turbine, developing a high shaft speed under even rather slow fluid flow, insures that the speeds of the primary element will be ample to result in high torque, so that the indicator may be of relatively rugged construction. Furthermore, the practical insensibility of the air drag instrument to temperature changes, without special compensating mechanism, makes a very simple construction available for many and variant uses. And since linear relationships exist between the rate of liquid flow, turbine-rotation and indicator-displacement, accurate marking of the scale in uniform graduations depends only upon the establishment of certain easily-ascertainable constants for any given conditions.

What I claim is:

1. A flow-meter comprising a body having a pipe engaging portion, a lower head of smaller diameter and an upper casing, a vertical shaft extending through said body, a disk-turbine in said head directly connected with said shaft, said head having inlet and outlet openings to the turbine disks, and indicating means comprising a rotatable primary element directly connected with said vertical shaft and a torsionally-restrained secondary element displaceable by the first and equipped to show its displacement in desired terms.

2. In a device of the character described, the combination of a body fitting having an intermediate part for pipe engagement, a lower head, and an upper shell, a shaft passing vertically from said shell to said head, a pressure-resisting seal for said shaft adjacent said pipe engaging portion of the body, an indicator in said shell comprising a rotatable primary member having a vertical axis and directly connected with the upper end of said shaft, a torsionally-restrained secondary element displaceable by the first, said secondary element associated with a scale for showing its deflections in desired terms, and a horizontal disk-turbine rotor in said head, said rotor directly connected with the bottom of said shaft, said head having inlet and outlet openings to the rotor disk.

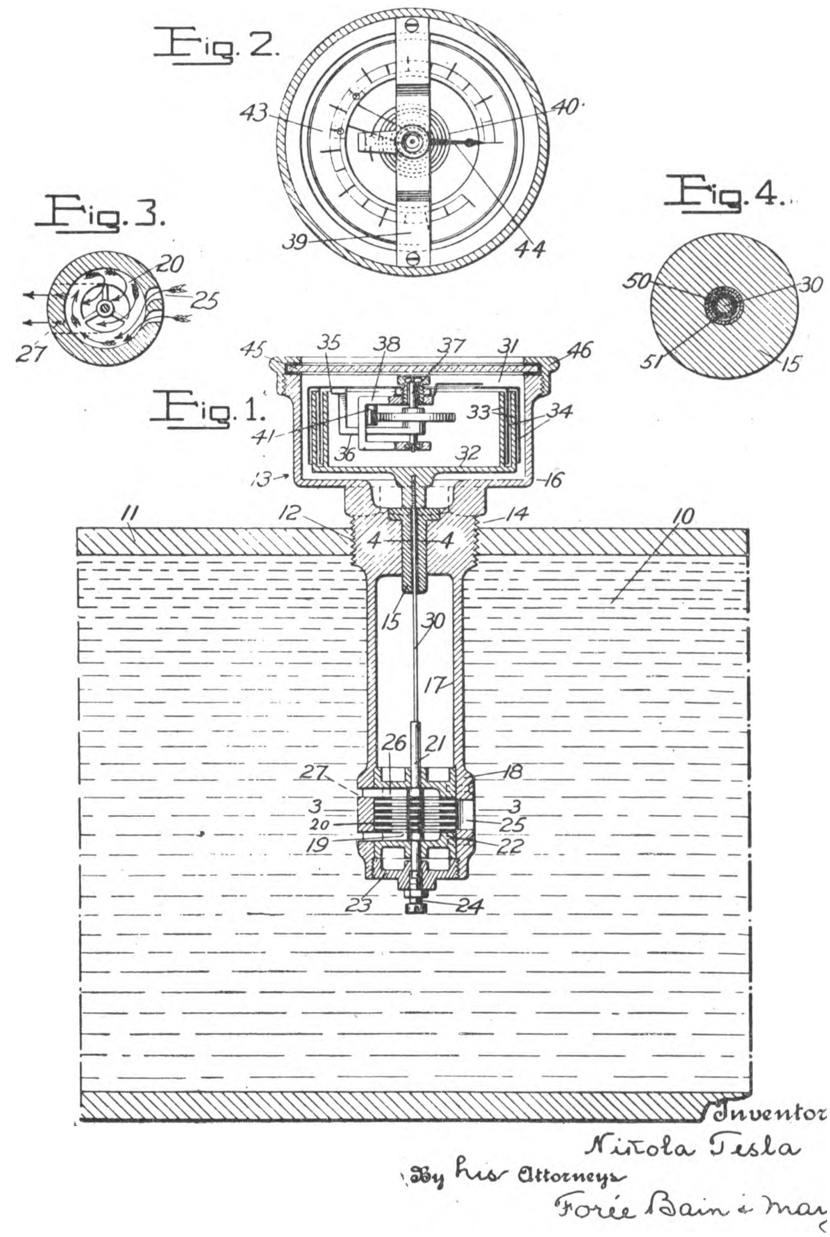
In testimony whereof I affix my signature.

NIKOLA TESLA.

P-410

N. TESLA.
FLOW METER.
APPLICATION FILED DEC. 18, 1916.

1,365,547. Patented Jan. 11, 1921.



VIII
VARIOUS PATENTS

UNITED STATES PATENT OFFICE.

NIKOLA TESLA, OF NEW YORK, N. Y., ASSIGNOR OF TWO-THIRDS TO ALFRED S. BROWN, OF SAME PLACE, AND CHARLES F. PECK, OF ENGLEWOOD, NEW JERSEY.

METHOD OF OBTAINING DIRECT FROM ALTERNATING CURRENTS.

SPECIFICATION forming part of Letters Patent No. 413,353, dated October 22, 1889.

Application filed June 12, 1889. Serial No. 314,069. (No model.)

To all whom it may concern:

Be it known that I, NIKOLA TESLA, a subject of the Emperor of Austria, from Smiljan, Lika, border country of Austria Hungary, temporarily residing in New York city, in the State of New York, have invented a certain new and useful Improvement in Methods of Obtaining Direct from Alternating Currents, of which the following is a specification, reference being had to the drawings accompanying and forming a part of the same.

In nearly all the more important industrial applications of electricity the current is produced by dynamo-electric machines driven by power, in the coils of which the currents developed are primarily in reverse directions or alternating; but as very many electrical devices and systems require direct currents, it has been usual to correct the current alternations by means of a commutator, instead of taking them off directly from the generating-coils.

The superiority of alternating-current machines in all cases where their currents can be used to advantage renders their employment very desirable, as they may be much more economically constructed and operated; and the object of this my present invention is to provide means for directing or converting at will at one or more points in a circuit alternating into direct currents.

Stated as broadly as I am able to express it, my invention consists in obtaining direct from alternating currents, or in directing the waves of an alternating current so as to produce direct or substantially direct currents by developing or producing in the branches of a circuit including a source of alternating currents, either permanently or periodically, and by electric, electro-magnetic, or magnetic agencies, manifestations of energy, or what may be termed active, resistances of opposite electrical character, whereby the currents or current-waves of opposite sign will be diverted through different circuits, those of one sign passing over one branch and those of opposite sign over another.

I may consider herein only the case of a circuit divided into two paths, inasmuch as any further subdivision involves merely an extension of the general principle. Selecting, then, any circuit through which is flowing an alternating current, I divide such circuit at any desired point into two branches or paths. In one of these paths I insert some device to create an electro-motive force counter to the waves or impulses of current of one sign and a similar device in the other branch which opposes the waves of opposite sign. Assume, for example, that these devices are batteries, primary or secondary, or continuous-current dynamo-machines. The waves or impulses of opposite direction composing the main current have a natural tendency to divide between the two branches; but by reason of the opposite electrical character or effect of the two branches one will offer an easy passage to a current of a certain direction, while the other will offer a relatively high resistance to the passage of the same current. The result of this disposition is, that the waves of current of one sign will, partly or wholly, pass over one of the paths or branches, while those, of the opposite sign pass over the other. There may thus be obtained from an alternating current two or more direct currents without the employment of any commutator such as it has been heretofore regarded as necessary to use. The current in either branch may be used in the same way and for the same purposes as any other direct current—that is, it may be made to charge secondary batteries, energize electro-magnets, or for any other analogous purpose.

In the drawings I have illustrated some of the various ways in which I may carry out this invention.

The several figures are diagrammatic in character, and will be described in detail in their order.

Figure 1 represents a plan of directing the alternating currents by means of devices purely electrical in character. Figs. 2, 3, 4, 5, 6, and 7 are diagrams illustrative of other ways of carrying out the invention, which will be hereinafter more particularly described.

In Fig. 1, A designates a generator of alternating currents, and B B the main or line circuit therefrom. At any given point in this circuit at or near which it is desired to obtain direct currents I divide the circuit B into two paths or branches C D. In each of these branches I place an electrical generator, which for the present we will assume produces direct or continuous currents. The direction of the current thus produced is opposite in one branch to that of the current in the other branch, or, considering the two blanches as forming a closed circuit, the generators E F are connected up in series therein, one generator in each part or half of the circuit. The electro motive force of the current sources E and F may be equal to or higher or lower than the electro-motive forces in the branches C D or between the points X and Y of the circuit B B. If equal, it is evident that current-waves of one sign will be opposed in one branch and assisted in the other to such an extent that all the waves of one sign will pass over one branch and those of opposite sign over the other. If, on the other hand, the electro-motive force of the sources E F be lower than that between X and Y, the currents in both branches will be alternating, but the waves of one sign will preponderate. One of the generators or sources of current E or F may be dispensed with; but it is preferable to employ both, if they offer an appreciable resistance, as the two branches will be thereby better balanced. The translating or other devices to be acted upon by the current are designated by the letters G, and they are inserted in the branches C D in any desired manner; but in order to better preserve an even balance between the branches due regard should be had to the number and character of the devices, as will be well understood.

Figs. 2, 3, 4, and 5 illustrate what may be termed "electro-magnetic" devices for accomplishing a similar result—that is to say, instead of producing directly by a generator an electro-motive force in each branch of the circuit, I may establish a field or fields of force and lead the branches through the same in such manner that an active opposition of opposite effect or direction will be developed therein by the passage or tendency to pass of the alternations of current. In Fig. 2, for example, A is the generator of alternating currents, B B the line-circuit, and C D the branches over which the alternating currents are directed In each branch I include the secondary of a transformer or induction-coil, which, since they correspond in their functions to the batteries of the previous figure, I have designated by the letters E F. The primaries H H' of the induction-coils or transformers are connected either in parallel or series with a source of direct or continuous currents I, and the number of convolutions is so calculated for the strength of the current from I that the cores J J' will be saturated. The connections are such that the conditions in the two transformers are of opposite character—that is to say, the arrangement is such that a current wave or impulse corresponding in direction with that of the direct current in one primary, as H, is of opposite direction to that in the other primary H'; hence it results that while one secondary offers a resistance or opposition to the passage through it of a wave of one sign the other secondary similarly opposes a wave of opposite sign. In consequence the waves of one sign will, to a greater or less extent, pass by way of one branch, while those of opposite sign in like manner pass over the other branch.

In lieu of saturating the primaries by a source of continuous current, I may include the primaries in the branches C D, respectively, and periodically short-circuit by any suitable mechanical devices—such as an ordinary revolving commutator—their secondaries. It will be understood of course that the rotation and action of the commutator must be in synchronism or in proper accord with the periods of the alternations in order to secure the desired results. Such a disposition I have represented diagrammatically in Fig. 3. Corresponding to the previous figures, A is the generator of alternating currents, B B the line, and C D the two branches for the direct currents. In branch C are included two primary coils E E', and in branch D are two similar primaries F F'. The corresponding secondaries for these coils and which are on the same subdivided cores J or J' are in circuits the terminals of which connect to opposite segments K K' and L L', respectively, of a commutator. Brushes *b b* bear upon the commutator and alternately short-circuit the plates K and K' and L, and L' through a connection *c*. It is obvious that either the magnets and commutator or the brushes may revolve.

The operation will be understood from a consideration of the effects of closing or short-circuiting the secondaries. For example, if at the instant when a given wave of current passes one set of secondaries be short-circuited, nearly all the current flows through the corresponding primaries; but the secondaries of the other branch being open-circuited the self-induction in the primaries is highest, and hence little or no current will pass through that branch. If, as the current alternates, the secondaries of the two branches are alternately short-circuited, the result will be that the currents of one sign pass over one branch and those of the opposite sign over the other. The disadvantages of this arrangement, which would seem to result from the employment of sliding contacts, are in reality very slight, inasmuch as the electro-motive force of the secondaries may be made exceedingly low, so that sparking at the brushes is avoided.

Fig. 4 is a diagram, partly in section, of another plan of carrying out the invention. The circuit B in this case is divided, as before, and each branch includes the coils of both the field and revolving armatures of two induction devices. The armatures O P are preferably mounted on the same shaft, and are adjusted relatively to one another in such manner that when the self-induction in one branch, as C, is maximum in the other branch D it is minimum. The armatures are rotated in synchronism with the alternations from the source A. The winding or position of the armature-coils is such that a current in a given direction passed through both armatures would establish in one poles similar to those in the adjacent poles of the field and in the other poles unlike the adjacent field-poles, as indicated by *n n s s* in the drawings. If the like poles are presented, as shown in circuit D, the condition is that of a closed secondary upon a primary, or the position of least inductive resistance; hence a given alternation of current will pass mainly through D. A half-revolution of the armatures produces an opposite effect, and the succeeding current impulse passes through C. Using this figure as an illustration, it is evident that the fields N M may be permanent magnets or independently excited and the armatures O P driven, as in the present case, so as to produce alternate currents, which will set up alternately impulses of opposite direction in the two branches D C, which in such case would include the armature-circuits and translating devices only.

In Fig. 5 a plan alternative with that shown in Fig. 3 is illustrated. In the previous case illustrated each branch C and D contained one or more primary coils, the secondaries of which were periodically short-circuited in synchronism with the alternations of current from the main source A, and for this purpose a commutator was employed. The latter may, however, be dispensed with and an armature with a closed coil substituted.

Referring to Fig. 5, in one of the branches, as C, are two coils M', wound on laminated cores, and in the other branches D are similar coils N'. A subdivided or laminated armature O', carrying a closed coil R', is rotatably supported between the coils M' N', as shown. In the position shown—that is, with the coil R' parallel with the convolutions of the primaries N' M'—practically the whole current will pass through branch D, because the self-induction in coils M' M' is maximum. If, therefore, the armature and coil be rotated at a proper speed relatively to the periods or alternations of the source A, the same results are obtained as in the case of Fig. 3.

Fig. 6 is an instance of what may be called, in distinction to the others, a "magnetic" means of securing the results arrived at in this invention. V and W ate two strong permanent magnets provided with armatures V' W', respectively. The armatures are made of thin laminæ of soft iron or steel, and the amount of magnetic metal which they contain is so calculated that they will be fully or nearly saturated by the magnets. Around the armatures are coils E F, contained, respectively, in the circuits C and D. The connections and electrical conditions in this case are similar to those in Fig. 2, except that the current source I of Fig. 2 is dispensed with and the saturation of the core of coils E F obtained from the permanent magnets.

In the illustrations heretofore given I have in each instance shown the two branches or paths containing the translating or induction devices as in derivation one to the other; but this is not always necessary. For example, in Fig. 7, A is an alternating-current generator; B B, the line wires or circuit. At any given point in the circuit I form two paths, as D D', and at another point two paths, as C C'. Either pair or group of paths is similar to the previous dispositions with the electrical source or induction device in one branch only, while the two groups taken together form the obvious equivalent of the cases in which an induction device or generator is included in both branches. In one of the paths, as D, are included the devices to be operated by the current. In the other branch, as D', is an induction device that opposes the current impulses of one direction and directs them through the branch D. So, also, in branch C are translating devices G, and in branch C' an induction device or its equivalent that diverts through C impulses of opposite direction to those diverted by the device in branch D'. I have also shown a special form of induction device for this purpose. J J' are the cores, formed with pole-pieces, upon which are wound the coils M N. Between these pole-pieces are mounted at right angles to one another the magnetic armatures O P, preferably mounted on the same shaft and designed to be rotated in synchronism with the alternations of current. When one of the armatures is in line with the poles or in the position occupied by armature P, the magnetic circuit of the induction device is practically closed; hence there will be the greatest opposition to the passage of a current through coils N N. The alternation will therefore pass by way of branch D. At the same time, the magnetic circuit of the other induction device being broken by the position of the armature O, there will be less opposition to the current in coils M, which will shunt the current from branch C. A reversal of the current being attended by a shifting of the armatures, the opposite effect is produced.

There are many other modifications of the means or methods of carrying out my invention; but I have not deemed it necessary herein to specifically refer to more than those described, as they involve the chief modifications of the plan. In all of these it will be observed that there is developed in one or all of the branches of a circuit from a source of alternating currents an active (as distinguished from a dead) resistance or opposition to the currents of one sign, for the purpose of diverting the currents of that sign through the other or another path, but permitting the currents of opposite sign to pass without substantial opposition.

Whether the division of the currents or waves of current of opposite sign be effected with absolute precision or not is immaterial to my invention, since it will be sufficient if the waves are only partially diverted or directed, for in such case the preponderating influence in each branch of the circuit of the waves of one sign secures the same practical results in many if not all respects as though the current were direct and continuous.

An alternating and direct current have been combined so that the waves of one direction or sign were partially or wholly overcome by the direct current; but by this plan only one set of alternations are utilized, whereas by my system the entire current is rendered available. By obvious applications of this discovery I am enabled to produce a self-exciting alternating dynamo, or to operate direct-current meters on alternating-current circuit, or to run various devices—such as arc lamps—by direct currents in the same circuit with incandescent lamps or other devices run by alternating currents.

It will be observed that if an intermittent counter or opposing force be developed in the branches of the circuit and of higher electromotive force than that of the generator an alternating current will result in each branch, with the waves of one sign preponderating, while a constantly or uniformly acting opposition in the branches of higher electro-motive force than the generator would produce a pulsating current, which conditions would be under some circumstances the equivalent to those I have previously described.

What I claim as my invention is—

1. The method herein set forth of obtaining direct from alternating currents, which consists in developing or producing in one branch of a circuit from an alternating-current source an active resistance to the current impulses of one direction, whereby the said currents or waves of current, will be diverted or directed through another branch.

2. The method of obtaining direct from alternating currents, which consists in dividing the path of an alternating current into branches, and developing in one of said branches, either permanently or periodically, an electrical force or active resistance counter to or opposing the currents or current-waves of one sign, and in the other branch a force counter to or opposing the currents or current-waves of opposite sign, as set forth.

3. The method of obtaining direct from alternating currents, which consists in dividing the path of an alternating current into branches, establishing fields of force and leading the said branches through the said fields of force in such relation to the lines of force therein that the impulses of current of one direction will be opposed in one branch and those of opposite direction in the other, as set forth.

NIKOLA TESLA.

Witnesses:
ROBT. F. GAYLORD,
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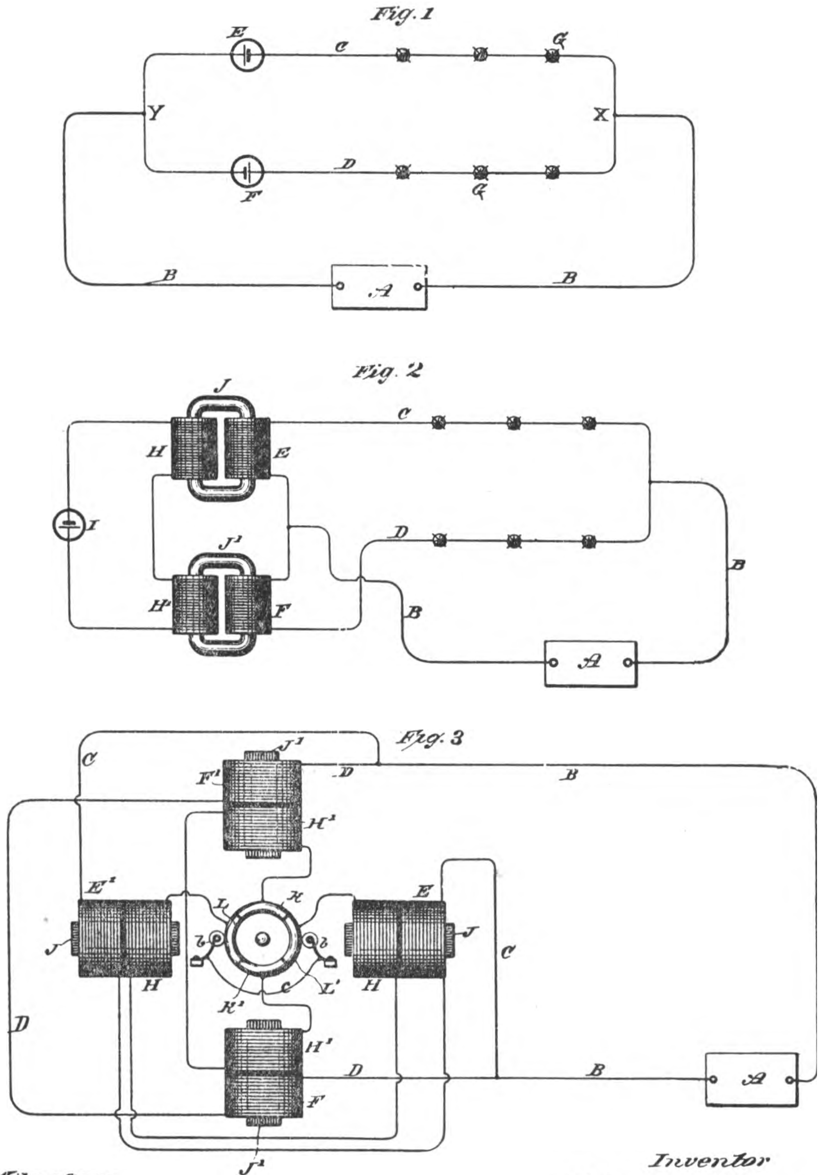
P-417

(No Model.) 3 Sheets—Sheet 1.

N. TESLA.

METHOD OF OBTAINING DIRECT FROM ALTERNATING CURRENTS.

No. 413,353. Patented Oct. 22, 1889.



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Robt. F. Gaylord

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Nikola Tesla
By
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Attorneys.

P-418

(No Model.) 3 Sheets—Sheet 2.

N. TESLA.

METHOD OF OBTAINING DIRECT FROM ALTERNATING CURRENTS.

No. 413,353. Patented Oct. 22, 1889.

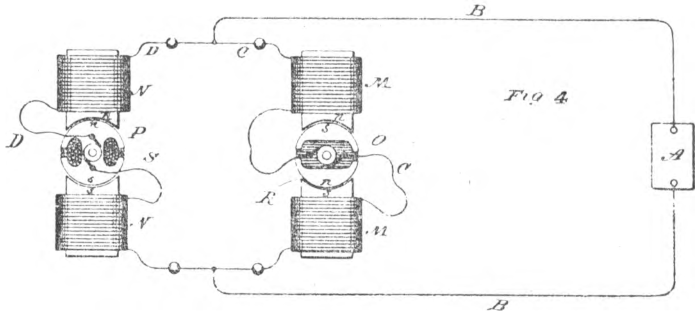


Fig 4.

Fig 5

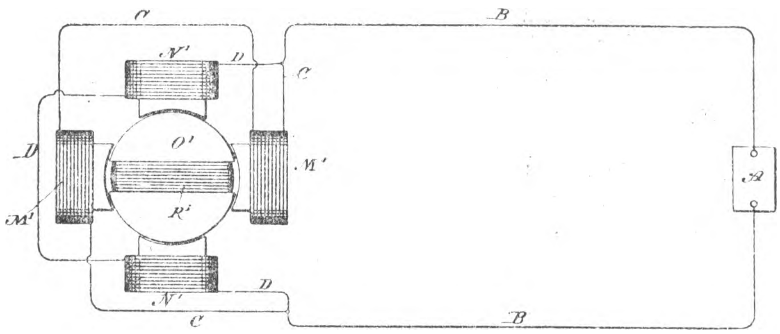
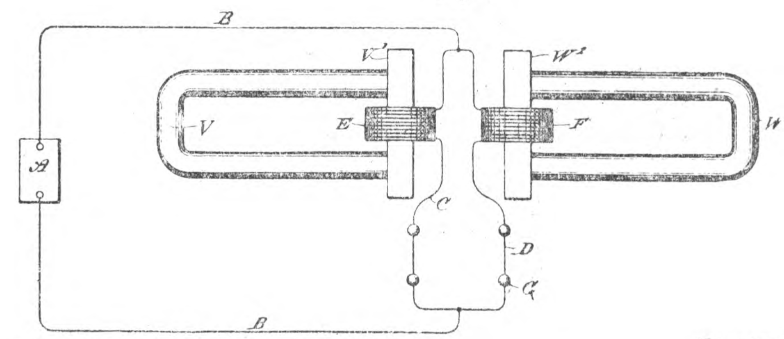


Fig 6



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P-419

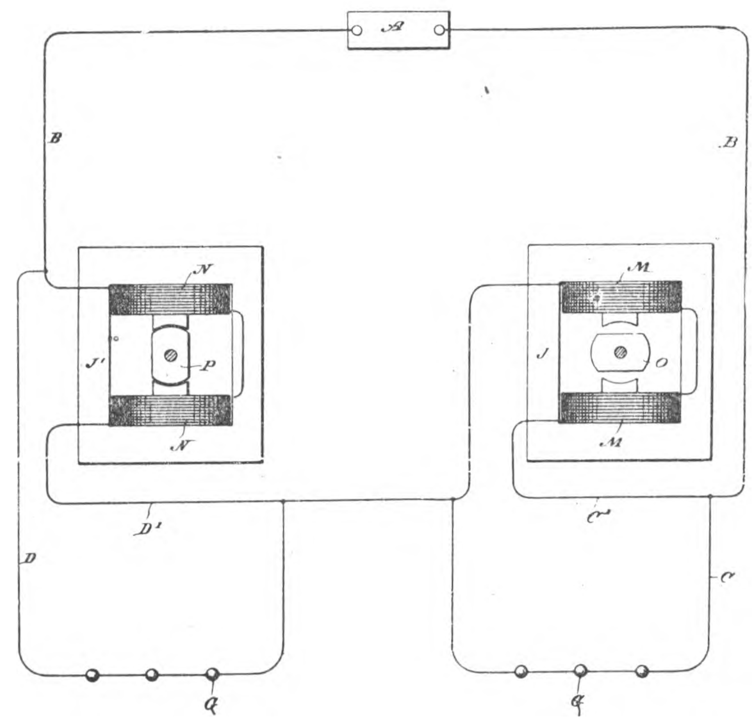
(No Model.) 3 Sheets—Sheet 3.

N. TESLA.

METHOD OF OBTAINING DIRECT FROM ALTERNATING CURRENTS.

No. 413,353. Patented Oct. 22, 1889.

Fig. 7



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UNITED STATES PATENT OFFICE

NIKOLA TESLA, OF NEW YORK. N. Y.

ELECTRICAL METER.

SPECIFICATION forming: part of Letters Patent No. 455,068, dated June 30, 1891.

Application filed March 27, 1891. Serial No. 386,666. (No model.)

To all whom it may concern:

Be it known that I, NIKOLA TESLA, a subject of the Emperor of Austria, from Smiljan, Lika, border country of Austria-Hungary, and a resident of New York, in the county and State of New York, have invented certain new and useful Improvements in Electrical Meters, of which the following is a specification, reference being had to the drawings accompanying and forming a part of the same.

My invention pertains to methods of and apparatus for estimating the electrical energy that has been expended in an electric circuit or any given portion of the same.

The principle of the invention is embodied in any form of apparatus in which a conductor immersed in an electrolytic solution is so arranged that metal may be deposited upon it or taken away from it in such manner that its electrical resistance is varied in a definite proportion to the strength of the current the energy of which is to be computed, whereby such variation in resistance may serve as a measure of the energy or may be utilized in various well-understood ways to bring into action suitable automatic registering mechanism when the resistance exceeds or falls below predetermined limits.

In carrying out my invention I prefer to employ an electrolytic cell, through which extend two conductors parallel and in close proximity to each other. I connect these conductors in series through a resistance, but in such manner that there is an equal difference of potential between them throughout their entire extent. The free ends or terminals of the conductors are connected either in series in the circuit supplying the current to the lamps or other devices or in parallel to a resistance in the said circuit and in series with the translating devices. Under such circumstances a current passing through the conductors establishes a difference of potential between them which is proportional to the strength of the current, in consequence of which there is a leakage of current from one conductor to the other across the solution. The strength of this leakage current is proportional to the difference of potential, and, therefore, in proportion to the strength of the current passing through the conductors. Moreover, as there is a constant difference of potential between the two conductors throughout the entire extent that is exposed to the solution, the current density through such solution is the same at all corresponding points, and hence the deposit is uniform along the whole of one of the conductors, while the metal is taken away uniformly front the other. The resistance of one conductor is by this means diminished, while that of the other is increased both in proportion to the strength of the current passing through the conductors. From such variation in the resistance of either or both of the conductors forming the positive and negative electrodes of the cell the current energy expended may be readily computed.

Other modified arrangements of the conductors are contemplated, as will be understood from the following description and reference to the drawings.

The figures are diagrams showing the meter in operative relations to a working-circuit and under slightly-modified arrangements.

In Fig. 1, G designates a suitable direct-current generator. L L are the conductors of the circuit extending therefrom and including and supplying lamps or other translating devices T. A is a tube, preferably of glass, the ends of which are sealed, as by means of insulating plugs or caps B B. C C' are two conductors extending through the tube A, their ends passing out through the plugs B to terminals thereon. These conductors may be corrugated or formed in other proper ways to offer the desired electrical resistance. R is a resistance connected in series with the two conductors C C', which by their free terminals are connected up in the circuit of one of the conductors L.

The method of using this device and computing by means thereof the energy of the current will be readily understood. First, the resistances of the two conductors C C', respectively, are accurately measured and noted. Then a known current is passed through the instrument for a given time, and by a second measurement, the increase and diminution of the resistances of the two conductors respectively taken. From these data the constant is obtained—that is to say, for example, the increase of resistance of one conductor or the diminution of the resistance of the other per lamp-hour. These two measurements evidently serve as a check, since the gain of one conductor should equal the loss of the other. A further check is afforded by measuring both wires in series with the resistance, in which case the resistance of the whole should remain constant.

In Fig. 2 the conductors C C' are connected in parallel, the current device at X passing in one branch first through a resistance R' and then through conductor C, while in the other branch it passes first through conductor C', and then through resistance R". The resistances R' R" are equal, as also are the resistances of the conductors C C'. It is, moreover, preferable that the respective resistances of the conductors C C' should be a known and convenient fraction of the coils or resistances R' R". It will be observed that in the arrangement shown in Fig. 2 there is a constant potential difference between the two conductors C C' throughout their entire length.

It will be seen that in both cases illustrated the proportionality of the increase or decrease of resistance to the current strength will always be preserved, for what one conductor gains the other loses, and the resistances of the conductors C C' being small as compared with the resistances in series with them. It will be understood that after each measurement or registration of a given variation of resistance in one or both conductors the direction of the current should be changed or the instrument reversed, so that the deposit will be taken from the conductor which has gained and added to that which has lost. This principle is capable of many modifications. For instance, since there is a section of the circuit—to wit, the conductor C or C'—that varies in resistance in proportion to the current strength, such variation may be utilized, as is done in many analogous cases, to effect the operation of various automatic devices, such as registers. I prefer, however, for the sake of simplicity to compute the energy by measurements of resistance.

The chief advantages of this invention are, first, that it is possible to read off directly the amount of the energy expended by means of a properly-constructed ohm-meter and without resorting to weighing the deposit; second, it is not necessary to employ shunts, for the whole of the current to be measured may be passed through the instrument; third, the accuracy of the instrument and correctness of the indications are but slightly affected by changes in temperature. In addition to these advantages the invention possesses the merit of economy in the waste of energy and simplicity, compactness, and cheapness in construction.

What I claim is—

1. The method of computing the amount of electrical energy expended in a given time in an electric circuit, which consists in maintaining by the current a potential difference between two conductors in an electrolytic solution uniform throughout the whole extent of such conductors exposed to the solution and measuring the variation of the resistance in one or both of said conductors due to the gain or loss of metal by electro-deposition, as set forth.

2. The combination, with an electric circuit, of a meter composed of an electrolytic cell and two conductors passing through the same, the said conductors being in or connected with the main circuit and so that a potential difference uniform throughout the whole extent exposed to the solution will be maintained between them, as set forth.

3. The combination, with an electric circuit containing translating devices, of a meter composed of an electrolytic cell and two conductors passing through the same and connected in series with the translating devices, and one or more resistances connected therewith for establishing a potential difference between the two conductors through the solution of the cell, as set forth.

4. An electrical meter consisting of an electrolytic cell, two parallel conductors extending through the same, the said conductors being connected together in series through a resistance and having terminals at their free ends for connection with a circuit, these parts being combined in the manner substantially, as set forth.

5. An electric meter consisting of a tubular cell containing an electrolytic solution and closed at the ends, two parallel conductors extending through the cell, a resistance-connection between the end of one conductor and the opposite end of the other, and terminals for the remaining ends of the respective conductors, these parts being combined as set forth.

NIKOLA TESLA.

Witnesses:
ROBT. F. GAYLORD,
PARKER W. PAGE.

P-422

(No Model.)

N. TESLA.
ELECTRICAL METER.

No. 455,068. Patented June 30, 1891.

Fig. 1

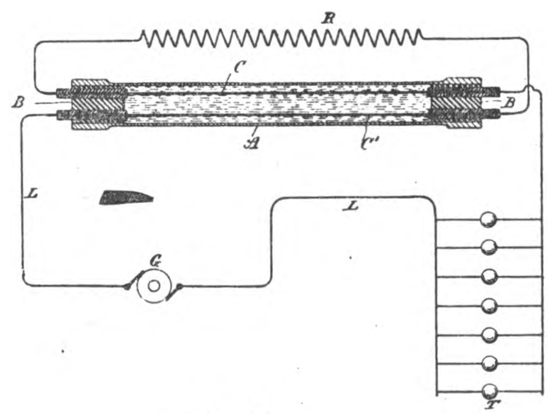
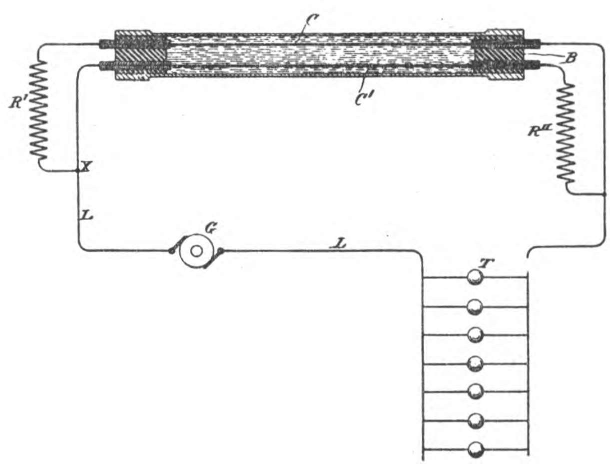


Fig. 2



Witnesses:
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Attorneys

UNITED STATES PATENT OFFICE.

NIKOLA TESLA, OF NEW YORK, N. Y.

ELECTRICAL CONDENSER.

SPECIFICATION forming part of Letters Patent No. 484,887, dated December 8, 1891.

Application filed August 1, 1891. Serial No. 401,356. (No model.)

To all whom it may concern

Be it known that I, NIKOLA TESLA, a citizen of the United States, residing at New York, in the county and State of New York, have invented a certain new and useful Improvement in Electrical Condensers, of which the following is a specification, reference being had to the accompanying drawings.

The subject of my present application is a new and improved electrical condenser constructed with a view of obviating certain defects which I have observed to exist in the ordinary forms of such apparatus when employed in the system devised by mo of producing light and other effects by means of currents of high frequency and high potential.

I have found that insulating material such as glass, mica, and, in general, those bodies which possess the highest specific inductive capacity are inferior as insulators in such devices when currents of the kind described are employed to those possessing high insulating power, together with a smaller specific inductive capacity, and I have also found that it is very desirable to exclude all gaseous matter from the apparatus, or any access to the same to the electrified surfaces, in order to prevent heating by molecular bombardment and the loss or injury consequent thereon. I have found that I may accomplish these results and produce highly efficient and reliable condensers by using oil as the dielectric, and in this my invention resides.

No special construction of the condenser is necessary to a demonstration of the invention; but the plan admits of a particular construction of condenser, in which the distance between the plates is adjustable, and of which I take advantage.

In the accompanying drawings, Figure 1 is a section of a condenser constructed in accordance with my invention and having stationary plates, and Fig. 2 is a similar view of a condenser with adjustable plates.

I use any suitable box or receptacle A to contain the plates or armatures. These latter are designated by B and C and are connected, respectively, to terminals D and E, which pass out through the sides of the case. The plates ordinarily are separated by strips of porous insulating material F, which are used merely for the purpose of maintaining them in position. The space within the can is filled with oil G. Such a condenser will prove highly efficient and will not become heated or permanently injured.

In many cases it is desirable to vary or adjust the capacity of a condenser, and this I provide for by securing the plates to adjustable supports—as, for example, to rods H—passing through stuffing-boxes K in the sides of the case A and furnished with nuts L, the ends of the rods being threaded for engagement with the nuts.

It is well known that oils possess insulating properties, and it has been a common practice to interpose a body of oil between two conductors for purposes of insulation; but I have discovered peculiar properties in oils which render them very valuable in this particular form of device, their employment in which has never heretofore and, so far as I am aware, been regarded as necessary or even desirable.

What I claim is—

1. An electric condenser composed of plates or armatures immersed in oil.

2. An electrical condenser composed of plates or armatures adjustable with respect to one another and immersed in oil

NIKOLA TESLA

Witnesses:
PARKER W. PAGE,
MARCELLA G. TRACY.

P-424

(No Model.)

N. TESLA.

ELECTRICAL CONDENSER.

No. 464,667. Patented Dec. 8, 1891

Fig. 1

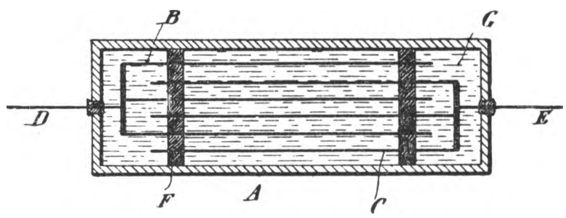
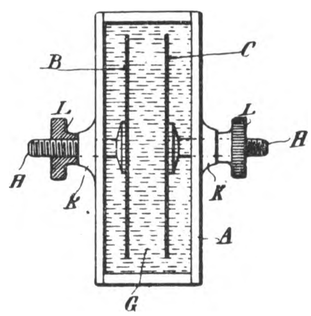


Fig 2



Witnesses:
Raphael Netter
Frank B Murphy.

Inventor
Nikola Tesla
by
Duncan & Page
Attorneys

UNITED STATES PATENT OFFICE.

NIKOLA TESLA, OF NEW YORK, N. Y.

ELECTRICAL CONDUCTOR.

SPECIFICATION forming part of Letters Patent No. 514,167, dated February 6, 1894.

Application filed January 2, 1892. Serial No. 416,773. (No model.)

To all whom it may concern:

Be it known that I, NIKOLA TESLA, a citizen of the United States, residing at New York, in the county and State of New York, have invented certain new and useful Improvements in Line Conductors for Systems of Electrical Distribution, of which the following is a specification, reference being had to the drawings accompanying and forming a part of the same.

In any system of electrical transmission or distribution in which currents of excessively high potential are employed, and more particularly, when the frequency is high, there is a dissipation of energy from the conductor or conductors of the line, due to the electrification of the atmosphere or other surrounding medium, or other causes.

Heretofore it has been, usual, in order to prevent loss by dissipation or interference by induction on line conductors, to insulate the same and inclose them in a continuous conducting sheathing or cover which has been connected with the ground by a good conducting path.

The object of my invention is to prevent loss on line conductors in a system of electrical transmission and distribution, more particularly such as that described by me in patent of June 23, 1891, No. 454,622, but in any other system in which alternating or, generally speaking, varying currents of excessively high potential are employed.

I have found that in these systems the use of a conducting sheath or screen around the line conductors and well grounded, or even brought into proximity to external conductors or large bodies, is attended by an actual and generally a serious loss of energy. I therefore maintain the sheath either entirely isolated or connected directly or inductively to the ground, through a path which will practically prevent the passage of currents over it. I have also found that when a continuous insulated sheath or screen is employed, there is greater liability to loss of energy by inductive action, for unless the sheath or screen be considerably shorter than the current waves passing in the conductor, electromotive forces will be set up between different points in the sheath, which will result in the passage between such points of induced currents. I, therefore, divide up the sheath or screen into short lengths, very much shorter than the wave lengths of the current used, so that the grounding of any one of such lengths or the approach thereto of a large body will result in an inappreciable loss, or at most a small local draining of the energy, while the tendency of currents to flow between different points in the sheath is effectually overcome. The function of the sheath as a static screen for preventing the dissipation of the electric energy, however, requires for its complete effectiveness an uninterrupted conducting partition or screen around the conductor. I attain this respect in the case of a sectional screen, by causing the ends of the insulated divisions or sections of the same to overlap, interposing a suitable insulating material between the overlapping portions. By means of a conductor or conductors thus protected, I may transmit with slight loss and to great distances currents of very high potential and extremely high frequency.

The invention is illustrated in the accompanying drawings in which—

Figure 1 illustrates portions of the conductor with the earth connections above described. Fig. 2 is a sectional view of a portion of the conductor on an enlarged scale.

A is the central wire or conductor that carries the current.

B is an insulating coating.

C is a conducting sheathing or screen, which may be externally insulated, if so desired. This sheathing is divided up, as shown, into short lengths or sections, and the end of one section overlaps or telescopes with the end of the adjacent sections but is insulated therefrom by the material D.

It is well known that a static screen, to be entirely effective as such, should have a ground connection, but it has been usual in such cases to provide a good electrical connection from the screen to earth. When a current of excessively high potential, however, is used, or when the frequency of the current is very high, such a connection is impracticable on account of the loss which follows. In such cases, therefore, I obtain the beneficial results of an earth connection while preventing the generally serious loss that would occur in the use of such currents, by providing between the sheath and the ground a path F of very high ohmic resistance or one containing a self-induction coil S properly determined with respect to the existing conditions so that it will effect the described result, or a condenser of very small capacity as shown at R. In such cases the sheathing or screen for practical purposes may be regarded as isolated from the ground, since by the character of the connection employed no appreciable loss results from the passage of current from the sheath to the ground.

No particular plan of construction need be followed in making up this conductor, and no special materials of the several kinds named need be used; the general construction and character of the conductor, apart from the particular features herein described, being entirely well understood by those skilled in the art.

What I claim is—

1. A conductor for electric circuits, composed of a wire for carrying the current, an insulated coating or covering and a surrounding conducting sheath or screen divided into insulated sections, as set forth.

2. A conductor for electric circuits, composed of a wire for carrying the current, a coating or covering of insulating material and a surrounding conducting sheath or screen divided into insulated sections, the ends of which overlap, as set forth.

3. The combination of a wire or conductor for conveying electric currents, an insulated coating or covering therefor, a conducting sheath or screen surrounding the insulating coating and a connection between said sheathing and the ground containing a condenser of very small capacity or its equivalent.

NIKOLA TESLA.

Witnesses:

ERNEST HOPKINSON,

PARKER W. PAGE.

P-427

(No Model.)

N. TESLA.
ELECTRICAL CONDUCTOR.

No. 514,167. Patented Feb. 6, 1894.

Fig. 1

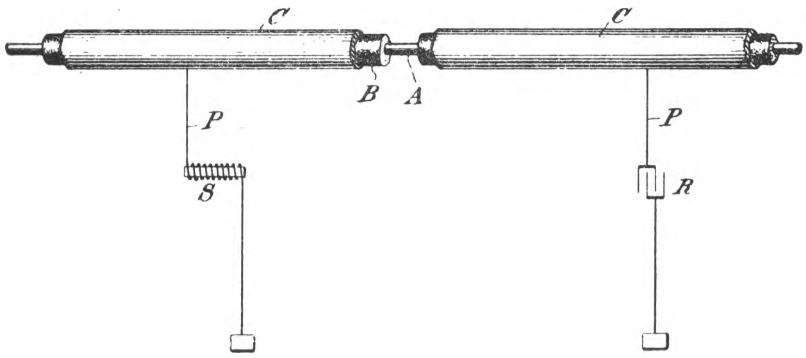
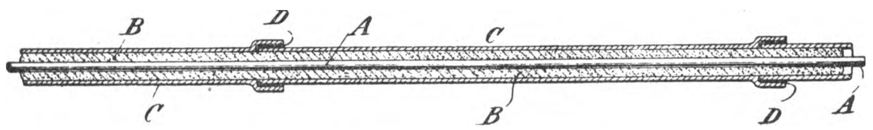


Fig. 2



Witnesses:
Raphaël Netter
Ernest Hopkinson

Inventor
Nikola Tesla
by Duncan & Page
Attorneys.

UNITED STATES PATENT OFFICE.

NIKOLA TESLA, OF NEW YORK, N. Y.

COIL FOR ELECTRO-MAGNETS.

SPECIFICATION forming part of Letters Patent No. 512,340, dated January 9, 1894.

Application filed July 7, 1893. Serial No. 479.804, (No model.)

To all whom it may concern:

Be it known that I, NIKOLA TESLA, a citizen of the United States, residing at New York, in the county and State of New York, have invented certain new and useful Improvements in Coils for Electro-Magnets and other Apparatus, of which the following is a specification, reference being had to the drawings accompanying and forming a part of the same.

In electric apparatus or systems in which alternating currents are employed the self-induction of the coils or conductors may, and, in fact, in many cases does operate disadvantageously by giving rise to false currents which often reduce what is known as the commercial efficiency of the apparatus composing the system or operate detrimentally in other respects. The effects of self-induction, above referred to, are known to be neutralized by proportioning to a proper degree the capacity of the circuit with relation to the self-induction and frequency of the currents. This has been accomplished heretofore by the use of condensers constructed and applied as separate instruments.

My present invention has for its object to avoid the employment of condensers which are expensive, cumbersome and difficult to maintain in perfect condition, and to so construct the coils themselves as to accomplish the same ultimate object.

I would here stale that by the term coils I desire to include generally helices, solenoids, or, in fact, any conductor the different parts of which by the requirements of its application or use are brought into such relations with each other as to materially increase the self-induction.

I have found that in every coil there exists a certain relation between its self-induction and capacity that permits a current of given frequency and potential to pass through it with no other opposition than that of ohmic resistance, or, in other words, as though it possessed no self-induction. This is due to the mutual relations existing between the special character of the current and the self-induction and capacity of the coil, the latter quantity being just capable of neutralizing the self-induction for that frequency. It is well-known that the higher the frequency or potential difference of the current the smaller the capacity required to counteract the self-induction; hence, in any coil, however small the capacity, it may be sufficient for the purpose stated if the proper conditions in other respects be secured. In the ordinary coils the difference of potential between adjacent turns or spires is very small, so that while they are in a sense condensers, they possess but very small capacity and the relations between the two quantities, self-induction and capacity, are not such as under any ordinary conditions satisfy the requirements herein contemplated, because the capacity relatively to the self-induction is very small.

In order to attain my object and to properly increase the capacity of any given coil, I wind it in such way as to secure a greater difference of potential between its adjacent turns or convolutions, and since the energy stored in the coil—considering the latter as a condenser, is proportionate to the square of the potential difference between its adjacent convolutions, it is evident that I may in this way secure by a proper disposition of these convolutions a greatly increased capacity for a given increase in potential difference between the turns.

I have illustrated diagrammatically in the accompanying drawings the general nature of the plan which I adept for carrying out this invention.

Figured is a diagram of a coil wound in the ordinary manner. Fig. 2 is a diagram of a winding designed to secure the objects of my invention.

Let A, Fig. 1, designate any given coil the spires or convolutions of which are wound upon and insulated from each other. Let it be assumed that the terminals of this coil show a potential difference of one hundred volts, and that there are one thousand convolutions; then considering any two contiguous points on adjacent convolutions let it be assumed that there will exist between them a potential difference of one-tenth of a volt. If now, as shown in Fig. 2, a conductor B be wound parallel with the conductor A and insulated from it, and the end of A be connected with the starting point of B, the aggregate length of the two conductors being such that the assumed number of convolutions or turns is the same, viz., one thousand, then the potential difference between any two adjacent points in A and B will be fifty volts, and as the capacity effect is proportionate to the square of this difference, the energy stored in the coil as a whole will now be two hundred and fifty thousand as great. Following out this principle, I may wind any given coil either in whole or in part, not only in the specific manner herein illustrated, but in a great variety of ways, well-known in the art, so as to secure between adjacent convolutions such potential difference as will give the proper capacity to neutralize the self-induction for any given current that may be employed. Capacity secured in this particular way possesses an additional advantage in that it is evenly distributed, a consideration of the greatest importance in many cases, and the results, both as to efficiency and economy, are the more readily and easily obtained as the size of the coils, the potential difference, or frequency of the currents are increased.

Coils composed of independent strands or conductors wound side by side and connected in series are not in themselves new, and I do not regard a more detailed description of the same as necessary. But heretofore, so far as I am aware, the objects in view have been essentially different from mine, and the results which I obtain even if an incident to such forms of winding have not been appreciated or taken advantage of.

In carrying out my invention it is to be observed that certain facts are well understood by those skilled in the art, viz: the relations of capacity, self-induction, and the frequency and potential difference of the current. What capacity, therefore, in any given case it is desirable to obtain and what special winding will secure it, are readily determinable from the other factors which are known

What I claim as my invention is—

1. A coil for electric apparatus the adjacent convolutions of which form parts of the circuit between which there exists a potential difference sufficient to secure in the coil a capacity capable of neutralizing its self-induction, as hereinbefore described.

2. A coil composed of contiguous or adjacent insulated conductors electrically connected in series and having a potential difference of such value as to give to the coil as a whole, a capacity sufficient to neutralize its self-induction, as set forth.

NIKOLA TESLA.

Witnesses:

ROBT. F. GAYLORD,

PARKER W. PAGE.

P-430

(No Model.)

N. TESLA.
COIL FOR ELECTRO MAGNETS.

No. 512,340 Patented Jan. 9, 1894.

Fig. 1

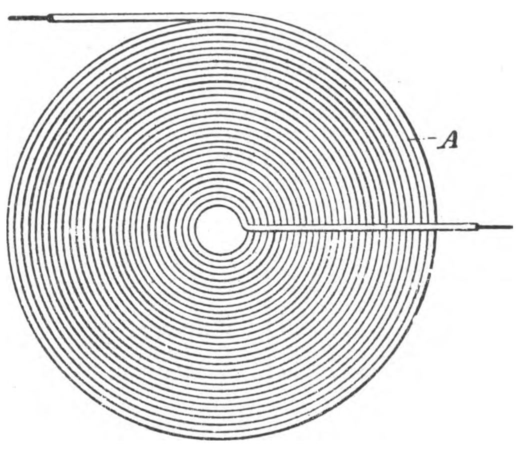
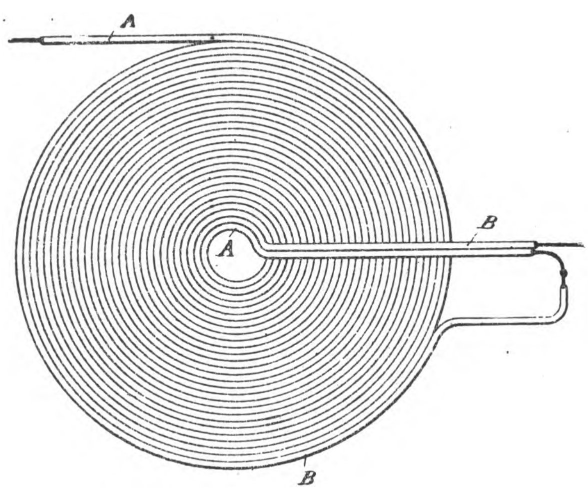


Fig. 2



Witnesses
Raphael Netter
James N. Catlow

Inventor
Nikola Tesla
By his Attorneys
Duncan & Page.

UNITED STATES PATENT OFFICE.

NIKOLA TESLA, OF NEW YORK, N, Y.

APPARATUS FOR PRODUCING OZONE.

SPECIFICATION forming part of Letters Patent No. 568,177, dated September 22, 1896.

Application filed June 17, 1896. Serial No. 595,927. (No model.)

To all whom it may concern:

Be it known that I, NIKOLA TESLA, a citizen of the United States, residing at New York, in the county and State of New York, have invented certain new and useful Improvements in Apparatus for Producing Ozone, of which the following is a specification, reference being had to the drawings accompanying and forming a part of the same.

The invention subject of my present application has primarily as its object to provide a simple, cheap, and effective apparatus for the production of ozone or such gases as are obtained by the action of high-tension electrical discharges, although in the application to such purposes of the apparatus heretofore invented by me and designed for the production of electric currents of high frequency and potential I have made certain improvements in such apparatus itself which are novel and useful in other and more general applications of the same. I have heretofore shown and described, notably in Patents No. 462,418, dated November 3, 1891, and No. 454,622, dated June 23, 1891, an apparatus devised for the purpose of converting and supplying electrical energy in a form suited for the production of certain novel electrical phenomena which require currents of higher frequency and potential than can readily or even possibly be developed by generator of the ordinary types or by such mechanical appliances as were theretofore known. This apparatus involved means for utilizing the intermittent or oscillating discharge of the accumulated electrical energy of a condenser or a circuit possessing capacity in what may be designated the "working" circuit or that which contains the translating devices or means for utilizing such currents. In my present improvement I have utilized appliances of this general character under conditions and in combination with certain instrumentalities, hereinafter described, which enable me to produce, without difficulty and at very slight expense, ozone in any desired quantities. I would state the apparatus which I have devised for this purpose is capable of other and highly important uses of a similar nature, but for purposes of the present case I deem it sufficient to describe its operation and effects when used for the purpose of generating ozone.

In the accompanying drawings, illustrative of the principle of construction and mode of operation of my improvement, Figure 1 is a diagrammatic illustration of the invention; and Fig. 2, a view, partly in side elevation and partly in section, of the apparatus as I construct it for practical use.

The device hereinafter described is especially designed for direct application to and use with existing circuits carrying direct currents, such as the ordinary municipal incandescent-lighting circuits.

Let A B designate the terminals from any given circuit of this character. In such circuit I connect up an electromagnetic motor C in any of the usual ways. That is to say, the coils of the field and armature may be in series or derivation or wholly independent, and either or both are connected up in the circuit. In the present instance one terminal, as B, is connected to one of the binding-posts, from which the circuit is led through one field-coil, D, the brushes and commutator E, the other field-coil, F, and thence to a brush G, which rests upon a circuit-controller II, consisting in general of a conducting disk or cylinder with insulating-sections in its periphery. The other terminal, as A, connects with a second brush K, bearing on the controller, so that the current which passes through and operates the motor is periodically interrupted. For this reason the iron cores of the motor should be laminated. Around the controller is formed a circuit of low self-induction, which includes a condenser Land the primary M of a transformer. The circuit including the motor is of relatively high self-induction, and this property is imparted to it by the coils of the motor, or, when these are not sufficient, by the addition of suitable choking-coils, so that at each break of the motor-circuit a current of high electromotive force will be developed for charging the condenser, which may therefore be small and inexpensive. The condenser discharges through the circuit which is completed through the brushes G K and the controller II, and since the self-induction of this circuit, as well as the capacity of the condenser itself, may be given practically any desired value the frequency of the discharge-current may be adjusted at will. The potential of the high-frequency discharge-current is raised by a secondary coil N in inductive relation to the primary M. The conductors of such secondary circuit are connected to two insulated conducting-plates P P, and when the apparatus is in operation a discharge in the form of streams will be maintained between such plates, as indicated by the wavy lines in the figures. If air be forced between the plates P during this discharge, the effectiveness of the apparatus is increased and ozone is generated in large quantities. In order to secure this result, I inclose the said plates P P in a easing R of any proper description, through which a current of air is maintained by a fan S, mounted on the shaft of the motor.

This apparatus may be constructed and combined in very compact form and small compass. Its operation involves but a small expenditure of energy, while it requires practically no care or attention for the continued production of ozone in unlimited amount.

What I claim as my invention is—

1. The combination with a circuit of direct currents, of a controller for making and breaking the same, a motor included in or connected with said circuit so as to increase its self-induction, and driving the said controller, a condenser in a circuit around the controller, and a transformer through the primary of which the condenser discharges, as set forth.

2. The combination with a circuit of direct currents, of a controller for making and breaking the same, a series-wound motor having its coils included in said circuit and driving the said controller, a condenser connected with the circuit around the point of interruption therein, and a transformer, the primary of which is in the discharge-circuit of the condenser, as set forth.

3. A device for producing ozone comprising in combination, surfaces between which an electrical discharge takes place, a transformer for producing the potential necessary for such discharge, a condenser in the primary circuit of the transformer, a charging circuit, means for charging the condenser by such circuit and discharging if through the primary of the transformer, and a device for maintaining a current of air between the discharge-surfaces, as set forth.

4. A device for producing ozone comprising in combination, surfaces between which an electrical discharge takes place, a transformer for producing the potential necessary for such discharge, a condenser in the primary circuit of the transformer, a charging-circuit, means for charging the condenser by such circuit and discharging it through the primary of the transformer, a motor operated by the charging-circuit, and a device operated thereby for maintaining a current of air between the discharge-surfaces, as set forth.

5. A device for producing ozone comprising in combination, surfaces between which an electrical discharge takes place, a transformer for producing the potential necessary for such discharge, a condenser in the primary circuit of the transformer, a charging-circuit, a circuit-controller effecting the charging and discharging of the condenser, and a fan-motor connected with the charging-circuit and operating the circuit-controller and adapted to maintain a current of air between the discharge-surfaces, as set forth.

6. A device for producing ozone comprising in combination, means for charging a condenser, a circuit of low self-induction and resistance into which the condenser discharges, a coil for raising the potential of such discharge, and means for passing a current of air through the high-potential discharge, as set forth.

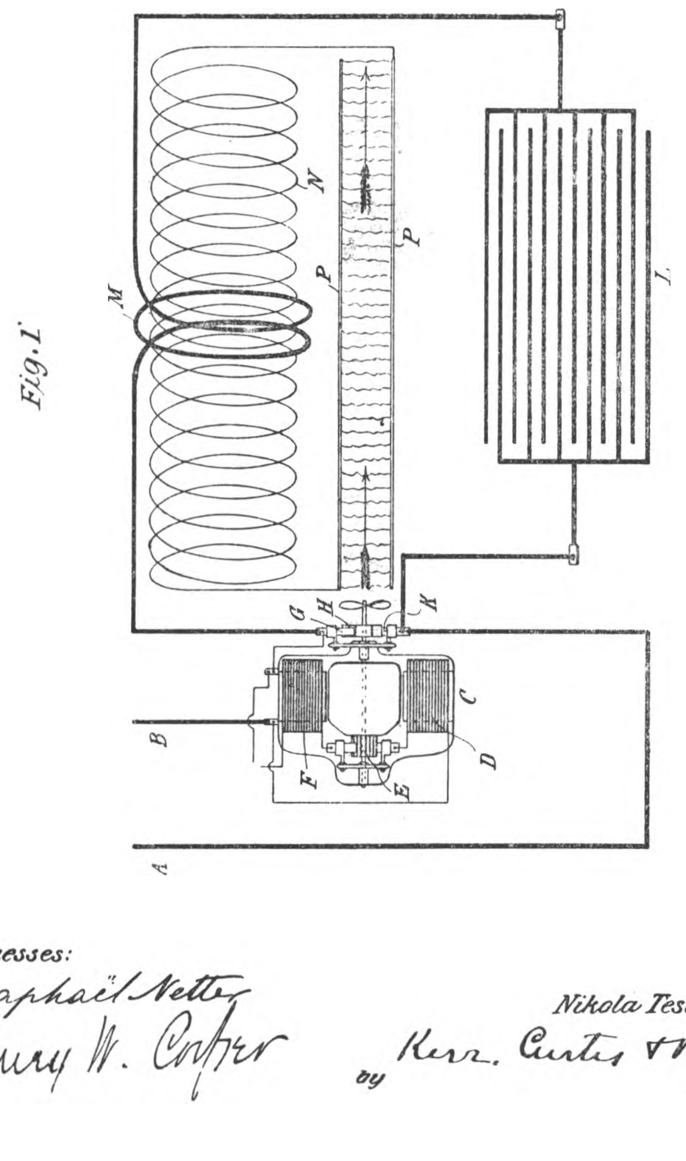
NIKOLA TESLA.

Witnesses:
DRURY W. COOPER,
M. LAWSON DYER.

(No Model.) 2 Sheets—Sheet 1

N. TESLA.
APPARATUS FOR PRODUCING OZONE.

No. 568,177 Patented Sept. 22, 1896.



Witnesses:
Raphaël Netter
Drury W. Cooper

Nikola Tesla, Inventor
by Kerr, Curtis & Page. Att'ys.

P-434

(No Model.) 2 Sheets—Sheet 2.

N. TESLA.
APPARATUS FOR PRODUCING OZONE.

No. 568,177. Patented Sept. 22, 1896.

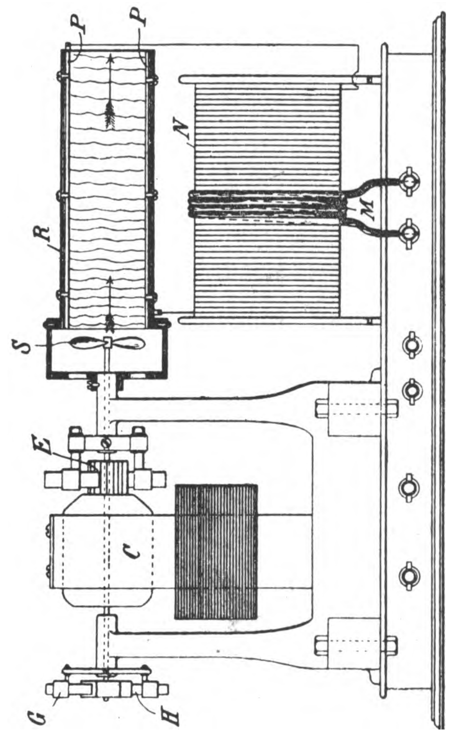


Fig. 2

Witnesses:
Raphaël Netter
Drury W. Cooper

Nikola Tesla, Inventor
by Kerr, Curtis & Page
Att'ys.

UNITED STATES PATENT OFFICE.

NIKOLA TESLA, OF NEW YORK, N. Y.

MANUFACTURE OF ELECTRICAL CONDENSERS, COILS, &c.

SPECIFICATION forming part of Letters Patent No. 577,671, dated February 23, 1897.

Application filed November 5, 1896. Serial No. 611,128. (No model.)

To all whom it may concern:

Be it known that I, NIKOLA TESLA, a citizen of the United States, residing at New York, in the county and State of New York, have invented certain new and useful Improvements in the Manufacture of Electrical Condensers, Coils, and Similar Devices, of which the following is a specification, reference being had to the drawing which accompanies and forms a part of the same.

My invention is an improvement in the manufacture of electrical condensers, coils, and other devices of a similar character in which conductors designed to form paths for currents of high potential are brought into close proximity with each other. Among such devices are included many forms of condensers, transformers, self induction coils, rheostats, and the like.

It has heretofore been shown by me that the efficiency and practicability of such devices are very greatly enhanced by the exclusion of air or gas from the dielectric separating the conductors or remote portions of the same conductor; and the object of my present improvement is to secure such exclusion of air in as perfect a manner as possible in a convenient and practicable way. To this end I place the condenser or other device to be treated in a. receptacle from which the air may be more or less perfectly exhausted, and while in vacuum I introduce an insulating substance, which liquefies when subjected to heat, such as paraffin, which surrounds the said device and finds its way into its interstices.

When the device has become thoroughly saturated with the insulating material, it is allowed to cool off usually until the material begins to solidify. Air is then admitted under pressure to the receptacle containing the device and the pressure maintained until the whole mass of insulating material has solidified. By this treatment the presence of air or vacuous spaces in the dielectric, which are otherwise liable to form by the contraction of the insulating material when cooling, is prevented.

Any plan may be followed or apparatus used for securing the two conditions necessary to the attainment of the desired result, that is to say, applying the fluid insulating material in vacuum and subsequently subjecting it to or solidifying it under pressure. The degree of exhaustion or of pressure may vary, very good results being secured by a vacuum of about twenty-nine inches and a pressure of about one hundred pounds. It may be stated, however, that when hydraulic pressure is applied very much higher pressures are readily secured and are of advantage.

In order to facilitate the carrying out of the process, I have devised a simple and useful apparatus, which is illustrated partly in section in the accompanying drawing. As the parts of said apparatus are all of well-known construction, the apparatus as a whole will be fully understood without a full description of its details.

A is a tank or receptacle that may be closed air-tight. Within this tank is a steam-coil C, surrounding a vessel B, preferably with slightly-sloping sides and provided with a tube or pipe D, opening into it near its base.

The condenser or other device to be treated is placed in the vessel B, and around the receptacle is packed a suitable insulating material in quantity sufficient when liquefied by heat to flow through the pipe D into the vessel B and fill the space in the latter up to the top of the condenser or other device placed therein.

It is desirable to run into the pipe D enough melted material to fill it before using the apparatus and to make the pipe of a poor heat-conducting material, so that a little time will elapse after the heat is applied to melt the material in the tank A before the flow through the pipe begins

When the apparatus has been thus prepared, the air from the interior of the tank A is withdrawn as completely as practicable by an air-pump E and steam is passed through the coil C. In order to prevent access of any of the volatile constituents of the insulating material to the pump, a condenser F, with a cooling-coil G, is interposed in the piping between the tank and pump. After a partial vacuum has been secured in the tank A and the liquefied insulating material has been run into the vessel B the pump may be stopped and the tank connected with a receiver H, from which the air has been exhausted, and the apparatus allowed to stand until all the interstices of the condenser have been permeated with the insulating material. The steam is then shut off and cold water passed through the coil C. The connections with the pump are then reversed and air is forced into the tank and receiver II and the further cooling and solidification of the insulating material carried on under a pressure considerably greater than that of the atmosphere. After the insulating material has cooled and solidified the condenser or other device, with the adhering mass of insulating material, is removed from the receptacle and the superfluous insulating material taken off.

I have found that condensers, transformers, and similar apparatus treated by this process are of very superior quality and especially suited for circuits which convey currents of high frequency and potential.

I am aware that conductors covered with a more or less porous material have been treated by placing them in a closed receptacle, exhausting the air from the receptacle, then introducing a fluid insulating compound and subjecting the same to pressure, for the purpose of more perfectly incorporating the insulating compound with the surrounding coating or covering of the conductors and causing such compound to enter the interstices in said covering, and I apply this principle of exhausting the air and introducing the fluid insulating compound under pressure in carrying out my improvement. My process, however, differs from the foregoing mainly in this, that I seek not only to fill the pores of any porous material that may be interposed between the conductors of such a device as a condenser or coil, but to fill up all the spaces in the dielectric, whereby air or vacuous spaces, the presence of which in the dielectric is so deleterious to the device, may be effectually prevented. To this end I permit the insulating compound after its incorporation with the device, under exhaustion and pressure, to cool and solidify, so that not only is the air replaced by a solid insulating compound, but the formation of vacuous spaces by the contraction of the mass on cooling prevented.

What I claim is—

The improvement in. the manufacture of electrical devices such as condensers, which consists in inclosing the device in an air-tight receptacle, exhausting the air from the receptacle, introducing into a vessel containing the device an insulating material rendered fluid by heat, and then when said material has permeated the interstices of the said device, subjecting the whole to pressure, and maintaining such pressure until the material has cooled and solidified, as set forth.

NIKOLA TESLA.

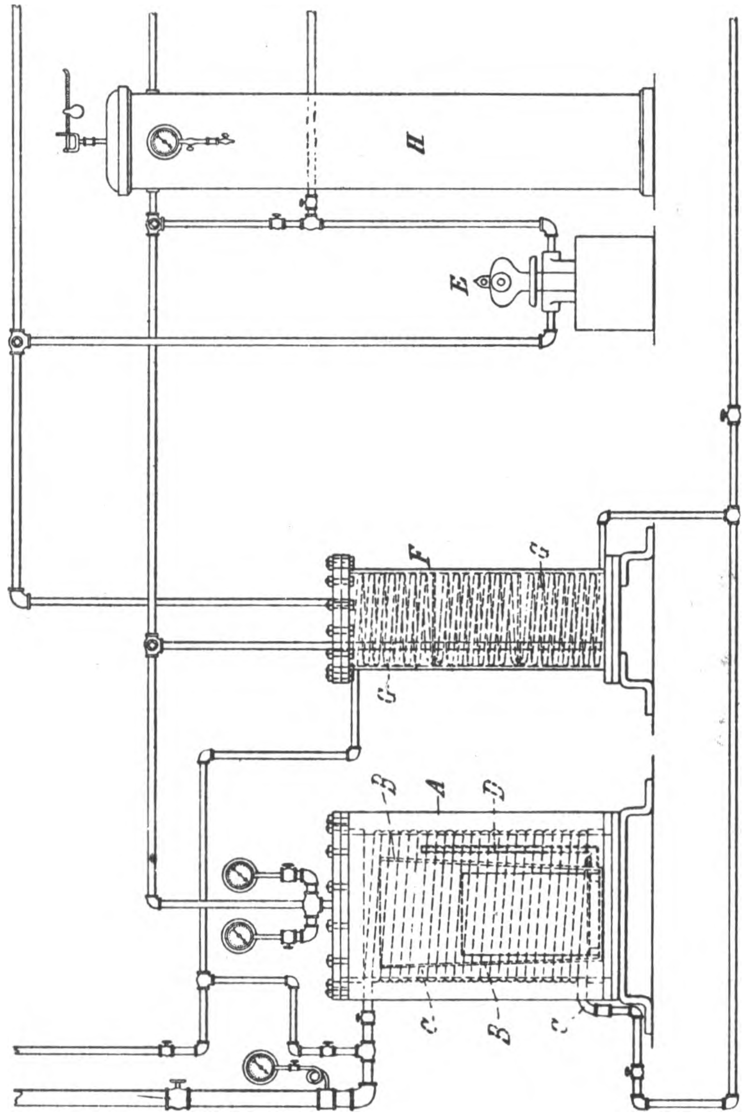
Witnesses:
M. LAWSON DYER,
PARKER W. PAGE.

(No Model.)

N. TESLA.

MANUFACTURE OF ELECTRICAL CONDENSERS, COILS, &c.

No. 577,671. Patented Feb. 23, 1897



WITNESSES
Edwin B. Hopkinson,
Benjamin Miller,

INVENTOR
Nikola Tesla
BY
Ken. Curtis & Page
ATTORNEYS.

UNITED STATES PATENT OFFICE.

NIKOLA TESLA, OF NEW YORK. N. Y.

ELECTRICAL IGNITER FOR GAS-ENGINES

SPECIFICATION forming part of Letters Patent No. 609,250, dated August 16, 1898.

Application filed February 17, 1897. Renewed June 15, 1898, Serial No. 683,524. (No model)

To all whom it may concern:

Be it known that I, NIKOLA TESLA, a citizen of the United States, residing at New York, in the county and State of New York, have invented certain new and useful Improvements in Electrical Igniters for Gas-Engines and Analogous Purposes, of which the following is a specification, reference being had to the drawing accompanying and forming a part of the same.

In certain kinds of apparatus it is necessary for the operation of the machine itself or for effecting the object for which it is used to produce an electric spark or any other similar local effect at a given instant of time or at predetermined intervals. For example, in certain gas or explosive engines a flame or spark is necessary for the ignition of an explosive mixture of air and gas under the piston, and the most effective way of igniting the gaseous mixture has been found to be the production in the cylinder at the proper moments of an electric spark. The only practicable device by which this has been accomplished heretofore is an induction-coil comprising a primary and secondary circuit with a buzzer or rapidly-acting automatic circuit-breaker in the primary and a circuit-controller, such as a switch or commutator, located also in the primary or battery circuit and operated by some moving portion of the apparatus to temporarily close such circuit at the proper time, and thereby set in operation the automatic circuit-breaker, which causes between secondary terminals in the cylinder the discharge which is necessary for the proper ignition of the explosive mixture Instead of thus temporarily closing the primary circuit the automatic circuit-breaker might be permitted to operate continuously, and the secondary, circuit normally broken, might be closed at the proper time to cause the spark to pass at any point. In either case the employment of a quick acting circuit-breaker is necessary, for unless the induction-coil be of large size and the source of current of considerable power a slow or gradual make and break of the primary of a simple transformer, such as would ordinarily be effected by a switch or commutator, would not effect a discharge of the character necessary for the proper ignition of the gas.

There is, however, no form of vibrating or quick acting circuit-breaker of which I am aware that can be depended upon to operate with certainty to produce such a spark or which will continue to operate for any length of time without deterioration, and hence not only in the case of engines of the kind described, but in other forms of apparatus which involve the use of a high-tension induction-coil with a quick-acting circuit-breaker, the operation of the machine is contingent upon the proper operation of a comparatively insignificant but essential part.

The object of my invention is to provide a more certain and satisfactory means for use with and control by such machines or apparatus as I have mentioned for producing sparks or discharges of the desired character, and to this end I employ the following arrangement. Any suitable moving portion of the apparatus is caused to mechanically control the charging of a condenser and its discharge through a circuit in inductive relation to a secondary circuit leading to the terminals between which the discharge is to occur, so that at the desired intervals the condenser may be discharged through its circuit and induce in the other circuit a current of high potential which produces the desired spark or discharge.

One practical means of accomplishing this is to employ any proper form of switch or commutator operated directly or through suitable intermediate devices by a moving part of the apparatus and which is caused to complete an electric circuit which has been previously broken or interrupted for an appreciable time when the occurrence of the spark or discharge is necessary. The circuit thus closed includes a condenser, which by this operation of the switch is permitted to discharge, through the primary of a transformer, energy which it had previously received during the interruption of said circuit from a battery or discharge of a self-induction coil in series with the battery in the charging circuit.

The ends of the secondary circuit of the transformer above mentioned are connected with the points or terminals in the machine between which the spark is to pass, and following the short-circuiting of the condenser by the closing of the switch a strong secondary discharge induced by the discharge of the condenser through the primary will occur. It is possible by this means not only to produce a strong discharge of high tension, as in the form of a spark well adapted for the ignition of gas or other purposes for which sparks are employed, but to secure such result by apparatus very much less complicated and expensive than that heretofore employed for the purpose and which will be capable of certain and effective operation for an indefinite period of time.

I have illustrated the principle of my improvement and the manner in which the same is or may be carried out in the drawing hereto annexed. The invention is shown as used for effecting the operation of the piston of a gas-engine, the figure being a diagram.

A designates the cylinder of a gas-engine, B the piston, and C the piston-rod. Other parts of the engine are omitted from the illustration as unnecessary to an understanding of the invention.

On the piston-rod C is a commutator or circuit-controller upon which bear the terminals *a b* of an electric circuit D. This commutator comprises a continuous ring *c* and a split ring *d* side by side, so that when the terminals are on the latter the circuit is interrupted, but when on the former it is closed. The to-and-fro movement of the piston, therefore, operates to alternately make and break the circuit, the position of the commutator being such that the make occurs at the moment desired for the ignition of the explosive charge under the piston.

In the circuit D is a battery or other source of current E and the primary F of a transformer. Across the two conductors of the circuit, between the battery and the primary F, is a condenser G, which is charged by the battery when circuit D is interrupted at the commutator and which discharges through the primary when such circuit is closed.

In order that the condenser may receive a charge of high tension, a self-induction coil H is introduced in the circuit between itself and the battery, which coil stores up the energy of the battery when the circuit D is closed at the commutator and discharges it into the condenser when the circuit is broken.

The primary F is combined with a secondary K, the conductors from which lead, respectively, to an insulated terminal L within the cylinder A and to any other conducting-body in the vicinity of such point as to the cylinder itself. In consequence of this arrangement, when the piston reaches the proper point the circuit D is closed, the energy of the condenser is discharged through the primary with a sudden rush, and a strong and effective spark or flash is produced between the point L and the cylinder or piston which ignites the charge of explosive gas.

It will be understood from the preceding description that I do not limit myself to the specific construction or arrangement of the devices employed in carrying out my improvement and that these may be varied within wide limits.

What I claim is—

1. In an apparatus which depends for its operation or effect upon the production of a sudden electric discharge at a given instant, or at predetermined intervals of time, the combination with a moving part of said apparatus of a switch or commutator, a condenser, a charging-circuit for the same, a primary circuit through which the condenser discharges, and a secondary circuit in inductive relation to the said primary circuit and connected with the terminals at the point in the apparatus where the discharge is required, the switch or commutator being operated by the said moving part to effect the discharge of the condenser at the proper intervals, as set forth.

2. In an apparatus which depends for its operation or effect upon the production of a sudden electric discharge at a given instant, or at predetermined intervals of time, the combination with a moving part of said apparatus of a circuit and a circuit-controller adapted to close said circuit at the time when the occurrence of said discharge is desired, a source of current in said circuit, a condenser adapted to be charged by said source while the circuit is interrupted, and a transformer through the primary of which the condenser discharges when the circuit is closed, the secondary of the transformer being connected with the terminals at the point in the apparatus where the discharge is required, as set forth.

3. In an apparatus which depends for its operation or effect upon the production of an electric discharge, at a given instant, or at predetermined intervals of time, the combination with a moving part of said apparatus of a circuit and a circuit-controller adapted to close said circuit at the time when the occurrence of the spark is desired, a source of current in said circuit, a self-induction coil which stores the energy of the source while the circuit is closed, a condenser into which said coil discharges when the circuit is broken, and a transformer through the primary of which the condenser discharges, the secondary of said transformer being connected with separated terminals at the point where the discharge is required.

4. In a gas or explosive engine of the kind described, the combination with a moving part of said engine of a circuit-closer or switch controlling the charging and discharging of a condenser, separated terminals in the cylinder or explosive-chamber, and a transformer through the primary of which the condenser discharges, the secondary being connected with the terminals in the cylinder, as set forth.

NIKOLA TESLA.

Witnesses:
M. LAWSON DYER,
EDWIN B. HOPKINSON.

P-440

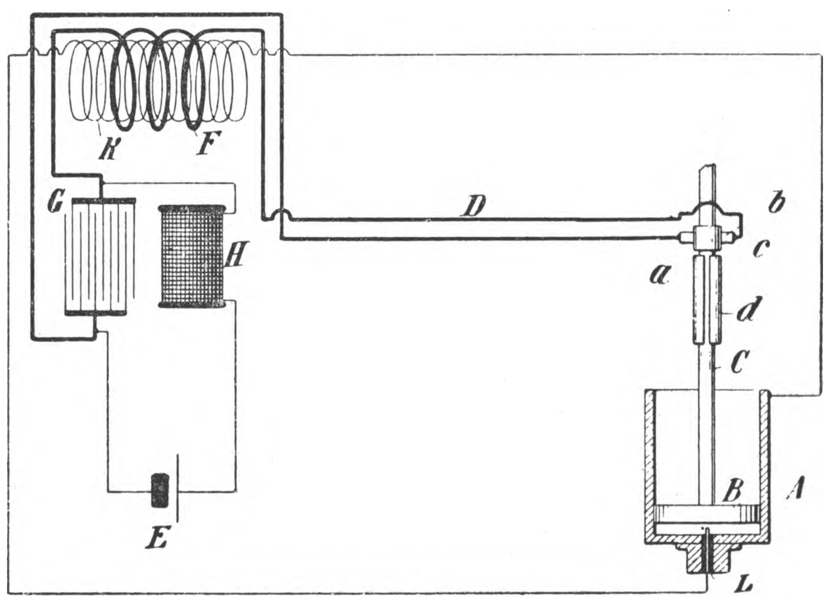
No. 609,250. Patented Aug. 16, 1898

N. TESLA.

ELECTRICAL IGNITER FOR GAS ENGINES.

(Application filed Feb. 17 1897. Renewed June 15, 1898)

(No Model.)



Witnesses:
M Lawson Dyer
Edwin B. Hopkinson

Nikola Tesla, Inventor
by Kerr, Curtis & Page Attys

UNITED STATES PATENT OFFICE.

NIKOLA TESLA. OF NEW YORK. N. Y.

FOUNTAIN.

1,113,716. Specification of Letters Patent. Patented Oct. 13, 1914.

Application filed October 28, 1913. Serial No. 797,718.

To all whom it may concern:

Be it known that I, NIKOLA TESLA, a citizen of the United States, residing at New York, borough of Manhattan, county and State of New York, have invented certain new and useful Improvements in Fountains, of which the following is a full, clear, and exact description.

It has been customary heretofore in fountains and aquarian displays, to project spouts, jets, or sprays of water from suitable fixtures, chiefly for decorative and beautifying purposes. Invariably, the quantity of the issuing fluid was small and the pleasing impression on the eye was solely the result of the more or less artistic arrangement of the streamlets and ornaments employed. The present invention is a departure from such practice in that it relies principally on the fascinating spectacle of a large mass of fluid in motion and the display of seemingly great power. Incidentally, it permits the realization of beautiful and striking views through illumination and the disposition of voluminous cascades which, moreover, may be applied to useful purposes in ways not practicable with the old and familiar devices. These objects are accomplished by the displacement of a great volume of fluid with a relatively small expenditure of energy in the production and maintenance of a veritable waterfall as distinguished from a mere spout, jet or spray.

The underlying idea of the invention can be carried out by apparatus of widely varied design, but in the present instance the simplest forms, of which I am aware, are shown as embodiments of the principle involved.

In the accompanying drawing, Figure 1 is a top plan and Fig. 2 a vertical central sectional view of an appliance which I have devised for the purpose. Fig. 3 and Fig. 4 illustrate corresponding views of a similar device of much simpler construction.

Referring to the first, 1 represents a receptacle of any suitable material, as metal, glass, porcelain, marble, cement or other compound, with a central hub 2 and a conical conduit 3, flared out at the top and provided with openings 4 at the bottom. In the hub 2 is inserted a shaft 5 rotatably supported on ball bearings 6 and carrying at its lower end a friction pulley or gear wheel 7. To the upper end of the shaft is fastened a casting 8, preferably of some non-corrosive alloy, with blades 9 constituting a screw which is shown in this instance as the best known propelling device; but it will be understood that other means may be employed. A motor 10 is suitably mounted so as to transmit through wheel 11, by friction or otherwise, power to the pulley or wheel 7 Openings 4 may be covered with removable strainers and receptacles 1 may be provided with convenient connections, respectively, for cleaning and renewing the liquid. It is thought unnecessary to. snow these attachments in the drawing.

The operation will be readily understood. Receptacle 1 being filled to the proper level with water or other fluid, and the power turned on, the propeller blades 9 are set in rotation and the fluid, drawn through the openings 4, is lifted to the horizontal flared out top of conduit 3 until it overflows in the form of a circular cascade.

In order to prevent the wetting of the bearings of shaft 5, the central hub 2 of receptacle 1 is made to project above conduit 3. The latter is funnel shaped for reasons of economy, and also for the purpose of reducing the speed and securing a smooth and even overflow. As the lift is inconsiderable, little power is needed to keep in motion a great volume of water and the impression produced on the observer is very striking. With the view of still further economizing energy, the bottom of receptacle 1 may be shaped as indicated by the dotted lines 12, in Fig. 2 so as to increase the velocity at the intake of the propeller.

To convey an idea of the results obtainable with a small apparatus, properly designed, it may be stated that by applying only 1/25 of a horse-power to the shaft and assuming a lift of eighteen inches, more than one hundred gallons per minute may be propelled, the depth of the fluid passing over the flared top of conduit 3, one foot in diameter, being nearly one-half inch. As the circulation is extremely rapid the total quantity of liquid required is comparatively small. About one tenth of that delivered per minute will be, generally, sufficient. Such a cascade presents a singularly attractive appearance and this feature may be still further enhanced by artistic grouping of plants or other objects around it, in which case the whole contrivance may be hidden from view. Particularly beautiful displays, however, are obtainable by illumination which may be carried out in many ways. To heighten the effect, a colored, opalescent or phosphorescent fluid may be employed. Sterilizing, aromatic or radio-active liquids may also be used, when so desired. The usual fountains are objectionable in many places on account of the facility they afford for the breeding of insects. The apparatus described not only makes this impossible but is a very efficient trap. Unlike the old devices in which only a very small volume of water is set in motion, such a waterfall is is highly effective in cooling the surrounding atmosphere. To still improve this action the free end 13 of the rotating shaft may be utilized to carry any kind of fan. The water may, of course, be artificially cooled.

The device described may be modified in many ways and also considerably simplified. For example, the propeller may be fixed directly to the shaft of the motor and the latter supported conveniently from above when many of the parts illustrated in Fig. 1 and Fig. 2 may be dispensed with. In fact, receptacle 1 itself may be replaced by an independent tank or basin so that the entire apparatus will only consist of a funnel shaped conduit, motor and propeller as a unit. Such a construction is shown in Fig. 3 and Fig. 4 in which 3 is a conical vessel provided with intake openings 4 and resting on a substantial base A motor 14, carrying on a strong shaft 5 a propeller 9, is fixed to supports 15 which extend from the inner side of conduit 3 and may be integral with the same. Obviously, to insure perfect working the weight of the moving parts and axial reaction of the propeller should be taken up or balanced as by a thrust bearing 16, or other means.

Apparatus of this description is especially intended for use in open basins or reservoirs in which it may be placed and put in action at short notice. When it is desired to produce large and permanent waterfalls the conduit 3 may be formed by masonry of appropriate architectural design.

The invention has an unlimited field of use in private dwellings, hotels, theaters, concert halls, hospitals, aquaria and, particularly, in squares, gardens and parks in which it may be carried out on a large scale so as to afford a magnificent spectacle far more captivating and stimulating to the public than the insignificant displays now in use.

I am well aware that artificial water falls have heretofore been exhibited and that fountains in which the same water is circulated are old and well known. But in all such cases independent pumps of small volumetric capacity were used to raise the water to an appreciable height which involved the expenditure of considerable energy, while the spectacle offered to the eye was uninteresting. In no instance, to my knowledge, has a great mass of fluid been propelled by the use of only such power as is required to lift it from its normal level through a relatively short space to that from which it overflows and descends as a cascade, nor have devices especially adapted for the purpose been employed.

What I claim is:

1. An artificial fountain consisting of an unobstructed conduit having an elevated overflow and adapted to be set in a body of water, and a propelling device for maintaining a rapid circulation of the water through the conduit.

2. An artificial fountain comprising in combination an unobstructed conduit having an elevated overflow and adapted to be set in a body of fluid, a propeller within the conduit for maintaining a rapid circulation of the fluid through the same, and a motor for driving the propeller.

3. The artificial fountain herein described, comprising in combination a receptacle, a central hollow conduit with an elevated overflow placed therein, a propeller within the conduit, and a motor for driving the propeller, so as to maintain a rapid circulation of fluid through the conduit.

4. The artificial fountain herein described, comprising in combination, a receptacle, a conduit with elevated overflow set therein, a central hub extending up through the conduit, a rotary shaft extending therethrough, and a propeller carried by the shaft for maintaining a rapid circulation of fluid through the conduit.

5. An artificial fountain comprising in combination with an unobstructed passage from the normal to the elevated fluid levels, of a propeller for maintaining a rapid circulation of the fluid through such passage and producing thereby a cascade with the expenditure of little energy.

6. An artificial fountain comprising a funnel shaped conduit adapted to be set in a body of fluid, and having openings near the lower end. and a propeller supported within the conduit and adapted when in operation to maintain a rapid circulation of water through the same.

In testimony whereof I affix my signature in the presence or two subscribing witnesses.

NIKOLA TESLA.

Witnesses:

M. LAWSON DYER,

WM. BOHLEBER.

P-443

N. TESLA.
FOUNTAIN.
APPLICATION FILED OCT. 38, 1913.

1,113,716. Patented Oct. 13, 1914.
2 SHEETS-SHEET 1.

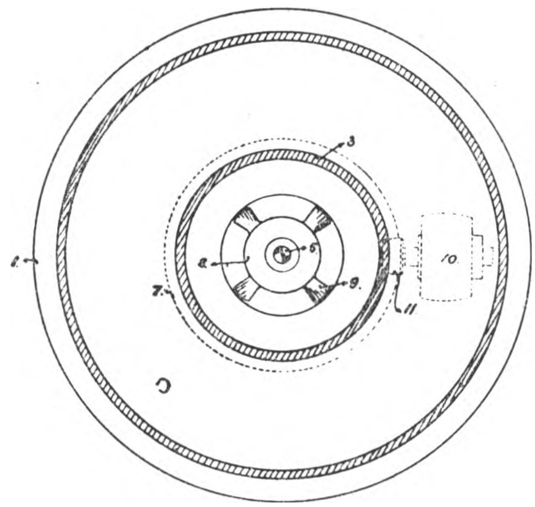


Fig 1

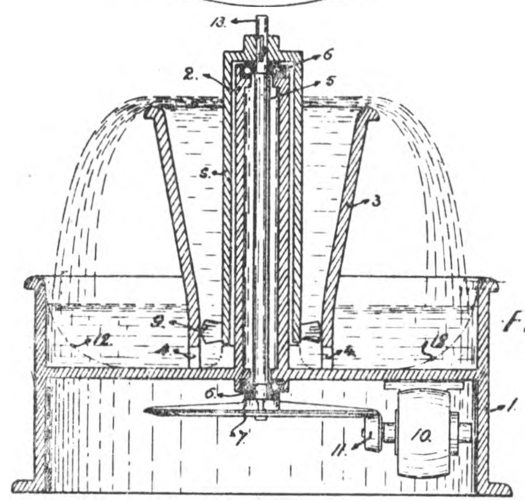


Fig 2

WITNESSES
[signature]
Wm Bohleber

INVENTOR
Nikola Tesla
BY
Kerr Page Cooper & Hayward
ATTORNEYS

P-444

N. TESLA
FOUNTAIN.
APPLICATION FILED OCT. 28, 1913.

1,113,716. Patented Oct. 13, 1914
2 SHEETS-SHEET 2.

Fig. 3.

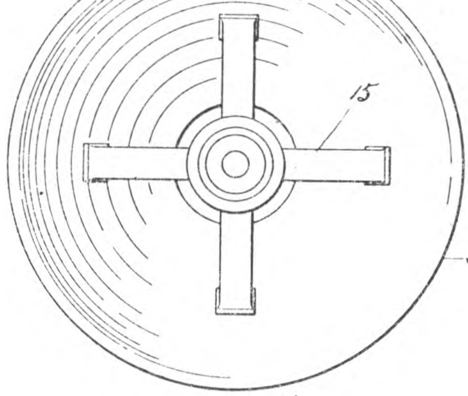
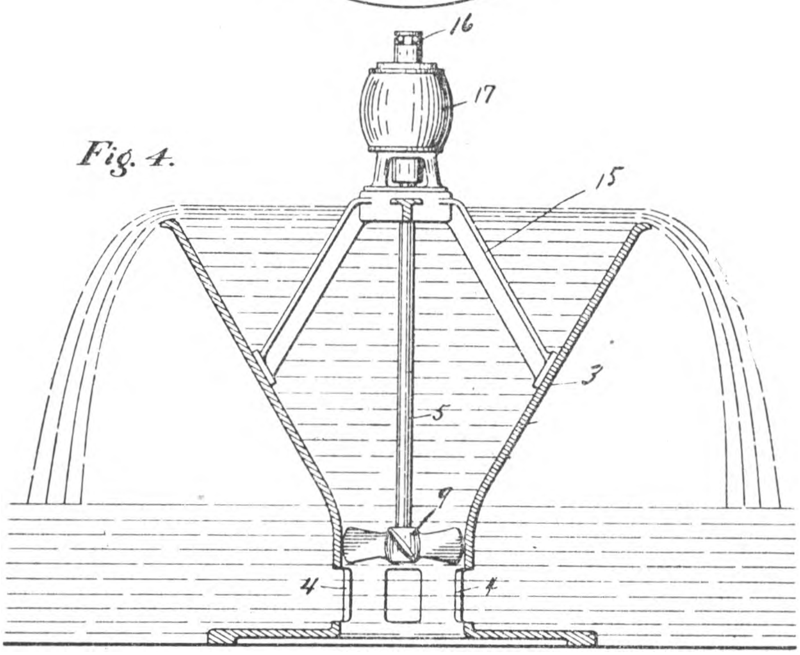


Fig. 4.



WITNESSES:
R. Diaz Buitrago
Wm. Bohleber

INVENTOR.
Nikola Tesla
BY
Kerr Page Cooper & Hayward
ATTORNEYS

UNITED STATES PATENT OFFICE.

NIKOLA TESLA, OF NEW YORK, N. Y.

VALVULAR CONDUIT.

1,329,559. Specification of Letters Patent. Patented Feb. 3, 1920.

Application filed February 21, 1916. Serial No. 79,703. Renewed July 8, 1919. Serial No. 309,482.

To all whom it may concern:

Be it known that I, NIKOLA TESLA, a citizen of the United States, residing at New York, in the county and State of New York, have invented certain new and useful Improvements in Valvular Conduits, of which the following is a full, clear, and exact description.

In most of the machinery universally employed for the development, transmission and transformation of mechanical energy, fluid impulses are made to pass, more or less freely, through suitable channels or conduits in one direction while their return is effectively checked or entirely prevented This function is generally performed by devices designated as valves, comprising carefully fitted members the precise relative movements of which are essential to the efficient and reliable operation of the apparatus. The necessity of, and absolute dependence on these, limits the machine in many respects, detracting from its practical value and adding greatly to its cost of manufacture and maintenance. As a rule the valve is a delicate contrivance, very liable to wear and get out of order and thereby imperil ponderous, complex and costly mechanism and, moreover, it fails to meet the requirements when the impulses are extremely sudden or rapid in succession and the fluid is highly heated or corrosive.

Though these and other correlated facts were known to the very earliest pioneers in the science and art of mechanics, no remedy has as yet been found or proposed to date so far as I am aware, and I believe that I am the first to discover or invent any means, which permit the performance of the above function without the use of moving parts, and which it is the object of this application to describe.

Briefly expressed, the advance I have achieved consists in the employment of a peculiar channel or conduit characterized by valvular action.

The invention can be embodied in many constructions greatly varied in detail, but for the explanation of the underlying principle it may be broadly stated that the interior of the conduit is provided with enlargements, recesses, projections, baffles or buckets which, while offering virtually no resistance to the passage of the fluid in one direction, other than surface friction, constitute an almost impassable barrier to its flow in the opposite sense by reason of the more or less sudden expansions, contractions, deflections, reversals of direction, stops and starts and attendant rapidly succeeding transformations of the pressure and velocity energies.

For the full and complete disclosure of the device and of its mode of action reference is made to the accompanying drawings in which—

Figure 1 is a horizontal projection of such a valvular conduit with the top plate removed.

Fig. 2 is side view of the same in elevation.

Fig. 3 is a diagram illustrative of the application of the device to a fluid propelling machine such as, a reciprocating pump or compressor, and

Fig. 4 is a plan showing the manner in which the invention is, or may be used, to operate a fluid propelled rotary engine or turbine.

Referring to Fig. 1, 1 is a casing of metal or other suitable material which may be cast, milled or pressed from sheet in the desired form. From its side-walls extend alternatively projections terminating in buckets 2 which, to facilitate manufacture are congruent and spaced at equal distances, but need not be. In addition to these there are independent partitions 3 which are deemed of advantage and the purpose of which will be made clear. Nipples 4 and 5, one at each end, are provided for pipe connection. The bottom is solid and the upper or open side is closed by a fitting plate 6 as shown in Fig. 2. When desired any number of such pieces may be joined in series, thus making up a valvular conduit of such length as the circumstances may require.

In elucidation of the mode of operation let it be assumed that the medium under pressure be admitted at 5. Evidently, its approximate path will be as indicated by the dotted line 7, which is nearly straight, that is to say, if the channel be of adequate cross-section, the fluid will encounter a very small resistance and pass through freely and undisturbed, at least to a degree. Not so if the entrance be at the opposite end 4. In this case the flow will not be smooth and continuous, but intermittent, the fluid being quickly deflected and reversed in direction, set in whirling motion, brought to rest and again accelerated, these processes following one another in rapid succession. The partitions 3 serve to direct the stream upon the buckets and to intensify the actions causing violent surges and eddies which interfere very materially with the flow through the conduit. It will be readily observed that the resistance offered to the passage of the medium will be considerable even if it be under constant pressure, but the impediments will be of full effect only when it is supplied in pulses and, more especially, when the same are extremely sudden and of high frequency. In order to bring the fluid masses to rest and to high velocity in short intervals of time energy must be furnished at a rate which is unattainable, the result being that the impulse cannot penetrate very far before it subsides and gives rise to movement in the opposite direction. The device not only acts as a hinderment to the bodily return of particles but also, in a measure, as a check to the propagation of a disturbance through the medium. Its efficacy is chiefly determined; first, by the magnitude of the ratio of the two resistances offered to disturbed and to undisturbed flow, respectively, in the directions from 4 to 5 and from 5 to 4, in each individual element of the conduit; second, by the number of complete cycles of action taking place in a given length of the valvular channel and, third, by the character of the impulses themselves. A fair idea may be gained from simple theoretical considerations.

Examining more closely the mode of operation it will be seen that, in passing from one to the next bucket in the direction of disturbed flow, the fluid undergoes two complete reversals or deflections through 180 degrees while it suffers only two small deviations from about 10 to 20 degrees when moving in the opposite sense. In each case the loss of head will be proportionate to a hydraulic coefficient dependent on the angle of deflection from which it follows that, for the same velocity, the ratio of the two resistances will be as that of the two coefficients. The theoretical value of this ratio may be 200 or more, but must be taken as appreciably less although the surface friction too is greater in the direction of disturbed flow. In order to keep it as large as possible, sharp bonds should be avoided, for these will add to both resistances and reduce the efficiency. Whenever practicable, the piece should be straight; the next best is the circular form.

That the peculiar function of such a conduit is enhanced by increasing the number of buckets or elements and, consequently, cyclic processes in a given length is an obvious conclusion, but there is no direct proportionality because the successive actions diminish in intensity. Definite limits, however, are set constructively and otherwise to the number of elements per unit length of the channel, and the most economical design can only be evolved through long experience.

Quite apart from any mechanical features of the device the character of the impulses has a decided influence on its performance and the best results will be secured, when there are produced at 4, sudden variations of pressure in relatively long intervals, while a constant pressure is maintained at 5. Such is the case in one of its most valuable industrial applications which will be specifically described.

In order to conduce to a better understanding, reference may first be made to Fig. 3 which illustrates another special use and in which 8 is a piston fixed to a shaft 9 and fitting freely in a cylinder 10. The latter is closed at both ends by flanged heads 11 and 12 having sleeves or stuffing boxes 13 and 14 for the shaft. Connection between the two compartments, 15 and 16, of the cylinder is established through a valvular conduit and each of the heads is similarly equipped. For the sake of simplicity these devices are diagrammatically shown, the solid arrows indicating the direction of undisturbed flow. An extension of the shaft 9 carries a second piston 17 accurately ground to and sliding easily in a cylinder 18 closed at the ends by plates and sleeves as usual. Both piston and cylinder are provided with inlet and outlet ports marked, respectively, 19 and 20. This arrangement is familiar, being representative of a prime mover of my invention, termed “mechanical oscillator”, with which it is practicable to vibrate a system of considerable weight many thousand times per minute.

Suppose now that such rapid oscillations are imparted by this or Other means to the piston 8. Bearing in mind the proceeding, the operation of the apparatus will be understood at a glance. While moving in the direction of the solid arrow, from 12 to 11, the piston 8 will compress the air or other medium in the compartment 16 and expel it from the same, the devices in the piston and head 11 acting, respectively, as closed and open valves. During the movement of the piston in the opposite direction, from 11 to 12, the medium which has meanwhile filled the chamber 15 will be transferred to compartment 16, egress being prevented by the device in head 12 and that in the piston allowing free passage. These processes will be repeated in very quick succession. If the nipples 4 and 5 are put in communication with independent reservoirs, the oscillations of the piston 8 will result in a compression of the air at 4 and rarefaction or the same at 5. Obviously, the valvular channels being turned the other way, as indicated by dotted lines in the lower part of the figure, the opposite will take place. The devices in the piston have been shown merely by way of suggestion and can be dispensed with. Each of the chambers 15 and 16 being connected to two conduits as illustrated, the vibrations of a solid piston as 8 will have the same effect and the machine will then ho a double acting pump or compressor. It. is likewise unessential that the medium should be admitted to the cylinder through such devices for in certain instances ports, alternately closed and opened by the piston, may serve the purpose. As a matter or course, this novel method of propelling fluids can be extended to multistage working in which case a number of pistons will be employed, preferably on the same shaft and of different diameters in conformity with well established principles of mechanical design. In this way any desired ratio of compression or degree of rarefaction may be attained.

Fig. 4 exemplifies a particularly valuable application of the invention to which reference has been made above. The drawing shows in vertical cross section a turbine which may be of any type but is in this instance one invented and described by me and supposed to be familiar to engineers. Suffice it to state that the rotor 21 of the same is composed of flat plates which are set in motion through the adhesive and viscous action of the working fluid, entering the system tangentially at the periphery and leaving it at the center. Such a machine is a thermodynamic transformer of an activity surpassing by far that of any other prime mover, it being demonstrated in practice that each single disk of the rotor is capable of performing as much work as a whole bucket-wheel. Besides, a number of other advantages, equally important, make it especially adapted for operation as an internal combustion motor. This may be done in many ways, but the simplest and most direct plan of which I am aware is the one illustrated here. Referring again to the drawing, the upper part of the turbine casing 22 has bolted to it a separate casting 23, the central cavity 24 of which forms the combustion chamber. To prevent injury through excessive heating a jacket 25 may be used, or else water injected, and when these means are objectionable recourse may be had to air cooling, this all the more readily as very high temperatures are practicable. The top of casting 23 is closed by a plate 26 with a sparking or hot wire plug 27 and in its sides are screwed two valvular conduits communicating with the central chamber 24. One of these is, normally, open to the atmosphere while the other connects to a source of fuel supply as a gas main 28. The bottom of the combustion chamber terminates in a suitable nozzle 29 which consists of separate piece of heat resisting material. To regulate the influx of the explosion constituents and secure the proper mixture the air and gas conduits are equipped, respectively, with valves 30 and 31. The exhaust openings 32 of the rotor should be in communication with a ventilator, preferably carried on the same shaft and of any suitable construction. Its use, however, while advantageous, is not indispensable the suction produced by the turbine rotor itself being, in some cases at least, sufficient to insure proper working. This detail is omitted from the drawing as unessential to the understanding.

But a few words will be needed to make clear the mode of operation. The air valve 30 being open and sparking established across terminals 27, the gas is turned on slowly until the mixture in the chamber 24 reaches the critical state and is ignited. Both the conduits behaving, with respect to efflux, as closed valves, the products of combustion rush out through the nozzle 29 acquiring still greater velocity by expansion and, imparting their momentum to the rotor 21, start it from rest. Upon the subsidence of the explosion the pressure in the chamber sinks below the atmospheric owing to the pumping action of the rotor or ventilator and new air and gas is permitted to enter, cleaning the cavity and channels and making up a fresh mixture which is detonated as before, and so on, the successive impulses of the working fluid producing an almost continuous rotary effort. After a short lapse of time the chamber becomes heated to such a degree that the ignition device may be shut off without disturbing the established régime. This manner of starting the turbine involves the employment of an unduly large combustion chamber which is not commendable from the economic point of view, for not only does it entail increased heat losses but the explosions cannot be made to follow one another with such rapidity as would be desirable to insure the best valvular action. When the chamber is small an auxiliary means for starting, as compressed air, may be. resorted to and a very quick succession of explosions can then be obtained. The frequency will be the greater the stronger the suction, and may, under certain conditions, reach hundreds and even thousands per second. It scarcely need be stated that instead of one several explosion chambers may be used for cooling purposes and also to increase the number of active pulses and the output of the machine.

Apparatus as illustrated in Fig. 4 presents the advantages of extreme simplicity, cheapness and reliability, there being no compressor, buckets or troublesome valve mechanism. It also permits, with the addition of certain well-known accessories, the. use of any kind of fuel and thus meets the pressing necessity of a self-contained, powerful, light and compact internal combustion motor for general work. When the attainment of the highest efficiency is the chief object, as in machines of large size, the explosive constituents will be supplied under high pressure and provision made for maintaining a vacuum at the exhaust. Such arrangements are quite familiar and lend themselves so easily to this improvement that an enlargement on this subject is deemed unnecessary.

The foregoing description will readily suggest to experts modifications both as regards construction and application of the device and I do not. wish to limit myself in these respects. The broad underlying idea of the invention is to permit the free passage of a fluid through a channel in the direction of the flow and to prevent its return through friction and mass resistance, thus enabling the performance of valve functions without any moving parts and thereby extending the scope and usefulness of an immense variety of mechanical appliances.

I do not claim the methods of and apparatus for the propulsion of fluids and thermodynamic transformation of energy herein disclosed, as these will be made subjects of separate applications.

I am aware that asymmetrical conduits have been constructed and their use proposed in connection with engines, but these have no similarity either in their construction or manner of employment with my valvular conduit. They were incapable of acting as valves proper, for the fluid was merely arrested in pockets and deflected through 90°, this result having at best only 25% of the efficiency attained in the construction herein described. In the conduit I have designed the fluid, as stated above, is deflected in each cycle through 360°, and a co-efficient approximating 200 can be obtained so that the device acts as a slightly leaking valve, and for that reason the term "valvular" has been given to it in contrast to asymmetrical conduits, as heretofore proposed, which were not valvular in action, but merely asymmetrical as to resistance.

Furthermore, the conduits heretofore constructed were intended to be used in connection with slowly reciprocating machines, in which case enormous conduit-length would be necessary, all this rendering them devoid of practical value. By the use of an effective valvular conduit, as herein described, and the employment of pulses of very high frequency, I am able to condense my apparatus and secure such perfect action as to dispense successfully with valves in numerous forms of reciprocating and rotary engines.

The high efficiency of the device, irrespective of the character of the pulses, is due to two causes: first, rapid reversal of direction of flow and, second, great relative velocity of the colliding fluid columns. As will be readily seen each bucket causes a deviation through an angle of 180°, and another change of 180° occurs in each of the spaces between two adjacent buckets. That is to say, from the time the fluid enters or leaves one of the recesses to its passage into, or exit from, the one following a complete cycle, or deflection through 360°, is effected. Observe now that the velocity is but slightly reduced in the reversal so that the incoming and deflected fluid columns meet with a relative speed, twice that of the flow, and the energy of their impact is four times greater than with a deflection of only 90°, as might be obtained with pockets such as have been employed in asymmetrical conduits for various purposes. The fact is, however, that in these such deflection is not secured, the pockets remaining filled with comparatively quiescent fluid and the latter following a winding path of least resistance between the obstacles interposed. In such conduits the action cannot be characterized as "valvular" because some of the fluid can pass almost unimpeded in a direction opposite to the normal flow. In my construction, as above indicated, the resistance in the reverse may be 200 times that in the normal direction. Owing to this a comparatively very small number of buckets or elements is required for checking the fluid. To give a concrete idea, suppose that the leak from the first element is represented by the fraction $\frac{1}{X}$, then after the *n*th bucket is traversed, only a quantity $\left(\frac{1}{X}\right)^n$ will escape and it is evident that X need not be a large number to secure a nearly perfect valvular action.

What I claim is:

1. A valvular conduit having interior walls of such conformation as to permit the free passage of fluid through it in the direction of flow but to subject it to rapid reversals of direction when impelled in the opposite sense and thereby to prevent its return by friction and mass resistance.

2. A valvular conduit composed of a closed passageway having recesses in its walls so formed as to permit a fluid to pass freely through it in the direction of flow, but to subject it to rapid reversals of direction when impelled in an opposite sense and thereby interpose friction and mass resistance to the return passage of the same.

3. A valvular conduit composed of a tube

or passageway with rigid interior walls formed with a series of recesses or pockets with surfaces that reverse a fluid tending to flow in one direction therein and thereby check or prevent flow of the fluid in that direction.

4. A valvular conduit with rigid interior walls of such character as to offer substantially no obstacle to the passage through it of fluid impulses in one direction, but to subject the fluid to rapid reversals of direction and thereby oppose and check impulses in the opposite sense.

5. A valvular conduit with rigid interior walls formed to permit fluid impulses under pressure to pass freely through it in one direction, but to subject them to rapid reversals of direction through 360° and thereby check their progress when impelled in the opposite sense.

A valvular conduit with rigid interior walls which permit fluid impulses to flow through it freely in one direction, formed at a plurality of points to reverse such fluid impulses when impelled in the opposite direction and check their flow.

7. A valvular conduit with rigid interior walls having pockets or recesses, and transversely inclined intermediate baffles to permit the free passage of fluid impulses in one direction but to deflect and check them when impelled in the opposite direction.

In testimony whereof I affix my signature

NIKOLA TESLA.

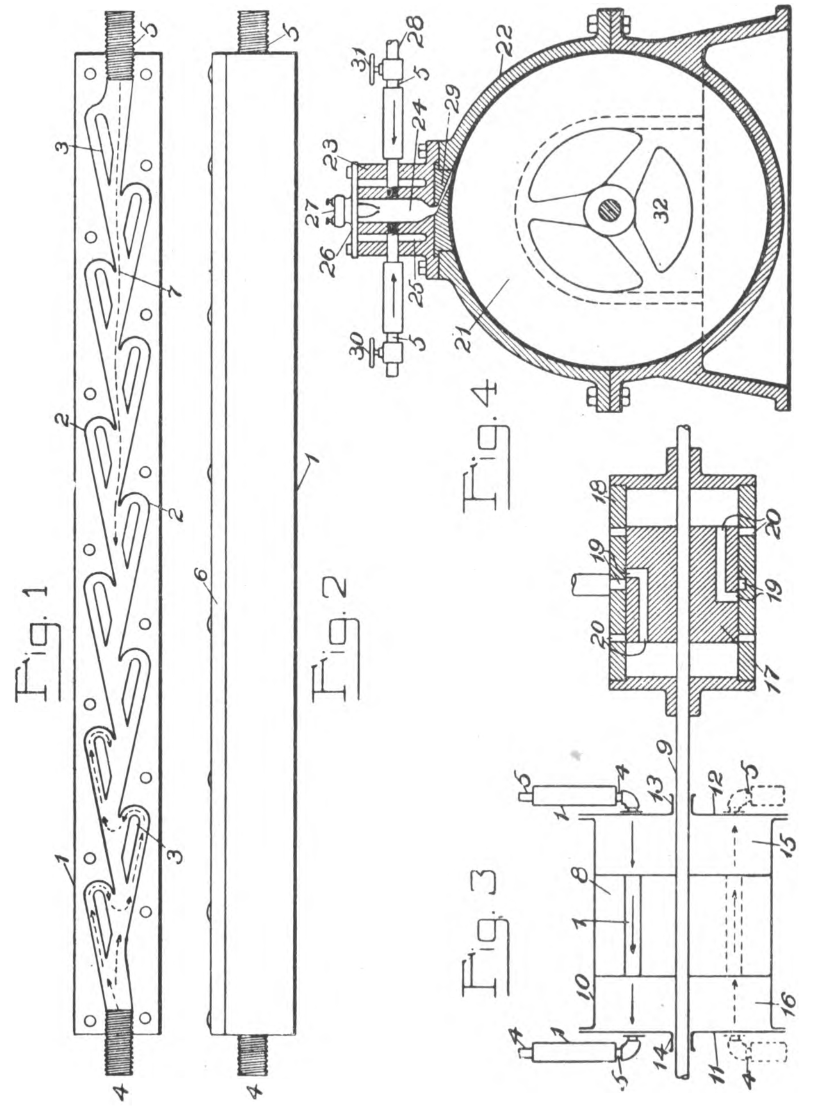
P-450

N. TESLA.

VALVULAR CONDUIT.

APPLICATION FILED FEB. 21, 1916. RENEWED JULY 8, 1919.

1,329,559. Patented Feb. 3, 1920.



INVENTOR

Nikola Tesla

BY

ATTORNEY

UNITED STATES PATENT OFFICE.

NIKOLA TESLA OF NEW YORK, N. Y.

LIGHTNING-PROTECTOR.

1,266,175. Specification of Letters Patent Patented May 14, 1918.

Application filed May 6, 1916. Serial No 95,830

To all whom it may concern:

Be it known that I, NIKOLA TESLA, a citizen of the United States, residing at New York, in the county and State of New York, have invented certain new and useful Improvements in Lightning Protectors, of which the following is a full, clear, and exact description.

The object of the present invention is to provide lightning protectors of a novel and improved design strictly in conformity with the true character of the phenomena, more efficient in action, and far more dependable in safe guarding life and property, than those heretofore employed.

To an understanding of the nature of my invention and its basic distinction from the lightning rods of common use, it is necessary briefly to explain the principles upon which my protector is designed as contrasted with those underlying the now-prevailing type of lightning rod.

Since the introduction of the lightning rod by Benjamin Franklin in the latter part of the eighteenth century, its adoption as a means of protection against destructive atmospheric discharges has been practically universal. Its efficacy, to a certain degree, has been unquestionably established through statistical records but there is generally prevalent, nevertheless, a singular theoretical fallacy as to its operation, and its construction is radically defective in one feature, namely its typical pointed terminal. In my lightning protector I avoid points, and use an entirely different type of terminal.

According to the prevailing opinion, the virtue of the Franklin type of lightning rod is largely based on the property of points or sharp edges to give off electricity into the air. As shown by Coulomb, the quantity of electricity per unit area, designated by him “electrical, density” increases as the radius of curvature of the surface is reduced. Subsequently it was proved, by mathematical analysis, that the accumulated charge created an outward normal force equal to 2π times the square of the density, and experiment has demonstrated that when the latter exceeds approximately 20 C. G. S. units, a streamer or corona is formed From these observations and deductions it is obvious that such may happen at a comparatively low pressure if the conductor is of extremely small radius, or pointed, and it is pursuant to a misapplication of these, and other, truths that the commercial lightning rod of today is made very slender and pointed. My invention, on the contrary, while taking cognizance of these truths, correctly applies them in the provision of a lightning protector that distinctively affords an elevated terminal having its outer conducting boundaries arranged on surfaces of large radii of curvature on two dimensions. The principles which underlie my invention and correct application of which dictate the form and manner of installation of my protector, I will now explain in contrast with the conventional pointed lightning rod.

In permitting leakage into the air, the needle-shaped lightning-rod is popularly believed to perform two functions: one to drain the ground of its negative electricity, the other to neutralize the positive of the clouds. To some degree it does both. But a systematic study of electrical disturbances in the earth has made it, palpably evident that the action of Franklin’s conductor, as commonly interpreted, is chiefly illusionary. Actual measurement proves the quantity of electricity escaping even from many points, to be entirely insignificant when compared with that induced within a considerable terrestrial area, and of no moment whatever in the process of dissipation. But it is true that the negatively charged air in the vicinity of the rod, rendered conductive through the influence of the same, facilitates the passage of the bolt. Therefore it increases the probability of a lighting discharge in its vicinity. The fundamental facts underlying this type of lightning-rod are: First, it attracts lightning, so that it will be struck oftener than would be the building if it were not present; second, it renders harmless most, but not all, of the discharges which it receives; third, by rendering the air conductive, and for other reasons, it is sometimes the cause of damage to neighboring objects; and fourth, on the whole, its power of preventing injury predominates, more or less, over the hazards it invites.

My protector, by contrast, is founded on principles diametrically opposite. Its terminal has a large surface. It secures a very low density and preserves the insulating qualities of the ambient medium, thereby minimizing leakage, and in thus acting as a quasi-repellant to increase enormously the safety factor.

For the best and most economical installation of protective devices according to my invention, those factors and phenomena that dictate size, number of protectors and physical qualities of the apparatus must be grasped by the installing engineer, and preliminarily, for full understanding of the principles of my invention, these should be briefly explained.

Economical installation, of course, demands that the protective capability of any given equipment be not needlessly greater than is required to meet the maximum expectancies under the conditions surrounding the particular building to be protected, and these depend, partially, as I shall show, upon the character of the landscape proximate to the building site.

In the drawings, Figures 1 to 4 inclusive, are diagrams requisite to illustration of the facts and conditions relevant, to the determination of specific installations of my invention, and Figs. 5 to 8 illustrate construction and application of the protectors. Specifically:

Fig. 1 is a landscape suited for purpose of explanation; Figs. 2, 3 and 4 are theoretical diagrams; Figs. 5 and 6 illustrate forms of improved protectors; and Figs. 7 mid 8 show buildings equipped with the same.

In Fig. 1, 1 represents Lord Kelvin's "reduced" area of the region, which is virtually part of the extended unruffled ocean-surface. (See "*Papers on Electrostatics and Magnetism*" by Sir William Thomson). Under ordinary weather conditions, when the sky is clear, the total amount of electricity distributed over the land is nearly the same as that which would be contained within its horizontal projection. But in times of storm, owing to the inductive action of the clouds, an immense charge may be accumulated in the locality, the density being greatest at the most elevated portions of the ground. Assuming this, under the conditions existing at any moment, let another spherical surface 2, concentric with the earth, be drawn—which may be called "electrical niveau"—such that the quantities stored over and under it are equal. In other words, their algebraic sum, taken relatively to the imaginary surface, in the positive and negative sense, is *nil.* Objects above the "niveau" are exposed to ever so much more risk than those below. Thus, a building at 3, on a site of excessive density, is apt to be hit sooner or later, while one in a depression 4, where the charge per unit area is very small, is almost entirely safe. It follows that the one building 3 requires more extensive equipment than does the other. In both instances, however, the probability of being struck is decreased by the presence of my protector, whereas it would be increased by the presence of the Franklin rod. for reasons that I will now explain.

An understanding of but part of the truths relative to electrical discharges, and their misapplication due to the want of fuller appreciation has doubtless been responsible for the Franklin lightning rod taking its conventional pointed form, but theoretical considerations, and the important discoveries that have been made in the course of investigations with a wireless transmitter of great activity by which arcs of a volume and tension comparable to those occurring in nature were obtained ("Problems of Increasing Human Energy" *Century Magazine* June 1900 and Patents 645,576, 649,621, 787,412 and 1,119,732) at once establish the fallacy of the hitherto prevailing notion on which the Franklin type of rod is based, show the distinctive novelty of my lightning protector, and guide the constructor in the use, of my invention.

In Fig. 2, 5 is a small sphere in contact with a large one, 6, partly shown. It can be proved by the theory of electric images that when the two bodies are charged the mean density on the small one will be only

$$\frac{\pi^2}{6} = 1.64493$$

times greater than that on the other. (See "*Electricity and Magnetism*" by Clerk Maxwell). In Fig. 3. the two spheres 7 and 8 are placed some distance apart and connected through a thin wire 9. This system having been excited as before, the density on the small sphere is likely to be many times that on the large one. Since both are at the same potential it follows directly that the densities on them will be inversely as their radii of curvature. If the density of 7 be designated as d and the radius r, then the charge $q = 4\pi r^2 d$, the potential $p = 4\pi rd$ and the outward force, normal to the surface, $f = 2\pi d^2$. As before stated, when d surpasses 20 C. G. S. units, the force f becomes sufficiently intense to break down the dielectric and a streamer or corona appears. In this case $p = 80\pi r$. Hence, with a sphere of one centimeter radius disruption would take place at a potential $p = 80\pi = 251.328$ E. S. units, or 75,398.4 volts. In reality, the discharge occurs at a lower pressure as a consequence of uneven distribution on the small sphere, the density being greatest on the, side turned away from the large one. In this respect the behavior of a pointed conductor is just the reverse. Theoretically, it might erroneously be inferred from the preceding, that sharp projections would permit electricity to escape at the lowest potentials, but this does not follow. The reason will be clear from an inspection of Fig.

4, in which such a needle-shaped conductor 10, is illustrated, a minute portion of its tapering end being marked 11. Were this portion removed from the large part 10 and electrically connected with the same through an infinitely thin wire, the charge would be given off readily. But the presence of 10 has the effect of reducing the capacity of 11, so that a much higher pressure is required to raise the density to the critical value. The larger the body, the more pronounced is this influence, which is also dependent on configuration, and is maximum for a sphere. When the, same is of considerable size it takes a much greater electromotive force than under ordinary circumstances to produce streamers from the point. To explain this apparent anomaly attention is called to Fig. 3. If the radii of the two spheres, 7 and 8, be designated *r* and R respectively, their charges *q* and *Q* and the distance between their centers D. the potential at 7, due to Q is $\frac{Q}{D}$ But. 7, owing to the metallic connection 9, is at the potential

$$\frac{Q}{R} = \frac{\ }{r}.$$

When D is comparable to R, the medium surrounding the small sphere will ordinarily be at a potential not much different from that of the latter and millions of volts may have to be applied before streamers issue, even from sharp protruding edges. It is important to bear this in mind, for the earth is but a vast conducting globe. It follows that a pointed lightning-rod must be run far above ground in order to operate at all, and from the foregoing it will be apparent that the pointing of the end, for supposed emissive effect, is in part neutralized by the increasing size below the extreme end, and the larger the rod. for reduction of electrode resistance, the more pronounced is this counter-influence. For these reasons it is important to bear in mind that sufficient thickness of the rod for very low electrode-resistance is rather incompatible with the high emissive capability sought in the needle-like Franklin-rod, but, as hereinafter set forth, it is wholly desirable in the use of my invention, wherein the terminal construction is intended for suppression of charge-emission rather than to foster it.

The notion that Franklin's device would be effective in dissipating terrestrial charges may be traced to early experiments with static frictional machines, when a needle was found capable of quickly draining an insulated electrified body. But the inapplicability of this fact to the conditions of lightning protection will be evident from examination of the simple theoretical principles involved, which at the same time substantiate the desirability of establishing protection by avoiding such drainage. The density at the pointed end *f* should be inversely as the radius of curvature of the surface, but such a condition is unrealizable. Suppose Fig. 4 to represent a conductor of radius 100 times that of the needle; then, although its surface per unit length is greater in the same radius, the capacity is only double. Thus, while twice the quantity of electricity is stored, the density on the rod is but one-fiftieth of that on the needle, from which it follows that the latter is far more efficient. But the emissive power of any such conductor is circumscribed. Imagine that the "pointed" (in reality blunt or rounded) end be continuously reduced in size so as to approximate the ideal more and more. During the process of reduction, the density will be increasing as the radius of curvature gets smaller, but in a proportion distinctly less than linear; on the other hand, the area of the extreme end. that is, the section through which the charge passes out into the air, will be diminishing as the square of the radius. This relation alone imposes a definite limit to the performance of a pointed conductor, and it should be noticed that the electrode resistance would be augmented at the same time. Furthermore, the efficacy of the rod is much impaired through potential due to the charge of the ground, as has been indicated with reference to Fig. 3. Practical estimates of the electrical quantities concerned in natural disturbances show, moreover, how absolutely impossible are the functions attributed to the pointed lightning conductor. A single cloud may contain 2×10^{12} G. S. units, or more, inducing in the earth an equivalent amount, which a number of lightning rods could not neutralize in many years. Particularly to instance conditions that may have to be met, reference is made to the *Electrical World* of March 5, 1904, wherein it appears that upon one occasion approximately 12,000 strokes occurred within two hours within a radius of less than 50 kilometers from the place of observation.

But although the pointed lightning rod is quite ineffective in the one respect noted, it has the property of attracting lightning to a high degree, firstly on account of its shape and secondly because it ionizes and renders conductive the surrounding air. This has been unquestionably established in long continued tests with the wireless transmitter above-mentioned, and in this feature lies the chief disadvantage of the Franklin type of apparatus.

All of the foregoing serves to show that since it is utterly impracticable to effect an equalization of charges emissively through pointed lightning-rods under the conditions presented by the vast forces of nature, great improvement lies in the attainment of a minimized probability of lightning stroke to the area to be protected coupled with adequate conductivity to render harmless those strokes that may, notwithstanding, occur.

Furthermore, a correct application of the truths that have thus been explained with reference to the familiar pointed type of lightning-rod not, only substantiates the theoretical propriety of the form in which I develop my improved lightning protector, but will lead the installing engineer properly to take cognizance of those conditions due to location of the building, with respect to surrounding earth formations and other buildings, probabilities of maximum potential-differences and charge-densities to be expected under the prevailing atmospheric conditions of the site, and desirable electrode resistance and capacities of the protectors installed.

The improved protector, as above stated, behaves in a manner just opposite to the Franklin type and is incomparably safer for this reason. The result is secured by the use of a terminal or conducting surface of large radius of curvature and sufficient area to make the density very small and thereby prevent the leakage of the charge and the ionization of the air. The device may be greatly varied in size and shape but it is essential that all its outer conducting elements should be disposed along an ideal enveloping surface of large radius and that they should have a considerable total area.

In Fig. 5, Fig. 6, Fig. 7 and Fig. 8, different kinds of such terminals and arrangements of same are illustrated. In Fig. 5, 12 is a cast or spun metal shell of ellipsoidal outlines, having on its under side a sleeve with a bushing 13 of porcelain or other insulating material, adapted to be slipped tightly on a rod 14, which may be an ordinary lightning conductor. Fig. 6 shows a terminal 15 made up of rounded or flat metal bars radiating from a central hub, which is supported directly on a similar rod und in electrical contact with the same. The special object of this type is to reduce the wind resistance, but it is essential that the bars have a sufficient area to insure small density, and also that they are close enough to make the aggregate capacity nearly equal to that of a continuous shell of the same outside dimensions. In Fig. 7 a cupola-shaped and earthed roof is carried by a chimney, serving in this way the twofold practical purpose of hood and protector. Any kind of metal may be used in its construction but it is indispensable that its outer surface should be free of sharp edges and projections from which streamers might emanate. In like manner mufflers, funnels and vents may be transformed into effective lightning protectors if equipped with suitable devices or designed in conformity with this invention. Still another modification is illustrated in Fig. 8 in which, instead of one, four grounded bars are provided with as many spun shells or attachments 18, with the obvious object of reducing the risk.

From the foregoing it will be clear that in all cases the terminal prevents leakage of electricity and attendant ionization of the air. It is immaterial to this end whether it is insulated or not. Should it be struck the current will pass readily to the ground either directly or, as in Fig. 5, through a small air-gap between 12 and 14. But such an accident is rendered extremely improbable owing to the fact that there are everywhere points and projections on which the terrestrial charge attains a high density and where the air is ionized. Thus the action of the improved protector is equivalent to a repellent force. This being so, it is not necessary to support it at a great height, but the ground connection should be made with the usual care and the conductor leading to it must be of as small a self-induction and resistance as practicable.

I claim as my invention:

1. A lightning protector consisting of an elevated terminal, having its outer conducting boundaries arranged on surfaces of large radii of curvature in both dimensions, and a grounded conductor of small self-induction, as set forth.

2. A lightning protector composed of a metallic shell of large radius of curvature, and a grounded conductor of small self-induction, as described.

3. Apparatus for protection against atmospheric discharges comprising an earth connection of small resistance, a conductor of small self-induction and a terminal carried by the same and having a large radius of curvature in two dimensions as, and for the purpose set forth.

4. In apparatus for protection against atmospheric discharges an insulated metallic shell of large radius of curvature supported by a grounded conductor and separated from the same through a small air-gap as, and for the purpose described.

5. A lightning protector comprising, in combination, an elevated terminal of large area and radius of curvature in two dimensions, and a grounded conductor of small self-induction, as set forth.

6. An apparatus for protection against lightning discharges, the combination of an elevated metallic roof of large area and radius of curvature in two dimensions, and a grounded conductor of small self-induction and resistance, as described.

7. As an article of manufacture a metallic shell of large radius of curvature provided with a sleeve adapted for attachment

to a lightning rod as, and for the purpose set forth.

8 A lightning protector comprising an ellipsoidal metallic shell and a grounded conductor of small self-induction, as set forth.

9. In apparatus for protection against atmospheric discharges a cupola shaped metallic terminal of smooth outer surface, in combination with a grounded conductor of small self-induction and resistance, as described.

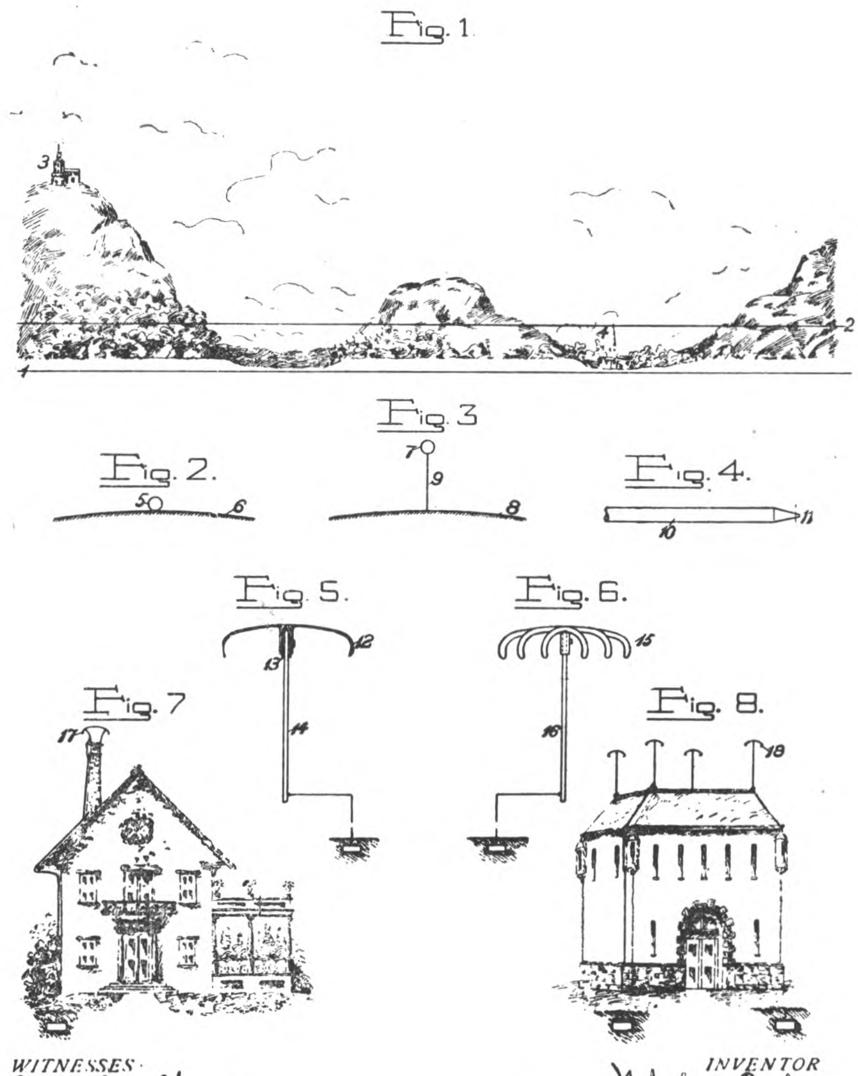
In testimony whereof I affix my signature.

NIKOLA TESLA.

P-456

N. TESLA.
LIGHTNING PROTECTOR.
APPLICATION FILED MAY 6, 1916.

1,266,175. Patented May 14, 1918.



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ARTICLES

I
SCIENTIFIC AND TECHNICAL ARTICLES

1

PHENOMENA OF ALTERNATING CURRENTS OF VERY HIGH FREQUENCY*

Electrical journals are getting to be more and more interesting. New facts are observed and new problems spring up daily which command the attention of engineers. In the last few numbers of the English journals, principally in the Electrician there have been several new matters brought up which have attracted more than usual attention. The address of Professor Crookes has revived the interest in his beautiful and skilfully performed experiments, the effect observed on the Ferranti mains has elicited the expressions of opinion of some of the leading English electricians, and Mr. Swinburne has brought out some interesting points in connection with condensers and dynamo excitation.

The writer's own experiences have induced him to venture a few remarks in regard to these and other matters, hoping that they will afford some useful information or suggestion to the reader.

Among his many experiments Professor Crookes shows some performed with tubes devoid of internal electrodes, and from his remarks it must be inferred that the results obtained with these tubes are rather unusual. If this be so, then the writer must regret that Professor Crookes, whose admirable work has been the delight of every investigator, should not have availed himself in his experiments of a properly constructed alternate current machine — namely, one capable of giving, say 10,000 to 20,000 alternations per second. His researches on this difficult but fascinating subject would then have been even more complete. It is true that when using such a machine in connection with an induction coil the distinctive character of the electrodes — which is desirable, if not essential, in many experiments — is lost, in most cases both the electrodes behaving alike; but on the other hand, the advantage is gained that the effects may be exalted at will. When using a rotating switch or commutator the rate of change obtainable in the primary current is limited. When the commutator is more rapidly revolved the primary current diminishes, and if the current be increased, the sparking, which cannot be completely overcome by the condenser, impairs considerably the virtue of the apparatus. No such limitations exist when using an alternate current machine as any desired rate of change may be produced in the primary current. It is thus, possible to obtain excessively high electromotive forces in the secondary circuit with a comparatively small primary current; moreover, the perfect regularity in the working of the apparatus may be relied upon.

The writer will incidentally mention that any one who attempts for the first time to construct such a machine will have a tale of woe to tell. He will first start out, as a matter of course, by making an armature with the required number of polar projections. He will then get the satisfaction of having produced an apparatus which is fit to accompany a thoroughly Wagnerian opera. It may besides possess the virtue of converting mechanical energy into heat in a nearly perfect manner. If there is a reversal in the polarity

* The Electrical World, Febr. 21, 1891

of the projections, he will get heat out of the machine; if there is no reversal, the heating will be less, but the output will be next to nothing. He will then abandon the iron in the armature, and he will get from the Scylla to the Charybdis. He will look for one difficulty and will find another, but, after a few trials, he may get nearly what he wanted.

Among the many experiments which may be performed with such a machine, of not the least interest are those performed with a high-tension induction coil. The character of the discharge is completely changed. The arc is established at much greater distances, and it is so easily affected by the slightest current of air that it often wriggles around in the most singular manner. It usually emits the rhythmical sound peculiar to the alternate current arcs, but the curious point is that the sound may be heard with a number of alternations far above ten thousand per second, which by many is considered to be about the limit of audition. In many respects the coil behaves like a static machine. Points impair considerably the sparking interval, electricity escaping from them freely, and from a wire attached to one of the terminals streams of light issue, as though it were connected to a pole of a powerful Toepler machine. All these phenomena are, of course, mostly due to the enormous differences of potential obtained. As a consequence of the self-induction of the coil and the high frequency, the current is minute while there is a corresponding rise of pressure. A current impulse of some strength started in such a coil should persist to flow no less than four ten-thousandths of a second. As this time is greater than half the period, it occurs that an opposing electromotive force begins to act while the current is still flowing. As a consequence, the pressure rises as in a tube filled with liquid and vibrated rapidly around its axis. The current is so small that, in the opinion and involuntary experience of the writer, the discharge of even a very large coil cannot produce seriously injurious effects, whereas, if the same coil were operated with a current of lower frequency, though the electromotive force would be much smaller, the discharge would be most certainly injurious. This result, however, is due in part to the high frequency. The writer's experiences tend to show that the higher the frequency the greater the amount of electrical energy which may be passed through the body without serious discomfort; whence it seems certain that human tissues act as condensers.

One is not quite prepared for the behavior of the coil when connected to a Leyden jar. One, of course, anticipates that since the frequency is high the capacity of the jar should be small. He therefore takes a very small jar, about the size of a small wine glass, but he finds that even with this jar the coil is practically short-circuited. He then reduces the capacity until he comes to about the capacity of two spheres, say, ten centimetres in diameter and two to four centimetres apart. The discharge then assumes the form of a serrated band exactly like a succession of sparks viewed in a rapidly revolving mirror; the serrations, of course, corresponding to the condenser discharges. In this case one may observe a queer phenomenon. The discharge starts at the nearest points, works gradually up, breaks somewhere near the top of the spheres, begins again at the bottom, and so on. This goes on so fast that several serrated bands are seen at once. One may be puzzled for a few minutes, but the explanation is simple enough. The discharge begins at the nearest points, the air is heated and carries the arc upward until it breaks, when it is re-established at the nearest points, etc. Since the current passes easily through a condenser of even small capacity, it will be found quite natural that connecting only one terminal to a body of the same size, no matter how well insulated, impairs considerably the striking distance of the arc.

Experiments with Geissler tubes are of special interest. An exhausted tube, devoid of electrodes of any kind, will light up at some distance from the coil. If a tube from a vacuum pump is near the coil the whole of the pump is brilliantly lighted. An incandescent lamp approached to the coil lights up and gets perceptibly hot. If a lamp have the terminals connected to one of the binding posts of the coil and the hand is approached to the bulb, a very curious and rather unpleasant discharge from the glass to the hand takes place, and the filament may become incandescent. The discharge resembles to some extent the stream issuing from the plates of a powerful Toepler machine, but is of incomparably greater quantity. The lamp in this case acts as a condenser, the rarefied gas being one coating, the operator's hand the other. By taking the globe of a lamp in the hand, and by bringing the metallic terminals near to or in contact with a conductor connected to the coil, the carbon is brought to bright incandescence and the glass is rapidly heated. With a 100-volt 10 c.p. lamp one may without great discomfort stand as much current as will bring the lamp to a considerable brilliancy; but it can be held in the hand only for a few minutes, as the glass is heated in an incredibly short time. When a tube is lighted by bringing it near to the coil it may be made to go out by interposing a metal plate on the hand between the coil and tube; but if the metal plate be fastened to a glass rod or otherwise insulated, the tube may remain lighted if the plate be interposed, or may even increase in luminosity. The effect depends on the position of the plate and tube relatively to the coil, and may be always easily foretold by *assuming* that conduction takes place from one terminal of the coil to the other. According to the position of the plate, it may either divert from or direct the current to the tube.

In another line of work the writer has in frequent experiments maintained incandescent lamps of 50 or 100 volts burning at any desired candle power with both the terminals of each lamp connected to a stout copper wire of no more than a few feet in length. These experiments seem interesting enough, but they are not more so than the queer experiment of Faraday, which has been revived and made much of by recent investigators, and in which a discharge is made to jump between two points of a bent copper wire. An experiment may be cited here which may seem equally interesting. If a Geissler tube, the terminals of which are joined by a copper wire, be approached to the coil, certainly no one would be prepared to see the tube light up. Curiously enough, it does light up, and, what is more, the wire does not seem to make much difference. Now one is apt to think in the first moment that the impedance of the wire might have something to do with the phenomenon. But this is of course immediately rejected, as for this an enormous frequency would be required. This result, however, seems puzzling only at first; for upon reflection it is quite clear that the wire can make but little difference. It may be explained in more than one way, but it agrees perhaps best with observation to assume that conduction takes place from the terminals of the coil through the space. On this assumption, if the tube with the wire be held in any position, the wire can divert little more than the current which passes through the space occupied by the wire and the metallic terminals of the tube; through the adjacent space the current passes practically undisturbed. For this reason, if the tube be held in any position at right angles to the line joining the binding posts of the coil, the wire makes hardly any difference, but in a position more or less parallel with that line it impairs to a certain extent the brilliancy of the tube and its facility to light up. Numerous other phenomena may be explained on the same assumption. For instance, if the ends of the tube be provided with washers of sufficient size and held in the line joining the terminals of the coil, it will not light up, and then nearly the whole of the current, which would otherwise pass uniformly through the space between the washers, is diverted through the wire. But if the tube be inclined sufficiently to that line, it will light up in spite of the washers. Also, if a metal plate be fastened upon a glass rod and held at right angles to the line joining the binding posts, and nearer to one of them, a tube held more or less parallel with the line will light up instantly when one of the terminals touches the plate, and will go out when separated from the plate. The greater the surface of the plate, up to a certain limit, the easier the tube will light up. When a tube is placed at right angles to the straight line joining the binding posts, and then rotated, its luminosity steadily increases until it is parallel with that line. The writer must state, however, that he does not favor the idea of a leakage or current through the space any more than as a suitable explanation, for he is convinced that all these experiments could not be performed with a static machine yielding a constant difference of potential, and that condenser action is largely concerned in these phenomena.

It is well to take certain precautions when operating a Ruhmkorff coil with very rapidly alternating currents. The primary current should not be turned on too long, else the core may get so hot as to melt the guta-percha or paraffin, or otherwise injure the insulation, and this may occur in a surprisingly short time, considering the current's strength. The primary current being turned on, the fine wire terminals may be joined without great risk, the impedance being so great that it is difficult to force enough current through the fine wire so as to injure it, and in fact the coil may be on the whole much safer when the terminals of the fine wire are connected than when they art insulated; but special care should be taken when the terminals are connected to the coatings of a Leyden jar, for with anywhere near the critical capacity, which just counteracts the self-induction at the existing frequency, the coil might meet the fate of St. Polycarpus. If an expensive vacuum pump is lighted up by being near to the coil or touched with a wire connected to one of the terminals, the current should be left on no more than a few moments, else the glass will be cracked by the heating of the rarefied gas in one of the narrow passages — in the writer's own experience *quod erat demonstrandum.*[1]

There are a good many other points of interest which may be observed in connection with such a machine. Experiments with the telephone, a conductor in a strong field or with a condenser or arc, seem to afford certain proof that sounds far above the usual accepted limit of hearing would be perceived. A telephone will emit notes of twelve to thirteen thousand vibrations per second; then the inability of the core to follow such rapid alternations begins to tell. If, however, the magnet and core be replaced by a condenser and the terminals connected to the high-tension secondary of a transformer, higher notes may still be heard. If the current be sent around a finely laminated core and a small piece of thin sheet iron be held gently against the core, a sound may be still heard with thirteen to fourteen thousand alternations per second, provided the current is sufficiently strong. A small coil, however, tightly packed between the poles of a powerful magnet, will emit a sound with the above number of alternations, and arcs may be audible with a still higher frequency. The limit of audition is variously estimated. In Sir. William Thomson's writings it is stated somewhere that ten thousand per second, or nearly so, is the limit. Other, but less reliable, sources give it as high as twenty-four thousand per second. The above experiments have convinced the writer that notes of an incomparably higher number of vibrations per second would be perceived provided they could be produced with sufficient power. There is no reason why it should not be so. The condensations and rarefactions of the air would necessarily set the diaphragm in a corresponding vibration and some sensation would be produced, whatever — within certain limits — the velocity of transmission to their nerve centres, though it is probable that for want of exercise the ear would not be able to distinguish any such high note. With the eye it is different; if the sense of vision is based upon some resonance effect, as many believe, no amount of increase in the intensity of the ethereal vibration could extend our range of vision on either side of the visible spectrum.

[1]) It is thought necessary to remark that, although the induction coil may give quite a good result when operated with such rapidly alternating currents, yet its construction, quite irrespective of the iron core, makes it very unfit for such high frequencies, and to obtain the best results the construction should be greatly modified.

The limit of audition of an arc depends on its size. The greater the surface by a given heating effect in the arc, the higher the limit of audition. The highest notes are emitted by the high-tension discharges of an induction coil in which the arc is, so to speak, all surface. If R be the resistance of an arc, and C the current, and the linear dimensions be n times increased, then the resistance is $\frac{R}{n}$, and with the same current density the current would be n^2C; hence the heating effect is n^3 times greater, while the surface is only n^2 times as great. For this reason very large arcs would not emit any rhythmical sound even with a very low frequency. It must be observed, however, that the sound emitted depends to some extent also on the composition of the carbon. If the carbon contain highly refractory material, this, when heated, tends to maintain the temperature of the arc uniform and the sound is lessened; for this reason it would seem that an alternating arc requires such carbons.

With currents of such high frequencies it is possible to obtain noiseless arcs, but the regulation of the lamp is rendered extremely difficult on account of the excessively small attractions or repulsions between conductors conveying these currents.

An interesting feature of the arc produced by these rapidly alternating currents is its persistency. There are two causes for it, one of which is always present, the other sometimes only. One is due to the character of the current and the other to a property of the machine. The first cause is the more important one, and is due directly to the rapidity of the alternations. When an arc is formed by a periodically undulating current, there is a corresponding undulation in the temperature of the gaseous column, and, therefore, a corresponding undulation in the resistance of the arc. But the resistance of the arc varies enormously with the temperature of the gaseous column, being practically infinite when the gas between the electrodes is cold. The persistence of the arc, therefore, depends on the inability of the column to cool. It is for this reason impossible to maintain an arc with the current alternating only a few times a second. On the other hand, with a practically continuous current, the arc is easily maintained, the column being constantly kept at a high temperature and low resistance. The higher the frequency the smaller the time interval during which the arc may cool and increase considerably in resistance. With a frequency of 10,000 per second or more in an arc of equal size excessively small variations of temperature are superimposed upon a steady temperature, like ripples on the surface of a deep sea. The heating effect is practically continuous and the arc behaves like one produced by a continuous current, with the exception, however, that it may not be quite as easily started, and that the electrodes are equally consumed; though the writer has observed some irregularities in this respect.

The second cause alluded to, which possibly may not be present, is due to the tendency of a machine of such high frequency to maintain a practically constant current. When the arc is lengthened, the electromotive force rises in proportion and the arc appears to be more persistent.

Such a machine is eminently adapted to maintain a constant current, but it is very unfit for a constant potential. As a matter of fact, in certain types of such machines a nearly constant current is an almost unavoidable result. As the number of poles or polar projections is greatly increased, the clearance becomes of great importance. One has really to do with a great number of very small machines. Then there is the impedance in the armature, enormously augmented by the high frequency. Then, again, the magnetic leakage is facilitated. If there are three or four hundred alternate poles, the leakage is so great that it is virtually the same as connecting, in a two-pole machine, the poles by a piece of iron. This disadvantage, it is true, may be obviated more or less by using a field throughout of the same polarity, but then one encounters difficulties of a different nature. All these things tend to maintain a constant current in the armature circuit.

In this connection it is interesting to notice that even to-day engineers are astonished at the performance of a constant current machine, just as, some years ago, they used to consider it an extraordinary performance if a machine was capable of maintaining a constant potential difference between the terminals. Yet one result is just as easily secured as the other. It must only be remembered that in an inductive apparatus of any kind, if constant potential is required, the inductive relation between the primary or exciting and secondary or armature circuit must be the closest possible; whereas, in an apparatus for constant current just the opposite is required. Furthermore, the opposition to the current's flow in the induced circuit must be as small as possible in the former and as great as possible in the latter case. But opposition to a current's flow may be caused in more than one way. It may be caused by ohmic resistance of self-induction. One may make the induced circuit of a dynamo machine or transformer of such high resistance that when operating devices of considerably smaller resistance within very wide limits a nearly constant current is maintained. But such high resistance involves a great loss in power, hence it is not practicable. Not so self-induction. Self-induction does not necessarily mean loss of power. The moral is, use self-induction instead of resistance. There is, however, a circumstance which favors the adoption of this plan, and this is, that a very high self-induction may be obtained cheaply by surrounding a comparatively small length of wire more or less completely with iron, and, furthermore, the effect may be exalted at will by causing a rapid undulation of the current. To sum up, the requirements for constant current are: Weak magnetic connection between the induced and inducing circuits, greatest possible self-induction with the least resistance, greatest practicable rate of change of the current. Constant potential, on the other hand, requires: Closest magnetic connection between the circuits, steady induced current, and, if possible, no reaction. If the latter conditions could be fully satisfied in a constant potential machine, its output would surpass many times that of a machine primarily designed to give constant current. Unfortunately, the type of machine in which these conditions may be satisfied is of little practical value, owing to the small electromotive force obtainable and the difficulties in taking off the current.

With their keen inventor's instinct, the now successful arc-light men have early recognized the desiderata of a constant current machine. Their arc light machines have weak fields, large armatures, with a great length of copper wire and few commutator segments to produce great variations in the current's strength and to bring self-induction into play. Such machines may maintain within considerable limits of variation in the resistance of the circuit a practically constant current. Their output is of course correspondingly diminished, and, perhaps with the object in view not to cut down the output too much, a simple device compensating exceptional variations is employed. The undulation of the current is almost essential to the commercial success of an arc-light system. It introduces in the circuit a steadying element taking the place of a large ohmic resistance, without involving a great loss in power, and, what is more important, it allows the use of simple clutch lamps, which with a current of a certain number of impulses per second, best suitable for each particular lamp, will, if properly attended to, regulate even better than the finest clock-work lamps. This discovery has been made by the writer — several years too late.

It has been asserted by competent English electricians that in a constant-current machine or transformer the regulation is effected by varying the phase of the secondary current. That this view is erroneous may be easily proved by using, instead of lamps, devices each possessing self-induction and capacity or self-induction and resistance — that is, retarding and accelerating components — in such proportions as to not affect materially the phase of the secondary current. Any number of such devices may be inserted or cut out, still it will be found that the regulation occurs, a constant current being maintained, while the electromotive force is varied with the number of the devices.

The change of phase of the secondary current is simply a result following from the changes in resistance, and, though secondary reaction is always of more or less importance, yet the real cause of the regulation lies in the existence of the conditions above enumerated. It should be stated, however, that in the case of a machine the above remarks are to be restricted to the cases in which the machine is independently excited. If the excitation be effected by commutating the armature current, then the fixed position of the brushes makes any shifting of the neutral line of the utmost importance, and it may not be thought immodest of the writer to mention that, as far as records go, he seems to have been the first who has successfully regulated machines by providing a bridge connection between a point of the external circuit and the commutator by means of a third brush. The armature and field being properly proportioned and the brushes placed in their determined positions, a constant current or constant potential resulted from the shifting of the diameter of commutation by the varying loads.

In connection with machines of such high frequencies, the condenser affords an especially interesting study. It is easy to raise the electromotive force of such a machine to four or five times the value by simply connecting the condenser to the circuit, and the writer has continually used the condenser for the purposes of regulation, as suggested by Blakesley in his book on alternate currents, in which he has treated the most frequently occurring condenser problems with exquisite simplicity and clearness. The high frequency allows the use of small capacities and renders investigation easy. But, although in most of the experiments the result may be foretold, some phenomena observed seem at first curious. One experiment performed three or four months ago with such a machine and a condenser may serve as an illustration. A machine was used giving about 20,000 alternations per second. Two bare wires about twenty feet long and two millimetres in diameter, in close proximity to each other, were connected to the terminals of the machine at the one end, and to a condenser at the other. A small transformer without an iron core, of course, was used to bring the reading within range of a Cardew voltmeter by connecting the voltmeter to the secondary. On the terminals of the condenser the electromotive force was about 120 volts, and from there inch by inch it gradually fell until at the terminals of the machine it was about 65 volts. It was virtually as though the condenser were a generator, and the line and armature circuit simply a resistance connected to it. The writer looked for a case of resonance, but he was unable to augment the effect by varying the capacity very carefully and gradually or by changing the speed of the machine. A case of pure resonance he was unable to obtain. When a condenser was connected to the terminals of the machine — the self-induction of the armature being first determined in the maximum and minimum position and the mean value taken — the capacity which gave the highest electromotive force corresponded most nearly to that which just counteracted the self-induction with the existing frequency. If the capacity was increased or diminished, the electromotive force fell as expected.

With frequencies as high as the above mentioned, the condenser effects are of enormous importance. The condenser becomes a highly efficient apparatus capable of transferring considerable energy.

The writer has thought machines of high frequencies may find use at least in cases when transmission at great distances is not contemplated. The increase of the resistance may be reduced in the conductors and exalted in the devices when heating effects are wanted, transformers may be made of higher efficiency and greater outputs and valuable results may be secured by means of condensers. In using machines of high frequency the writer has been able to observe condenser effects which would have otherwise escaped his notice. He has been very much interested in the phenomenon observed on the Ferranti main which has been so much spoken of. Opinions have been expressed by competent electricians, but up to the present all still seems to be conjecture. Undoubtedly in the views expressed the truth must be contained, but as the opinions differ some must be erroneous. Upon seeing the diagram of M. Ferranti in the Electrician of Dec. 19 the writer has formed his opinion of the effect. In the absence of all the necessary data he must content himself to express in words the process which, in his opinion, must undoubtedly occur. The condenser brings about two effects: (1) It changes the phases of the currents in the branches; (2) it changes the strength of the currents. As regards the change in phase, the effect of the condenser is to accelerate the current in the secondary at Deptford and to retard it in the primary at London. The former has the effect diminishing the self-induction in the Deptford primary, and this means lower electromotive force on the dynamo. The retardation of the primary at London, as far as merely the phase is concerned, has little or no effect since the phase of the current in the secondary in London is not arbitrarily kept.

Now, the second effect of the condenser is to increase the current in both the branches. It is immaterial whether there is equality between the currents or not; but it is necessary to point out, in order to see the importance of the Deptford step-up transformer, that an increase of the current in both the branches produces opposite effects. At Deptford it means further lowering of the electromotive force at the primary, and at London it means increase of the electromotive force at the secondary. Therefore, all the things co-act to bring about the phenomenon observed. Such actions, at least, have been formed to take place under similar conditions. When the dynamo is connected directly to the main, one can see that no such action can happen.

The writer has been particularly interested in the suggestions and views expressed by Mr. Swinburne. Mr. Swinburne has frequently honored him by disagreeing with his views. Three years ago, when the writer, against the prevailing opinion of engineers, advanced an open circuit transformer, Mr. Swinburne was the first to condemn it by stating in the Electrician: “The (Tesla) transformer must be inefficient; it has magnetic poles revolving, and has thus an open magnetic circuit”. Two years later Mr. Swinburne becomes the champion of the open circuit transformer, and offers to convert him. But, tempora mutantur, et nos mutamur in illis.

The writer cannot believe in the armature reaction theory as expressed in Industries, though undoubtedly there is some truth in it. Mr. Swinburne’s interpretation, however, is so broad that it may mean anything.

Mr. Swinburne seems to have been the first who has called attention to the heating of the condensers. The astonishment expressed at that by the ablest electrician is a striking illustration of the desirability to execute experiments on a large scale. To the scientific investigator, who deals with the minutest quantities, who observes the faintest effects, far more credit is due than to one who experiments with apparatus on an industrial scale; and indeed history of science has recorded examples of marvelous skill, patience and keenness of observation. But however great the skill, and however keen the observer’s perception, it can only be of advantage to magnify an effect and thus facilitate its study. Had Faraday carried out but one of his experiments on dynamic induction on a large scale it would have resulted in an incalculable benefit.

In the opinion of the writer, the heating of the condensers is due to three distinct causes: first, leakage or conduction; second, imperfect elasticity in the dielectric, and, third, surging of the charges in the conductor.

In many experiments he has been confronted with the problem of transferring the greatest possible amount of energy across a dielectric. For instance, he has made incandescent lamps the ends of the filaments being completely sealed in glass, but attached to interior condenser coatings so that all the energy required had to be transferred across the glass with a condenser surface of no more than a few centimetres square. Such lamps would be a practical success with sufficiently high frequencies. With alternations as high as 15,000 per second it was easy to bring the filaments to incandescence. With lower frequencies this could also be effected, but the potential difference had, of course, to be increased. The writer has then found that the glass gets, after a while, perforated and the vacuum is impaired. The higher the frequency the longer the lamp can withstand. Such a deterioration of the dielectric always takes place when the amount of energy transferred across a dielectric of definite dimensions and by a given frequency is too great. Glass withstands best, but even glass is deteriorated. In this case the potential difference on the plates is of course too great and losses by conduction and imperfect elasticity result. If it is desirable to produce condensers capable to stand differences of potential, then the only dielectric which will involve no losses is a gas under pressure. The writer has worked with air under enormous pressures, but there are a great many practical difficulties in that direction. He thinks that in order to make the condensers of considerable practical utility, higher frequencies should be used: though such a plan has besides others the great disadvantage that the system would become very unfit for the operation of motors.

If the writer does not err Mr. Swinburne has suggested a way of exciting an alternator by means of a condenser. For a number of years past the writer has carried on experiments with the object in view of producing a practical self-exciting alternator. He has in a variety of ways succeeded in producing some excitation of the magnets by means of alternating currents, which were not commutated by mechanical devices. Nevertheless, his experiments have revealed a fact which stands as solid as the rock of Gibraltar. No practical excitation can be obtained with a single periodically varying and not commutated current. The reason is that the changes in the strength of the exciting current produce corresponding changes in the field strength, with the result of inducing currents in the armature; and these currents interfere with these produced by the motion of the armature through the field, the former being a quarter phase in advance of the latter. If the field be laminated, no excitation can be produced; if it be not laminated, some excitation is produced, but the magnets are heated. By combining two exciting currents — displaced by a quarter phase, excitation may be produced in both cases, and if the magnet be not laminated the heating effect is comparatively small, as a uniformity in the field strength is maintained, and, were it possible to produce a perfectly uniform field, excitation on this plan would give quite practical results. If such results are to be secured by the use of a condenser, as suggested by Mr. Swinburne, it is necessary to combine two circuits separated by a quarter phase; that is to say, the armature coils must be wound in two sets and connected to one or two independent condensers. The writer has done some work in that direction, but must defer the description of the devices for some future time.

2

AN ELECTROLYTIC CLOCK*

If a delicately and pivoted and well-balanced metal disc or cylinder be placed in a proper plating solution midway between the anode and cathode, one half of the disc becomes electro positive and the other half electro negative. Owing to this fact metal is deposited on one, and taken off from the other half, and the disc is caused to rotate under the action of gravity. As the amount of metal deposited and taken off is proportionate to the current strength, the speed of rotation, if it be small, is proportionate to the current.

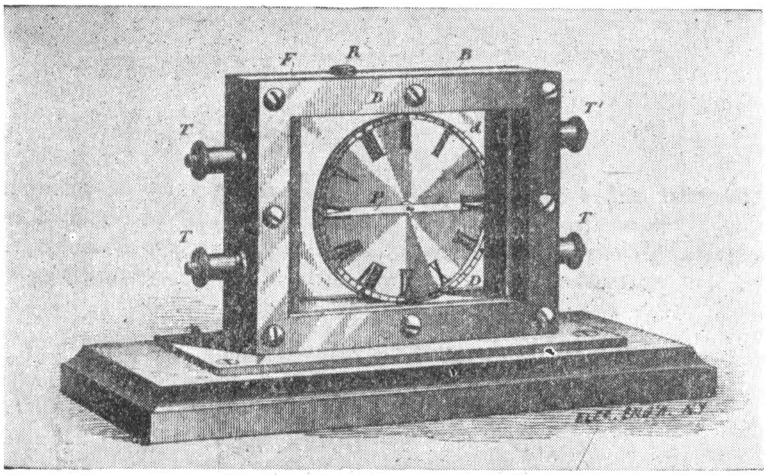
The first device of this kind was operated by me early in 1888, in the endeavor to construct an electric meter. Upon learning, however, that I had been anticipated by others, as far as the principle is concerned, I devised the apparatus illustrated in the accompanying engraving. Here F is a rectangular frame of hard rubber which is fastened upon a wooden base. This frame is about ½ inch thick, 6 inches long and 5 inches high. On both of its upright sides are fastened thick metal plates which serve as the electrodes. These plates are held firmly against the rubber frame by the binding posts T T and T_1 T_1. On the lateral sides of the frame are fastened the brass plates B and B_1, respectively, of the same shape as the rubber frame F. These brass plates serve to keep in place two plates of polished glass, and the vessel is hermetically sealed by placing a soft rubber washer under and above each of the glass plates. In this manner the plates may be screwed on tight without fear of breaking them.

The plating solution, which in this case is a concentrated solution of sulphate of copper, is poured in through an opening on the top of the rubber frame, which is closed by a plug R.

In the centre of the vessel is placed a light and delicately balanced copper disc D, the axis of which is supported by a capillary glass tube which is fixed to one of the glass plates by means of sealing wax, or other material not attacked by the liquid. To diminish the friction as much as possible, the capillary tube which serves as a bearing contains a drop of oil. The centre of disc should be equi-distant from both the electrodes. To one side of the axis of the disc is fastened a very light indicator or pointer consisting preferably of a thin glass thread. The glass plate next to this pointer has a circle with the usual hour divisions engraved upon it, as on a clock dial. This circle may be movable so that it can be put in any position relatively to the pointer. If the dial is not movable then a thin wire of annealed iron may be used as on a pointer. The wire should then be so placed that it is exactly in the centre of the solution. By means of a horse-shoe magnet the disc may then be rotated and set in proper position.

* The Electrical Engineer, May 6, 1891.

The copper solution being carefully poured in, and the plug R replaced, the terminals of a constant current battery are connected to the binding-posts T T_1, and from time to time the rotation of the disc is observed. A shunt is connected to the other two binding-posts T T_1, and by varying the resistance of this shunt, or other disc, the speed of rotation is regulated until it is made to correspond to the division of the dial; that is, until, for instance, one turn is made in 12 hours.



Obviously this instrument was not devised for a practical purpose. Neither will it be quite exact in its indications. There are certain errors, unavoidable from the principle; for instance, the friction, which cannot be completely overcome. But the device is interesting as a means of indicating time in a novel manner. It will, however, be found that by a careful construction, constant current, and a temperature compensator, it may be made to rotate with almost perfect uniformity. The current density should, of course, be very small to secure the best results, and the disc of about 3 inches diameter should turn once in 6 hours. It is probable that with a silver solution and a silver plate better results would be obtained.

It is very interesting to note the appearance of the solution and disc in such a narrow transparent vessel. The solution appears a clear blue, one side of the disc seems to be silver white in a certain position, and the other half is dark like tarnished silver. There is no line of demarcation, but the shades melt beautifully together.

3

ALTERNATE CURRENT ELECTROSTATIC INDUCTION APPARATUS*

About a year and a half ago while engaged in the study of alternate currents of short period, it occurred to me that such currents could be obtained by rotating charged surfaces in close proximity to conductors. Accordingly I devised various forms of experimental apparatus of which two are illustrated in the accompanying engravings.

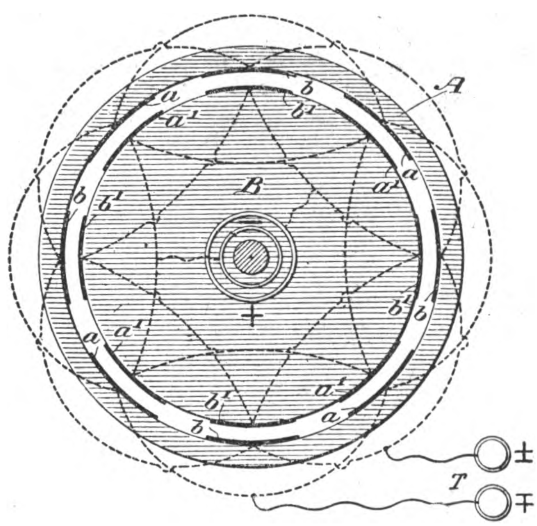


Fig. 1.

In the apparatus shown in Fig. 1, A is a ring of dry shellacked hard wood provided on its inside with two sets of tin-foil coatings, a and *b,* all the *a* coatings and all the *b* coatings being connected together, respectively, but independent from each other. These two sets of coatings are connected to two terminals, T. For the sake of clearness only a few coatings are shown. Inside of the ring A, and in close proximity to it there is arranged to rotate a cylinder B, likewise of dry, shellacked hard wood, and provided with two similar sets of coatings, a^1 and b^1, all the coatings a^1 being connected to one ring and all the others, b^1, to another marked + and –. These two sets, a^1 and b^1 are charged to a high potential by a Holtz or Wimshurst machine, and may be connected to a jar of some capacity. The inside of ring A is coated with mica in order to increase the induction and also to allow higher potentials to be used.

* The Electrical Engineer, N.Y., May 6, 1891

When the cylinder B with the charged coatings is rotated, a circuit connected to the terminals T is traversed by alternating currents. Another form of apparatus is illustrated in Fig. 2. In this apparatus the two sets of tin-foil coatings are glued on a plate of ebonite, and a similar plate which is rotated, and the coatings of which are charged as in Fig. 1, is provided.

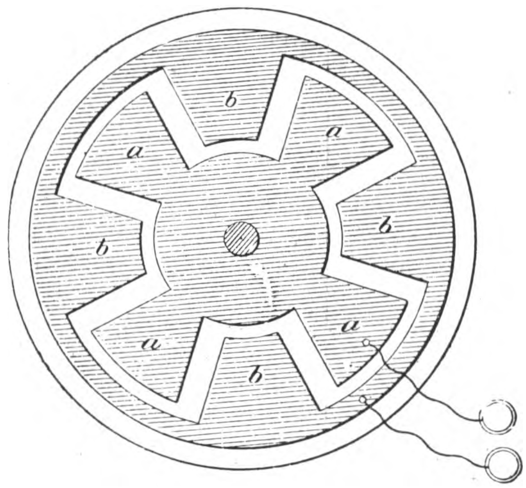


Fig. 2.

The output of such an apparatus is very small, but some of the effects peculiar to alternating currents of short periods may be observed. The effects, however, cannot be compared with those obtainable with an induction coil which is operated by an alternate current machine of high frequency, some of which were described by me a short while ago.

4

ELECTRIC DISCHARGE IN VACUUM TUBES*

In *The Electrical Engineer* of June 10 I have noted the description of some experiments of Prof. J. J. Thomson, on the "Electric Discharge in Vacuum Tubes," and in your issue of June 24 Prof. Elihu Thomson describes an experiment of the same kind. The fundamental idea in these experiments is to set up an electromotive force in a vacuum tube — preferably devoid of any electrodes — by means of electromagnetic induction, and to excite the tube in this manner.

As I view the subject I should think that to any experimenter who had carefully studied the problem confronting us and who attempted to find a solution of it, this idea must present itself as naturally as, for instance, the idea of replacing the tinfoil coatings of a Leyden jar by rarefied gas and exciting luminosity in the condenser thus obtained by repeatedly charging and discharging it. The idea being obvious, whatever merit there is in this line of investigation must depend upon the completeness of the study of the subject and the correctness of the observations. The following lines are not penned with any desire on my part to put myself on record as one who has performed similar experiments, but with a desire to assist other experimenters by pointing out certain peculiarities of the phenomena observed, which, to all appearances, have not been noted by Prof. J. J. Thomson, who, however, seems to have gone about systematically in his investigations, and who has been the first to make his results known. These peculiarities noted by me would seem to be at variance with the views of Prof. J. J. Thomson, and present the phenomena in a different light.

My investigations in this line occupied me principally during the winter and spring of the past year. During this time many different experiments were performed, and in my exchanges of ideas on this subject with Mr. Alfred S. Brown, of the Western Union Telegraph Company, various different dispositions were suggested which were carried out by me in practice. Fig. 1 may serve as an example of one of the many forms of apparatus used. This consisted of a large glass tube sealed at one end and projecting into an ordinary incandescent lamp bulb. The primary, usually consisting of a few turns of thick, well-insulated copper sheet was inserted within the tube, the inside space of the bulb furnishing the secondary. This form of apparatus was arrived at after some experimenting, and was used principally with the view of enabling me to place a polished reflecting surface on the inside of the tube, and for this purpose the last turn of the primary was covered with a thin silver sheet. In all forms of apparatus used there was no special difficulty in exciting a luminous circle or cylinder in proximity to the primary.

As to the number of turns, I cannot quite understand why Prof. J. J. Thomson should think that a few turns were "quite sufficient", but lest I should impute to him an opinion he may not have, I will add that I have gained this impression from the

* The Electrical Engineer. N.Y., July 1, 1891

reading of the published abstracts of his lecture. Clearly, the number of turns which gives the best result in any case, is dependent on the dimensions of the apparatus, and, were it not for various considerations, one turn would always give the best result.

I have found that it is preferable to use in these experiments an alternate current machine giving a moderate number of alternations per second to excite the induction coil for charging the Leyden jar which discharges through the primary — shown diagrammatically in Fig. 2, — as in such case, before the disruptive discharge takes place, the tube or bulb is slightly excited and the formation of the luminous circle is decidedly facilitated. But I have also used a Wimshurst machine in some experiments.

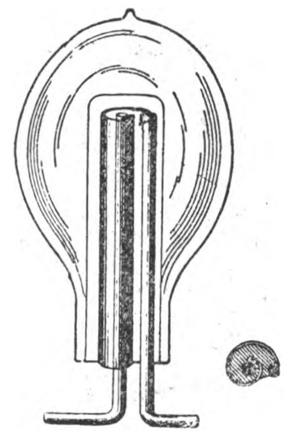


Fig. 1.

Prof. J. J. Thomson's view of the phenomena under consideration seems to be that they are wholly due to electro-magnetic action. I was, at one time, of the same opinion, but upon carefully investigating the subject I was led to the conviction that they are more of an electrostatic nature. It must be remembered that in these experiments we have to deal with primary currents of an enormous frequency or rate of change and of high potential, and that the secondary conductor consists of a rarefied gas, and that under such conditions electrostatic effects must play an important part.

In support of my view I will describe a few experiments made by me. To excite luminosity in the tube it is not absolutely necessary that the conductor should be closed. For instance, if an ordinary exhausted tube (preferably of large diameter) be surrounded by a spiral of thick copper wire serving as the primary, a feebly luminous spiral may be induced in the tube, roughly shown in Fig. 3. In one of these experiments a curious phenomenon was observed; namely, two intensely luminous circles, each of them close to a turn of the primary spiral, were formed inside of the tube, and I attributed this phenomenon to the existence of nodes on the primary. The circles were connected by a faint luminous spiral parallel to the primary and in close proximity to it. To produce this effect I have found it necessary to strain the jar to the utmost. The turns of the spiral tend to close and form circles, but this, of course, would be expected, and does not necessarily indicate an electro-magnetic effect; whereas the fact that a glow can be produced along the primary in the form of an open spiral argues for an electrostatic effect.

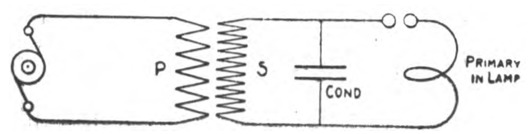


Fig. 2.

In using Dr. Lodges recoil circuit, the electrostatic action is likewise apparent. The arrangement is illustrated in Fig. 4. In his experiments two hollow exhausted tubes H H were slipped over the wires of the recoil circuit and upon discharging the jar in the usual manner luminosity was excited in the tubes.

Another experiment performed is illustrated in Fig. 5. In this case an ordinary lamp-bulb was surrounded by one or two turns of thick copper wire P and the luminous circle L excited in the bulb by discharging the jar through the primary. The lamp-bulb was provided with a tinfoil coating on the side opposite to the primary and each time the tinfoil coating was connected to the ground or to a large object the luminosity of the circle was considerably increased. This was evidently due to electrostatic action.

In other experiments I have noted that when the primary touches the glass the luminous circle is easier produced and is more sharply defined; but I have not noted that, generally speaking, the circles induced were very sharply defined, as Prof. J. J. Thomson has observed; on the contrary, in my experiments they were broad and often the whole of the bulb or tube was illuminated; and in one case I have observed an intensely purplish glow, to which Prof. J. J. Thomson refers. But the circles were always in close proximity to the primary and were considerably easier produced when the latter was very close to the glass, much more so than would be expected assuming the action to be electromagnetic and considering the distance; and these facts speak for an electrostatic effect.

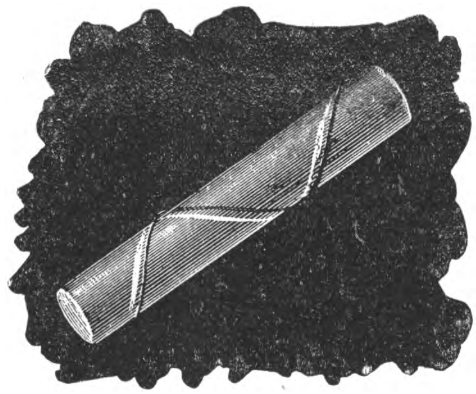


Fig. 3.

Furthermore I have observed that there is a molecular bombardment in the plane of the luminous circle at right angles to the glass — supposing the circle to be in the plane of the primary — this bombardment being evident from the rapid heating of the glass near the primary. Were the bombardment not at right angles to the glass the heating could not be so rapid. If there is a circumferential movement of the molecules constituting the luminous circle, I have thought that it might be rendered manifest by placing within the tube or bulb, radially to the circle, a thin plate of mica coated with some phosphorescent material and another such plate tangentially to the circle. If the molecules would move circumferentially, the former plate would be rendered more intensely phosphorescent. For want of time I have, however, not been able to perform the experiment.

Another observation made by me was that when the specific inductive capacity of the medium between the primary and secondary is increased, the inductive effect is augmented. This is roughly illustrated in Fig. 6. In this case luminosity was excited in an exhausted tube or bulb B and a glass tube T slipped between the primary and the bulb, when the effect pointed out was noted. Were the action wholly electromagnetic no change could possibly have been observed.

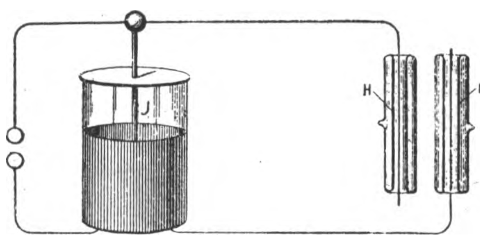


Fig. 4.

I have likewise noted that when a bulb is surrounded by a wire closed upon itself and in the plane of the primary, the formation of the luminous circle within the bulb is not prevented. But if instead of the wire a broad strip of tinfoil is glued upon the bulb, the formation of the luminous band was prevented, because then the action was distributed over a greater surface. The effect of the closed tinfoil was no doubt of an electrostatic nature, for it presented a much greater resistance than the closed wire and produced therefore a much smaller electromagnetic effect.

Some of the experiments of Prof. J. J. Thomson also would seem to show some electrostatic action. For instance, in the experiment with the bulb enclosed in a bell jar, I should think that when the latter is exhausted so far that the gas enclosed reaches the maximum conductivity, the formation of the circle in the bulb and jar is prevented because of the space surrounding the primary being highly conducting; when the jar is further exhausted, the conductivity of the space around the primary diminishes and the circles appear necessarily first in the bell jar, as the rarefied gas is nearer to the primary. But were the inductive effect very powerful, they would probably appear in the bulb also. If, however, the bell jar were exhausted to the highest degree they would very likely show themselves in the bulb only, that is, supposing the vacuous space to be non-conducting. On the assumption that in these phenomena electrostatic actions are concerned we find it easily explicable why the

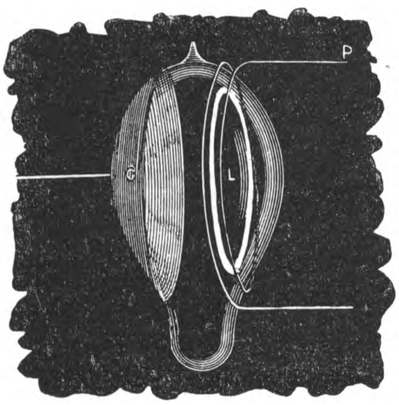


Fig. 5.

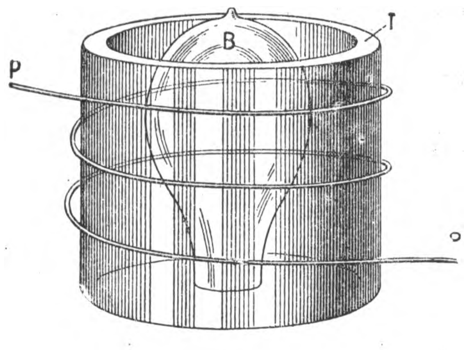


Fig. 6.

introduction of mercury or the heating of the bulb prevents the formation of the luminous band or shortens the after-glow; and also why in some cases a platinum wire may prevent the excitation of the tube. Nevertheless some of the experiments of Prof. J. J. Thomson would seem to indicate an electromagnetic effect. I may add that in one of my experiments in which a vacuum was produced by the Torricellian method, I was unable to produce the luminous band, but this may have been due to the weak exciting current employed.

My principal argument is the following: I have experimentally proved that if the same discharge which is barely sufficient to excite a luminous band in the bulb when passed through the primary circuit be so directed as to exalt the electrostatic inductive effect — namely, by converting upwards — an exhausted tube, devoid of electrodes, may be excited at a distance of several feet.

NOTE BY PROF. J. J. THOMSON IN THE LONDON *ELECTRICIAN,* JULY 24, 1891

"Mr. Tesla seems to ascribe the effects he observed to electrostatic action, and I have no doubt, from the description he gives of his method of conducting his experiments, that in them electrostatic action plays a very important part. He seems, however, to have misunderstood my position with respect to the cause of these discharges, which is not, as he implies, that luminosity in tubes without electrodes cannot be produced by electrostatic action, but that it can also be produced when this action is excluded. As a matter of fact, it is very much easier to get the luminosity when these electrostatic effects are operative than when they are not. As an illustration of this I may mention that the first experiment I tried with the discharge of a Leyden jar produced luminosity in the tube, but it was not until after six weeks' continuous experimenting that I was able to get a discharge in the exhausted tube which I was satisfied was due to what is ordinarily called electrodynamic action. It is advisable to have a clear idea of what we mean by electrostatic action. If, previous to the discharge of the jar, the primary coil is raised to a high potential, it will induce over the glass of the tube a distribution of electricity. When the potential of the primary suddenly falls, this electrification will redistribute itself, and may pass through the rarefied gas and produce luminosity in doing so. Whilst the discharge of the jar is going on, it is difficult, and, from a theoretical point of view, undesirable, to separate the effect into parts, one of which is called electrostatic, the other electromagnetic; what we can prove is that in this case the discharge is not such as would be produced by electromotive forces derived from a potential function. In my experiments the primary coil was connected to earth, and, as a further precaution, the primary was separated from the discharge tube by a screen of blotting paper, moistened with dilute sulphuric acid, and connected to earth. Wet blotting paper is a sufficiently good conductor to screen off a stationary electrostatic effect, though it is not a good enough one to stop waves of alternating electromotive intensity. When showing the experiments to the Physical Society I could not, of course, keep the tubes covered up, but, unless my memory deceives me, I stated the precautions which had been taken against the electrostatic effect. To correct misapprehension I may state that I did not read a formal paper to the Society, my object being to exhibit a few of the most typical experiments. The account of the experiments in the *Electrician* was from a reporter's note, and was not written, or even read, by me. I have now almost finished writing out, and hope very shortly to publish, an account of these and a large number of allied experiments, including some analogous to those mentioned by Mr. Tesla on the effect of conductors placed near the discharge tube, which I find, in some cases, to produce a diminution, in others an increase, in the brightness of the discharge, as well as some on the effect of the presence of substances of large specific inductive capacity. These seem to me to admit of a satisfactory explanation, for which, however, I must refer to my paper."

REPLY TO J. J. THOMSON'S NOTE IN THE *ELECTRICIAN,* JULY 24, 1891.[1]

In *The Electrical Engineer* of August 12, I find some remarks of Prof. J. J. Thomson, which appeared originally in the London *Electrician* and which have a bearing upon some experiments described by me in your issue of July 1.

I did not, as Prof. J. J. Thomson seems to believe, misunderstand his position in regard to the cause of the phenomena considered, but I thought that in his experiments, as well as in my own, electrostatic effects were of great importance. It did not appear, from the meagre description of his experiments, that all possible precautions had been taken to exclude these effects. I did not doubt that luminosity could be excited in a closed tube when electrostatic action is completely excluded. In fact, at the outset, I myself looked for a purely electrodynamic effect and believed that I had obtained it. But many experiments performed at that time proved to me that the electrostatic effects were generally of far greater importance, and admitted of a more satisfactory explanation of most of the phenomena observed.

In using the term *electrostatic* I had reference rather to the nature of the action than to a stationary condition, which is the usual acceptance of the term. To express myself more clearly, I will suppose that near a closed exhausted tube be placed a small sphere charged to a very high potential. The sphere would act inductively upon the tube, and by distributing electricity over the same would undoubtedly produce luminosity (if the potential be sufficiently high), until a permanent condition would be reached. Assuming the tube to be perfectly well insulated, there would be only one instantaneous flash during the act of distribution. This would be due to the electrostatic action simply.

But now, suppose the charged sphere to be moved at short intervals with great speed along the exhausted tube. The tube would now be permanently excited, as the moving sphere would cause a constant redistribution of electricity and collisions of the molecules of the rarefied gas. We would still have to deal with an electrostatic effect, and in addition an electrodynamic effect would be observed. But if it were found that, for instance, the effect produced depended more on the specific inductive

[1] The Electrical Engineer, N.Y., August 26, 1891.

capacity than on the magnetic permeability of the medium — which would certainly be the case for speeds incomparably lower than that of light — then I believe I would be justified in saying that the effect produced was more of an electrostatic nature. I do not mean to say, however, that any similar condition prevails in the case of the discharge of a Leyden jar through the primary, but I think that such an action would be desirable.

It is in the spirit of the above example that I used the terms "more of an electrostatic nature," and have investigated the influence of bodies of high specific inductive capacity, and observed, for instance, the importance of the quality of glass of which the tube is made. I also endeavored to ascertain the influence of a medium of high permeability by using oxygen. It appeared from rough estimation that an oxygen tube when excited under similar conditions — that is, as far as could be determined — gives more light; but this, of course, may be due to many causes.

Without doubting in the least that, with the care and precautions taken by Prof. J. J. Thomson, the luminosity excited was due solely to electrodynamic action, I would say that in many experiments I have observed curious instances of the ineffectiveness of the screening, and I have also found that the electrification through the air is often of very great importance, and may, in some cases, determine the excitation of the tube.

In his original communication to the *Electrician,* Prof. J. J. Thomson refers to the fact that the luminosity in a tube near a wire through which a Leyden jar was discharged was noted by Hittorf. I think that the feeble luminous effect referred to has been noted by many experimenters, but in my experiments the effects were much more powerful than those usually noted.

5

NOTES ON A UNIPOLAR DYNAMO*

It is characteristic of fundamental discoveries, of great achievements of intellect, that they retain an undiminished power upon the imagination of the thinker. The memorable experiment of Faraday with a disc rotating between the two poles of a magnet, which has borne such magnificent fruit, has long passed into every-day experience; yet there are certain features about this embryo of the present dynamos and motors which even to-day appear to us striking, and are worthy of the most careful study.

Consider, for instance, the case of a disc of iron or other metal revolving between the two opposite poles of a magnet, and the polar surfaces completely covering both sides of the disc, and assume the current to be taken off or conveyed to the same by contacts uniformly from all points of the periphery of the disc. Take first the case of a motor. In all ordinary motors the operation is dependent upon some shifting or change of the resultant of the magnetic attraction exerted upon the armature, this process being effected either by some mechanical contrivance on the motor or by the action of currents of the proper character. We may explain the operation of such a motor just as we can that of a water-wheel. But in the above example of the disc surrounded completely by the polar surfaces, there is no shifting of the magnetic action, no change whatever, as far as we know, and yet rotation ensues. Here, then, ordinary considerations do not apply; we cannot even give a superficial explanation, as in ordinary motors, and the operation will be clear to us only when we shall have recognized the very nature of the forces concerned, and fathomed the mystery of the invisible connecting mechanism.

Considered as a dynamo machine, the disc is an equally interesting object of study. In addition to its peculiarity of giving currents of one direction without the employment of commutating devices, such a machine differs from ordinary dynamos in that there is no reaction between armature and field. The armature current tends to set up a magnetization at right angles to that of the field current, but since the current is taken off uniformly from all points of the periphery, and since, to be exact, the external circuit may also be arranged perfectly symmetrical to the field magnet, no reaction can occur. This, however, is true only as long as the magnets are weakly energized, for when the magnets are more or less saturated, both magnetizations at right angles seemingly interfere with each other.

For the above reason alone it would appear that the output of such a machine should, for the same weight, be much greater than that of any other machine in which the armature current tends to demagnetize the field. The extraordinary output of the Forbes unipolar dynamo and the experience of the writer confirm this view.

Again, the facility with which such a machine may be made to excite itself is striking, but this may be due — besides to the absence of armature reaction — to the perfect smoothness of the current and non-existence of self-induction.

* The Electrical Engineer, N.Y., Sept. 2, 1891.

If the poles do not cover the disc completely on both sides, then, of course, unless the disc be properly subdivided, the machine will be very inefficient. Again, in this case there are points worthy of notice. If the disc be rotated and the field current interrupted, the current through the armature will continue to flow and the field magnets will lose their strength comparatively slowly. The reason for this will at once appear when we consider the direction of the currents set up in the disc.

Referring to the diagram Fig. 1, *d* represents the disc with the sliding contacts B B' on the shaft and periphery. N and S represent the two poles of a magnet. If the

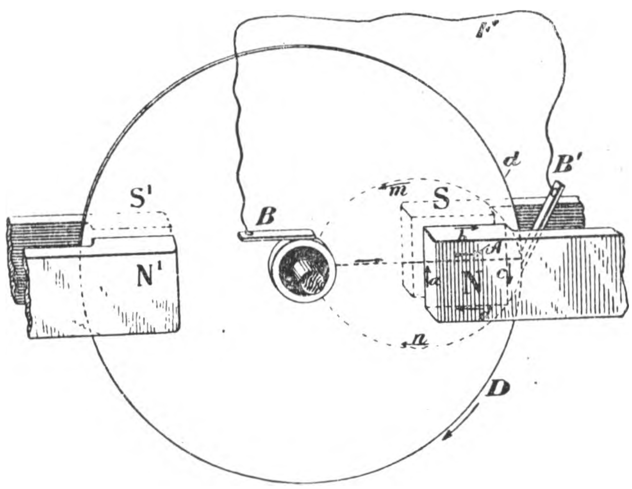


Fig. 1.

pole N be above, as indicated in the diagram, the disc being supposed to be in the plane of the paper, and rotating in the direction of the arrow D, the current set up in the disc will flow from the centre to the periphery, as indicated by the arrow A. Since the magnetic action is more or less confined to the space between the poles N S, the other portions of the disc may be considered inactive. The current set up will therefore not wholly pass through the external circuit F, but will close through the disc itself, and generally, if the disposition be in any way similar to the one illustrated, by far the greater portion of the current generated will not appear externally, as the circuit F is practically short-circuited by the inactive portions of the disc. The direction of the resulting currents in the latter may be assumed to be as indicated by the dotted lines and arrows *m* and *n*; and the direction of the energizing field current being indicated by the arrows *a b c d,* an inspection of the figure shows that one of the two branches of the eddy current, that is, A B' *m* B, will tend to demagnetize the field, while the other branch, that is, A B' *n* B, will have the opposite effect. Therefore, the branch A B' *m* B, that is, the one which is *approaching* the field, will repel the lines of the same, while branch A B' *n* B, that is, the one *leaving* the field, will gather the lines of force upon itself.

In consequence of this there will be a constant tendency to reduce the current flow in the path A B' *m* B, while on the other hand no such opposition will exist in path A B' *n* B, and the effect of the latter branch or path will be more or less preponderating over that of the former. The joint effect of both the assumed branch currents might be represented by that of one single current of the same direction as that energizing the field. In other words, the eddy currents circulating in the disc will energize the field magnet. This is a result quite contrary to what we might be led to suppose at first, for we would naturally expect that the resulting effect of the armature currents would be such as to oppose the field current, as generally occurs when a primary and secondary conductor are placed in inductive relations to each other. But it must be remembered that this result from the peculiar disposition in this case, namely, two paths being afforded to the current, and the latter selecting that path which offers the least opposition to its flow. From this we see that the eddy currents flowing in the disc partly energize the field, and for this reason when the field current is interrupted the currents in the disc will continue to flow, and the field magnet will lose its strength with comparative slowness and may even retain a certain strength as long as the rotation of the disc is continued.

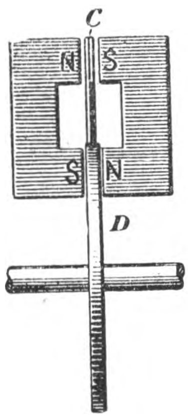


Fig. 2.

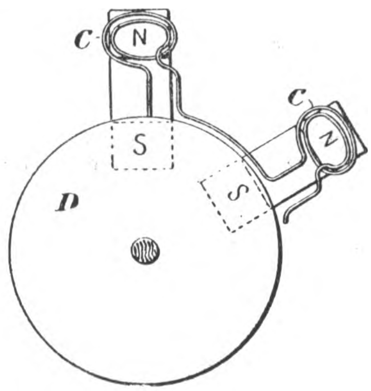


Fig. 3.

The result will, of course, largely depend on the resistance and geometrical dimensions of the path of the resulting eddy current and on the speed of rotation; these elements, namely, determine the retardation of this current and its position relative to the field. For a certain speed there would be a maximum energizing action; then at higher speeds, it would gradually fall off to zero and finally reverse, that is, the resultant eddy current effect would be to weaken the field. The reaction would be best demonstrated experimentally by arranging the fields N S, N' S', freely movable on an axis concentric with the shaft of the disc. If the latter were rotated as before in the direction of the arrow D, the field would be dragged in the same direction with a torque, which, up to a certain point, would go on increasing with the speed of rotation, then fall off, and, passing through zero, finally become negative; that is, the field would begin to rotate in opposite direction to the disc. In experiments with alternate current motors in which the field was shifted by currents of differing phase, this interesting result was observed. For very low speeds of rotation of the field the motor would show a torque of 900 lbs. or more, measured on a pulley 12 inches in diameter. When the speed of rotation of the poles was increased, the torque would diminish, would finally go down to zero, become negative, and then the armature would begin to rotate in opposite direction to the field.

To return to the principal subject; assume the conditions to be such that the eddy currents generated by the rotation of the disc strengthen the field, and suppose the latter gradually removed while the disc is kept rotating at an increased rate. The current, once started, may then be sufficient to maintain itself and even increase in strength, and then we have the case of Sir William Thomson's "current accumulator."

But from the above considerations it would seem that for the success of the experiment the employment of a disc *not subdivided* would be essential, for if there should be a radial subdivision, the eddy currents could not form and the self-exciting action would cease. If such a radially subdivided disc were used it would be necessary to connect the spokes by a conducting rim or in any proper manner so as to form a symmetrical system of closed circuits.

The action of the eddy currents may be utilized to excite a machine of any construction. For instance, in Figs. 2 and 3 an arrangement is shown by which a machine with a disc armature might be excited. Here a number of magnets, N S, N S, are placed radially on each side of a metal disc D carrying on its rim a set of insulated coils, C C. The magnets form two separate fields, an internal and an external one, the solid disc rotating in the field nearest the axis, and the coils in the field further from it. Assume the magnets slightly energized at the start; they could be strengthened by the action of the eddy currents in the solid disc so as to afford a stronger field! for the peripheral coils. Although there is no doubt that under proper conditions a machine might be excited in this or a similar manner, there being sufficient experimental evidence to warrant such an assertion, such a mode of excitation would be wasteful.

But a unipolar dynamo or motor, such as shown in Fig. 1 may be excited in an efficient manner by simply properly subdividing the disc or cylinder in which the currents are set up, and it is practicable to do away with the field coils which are usually employed. Such a plan is illustrated in Fig. 4. The disc or cylinder D is supposed to be arranged to rotate between the two poles N and S of a magnet, which completely cover it on both sides, the contours of the disc and poles being represented by the

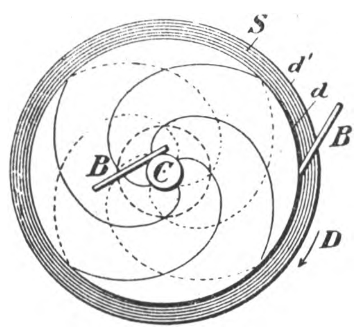


Fig. 4.

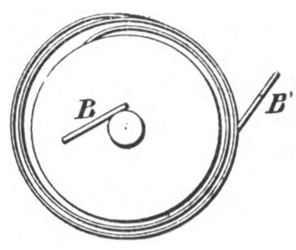


Fig. 5.

circles *d* and *d'* respectively, the upper pole being omitted for the sake of clearness. The cores of the magnet are supposed to be hollow, the shaft C of the disc passing through them. If the unmarked pole be below, and the disc be rotated screw fashion, the current will be, as before, from the centre to the periphery, and may be taken off by suitable sliding contacts, B B', on the shaft and periphery respectively. In this arrangement the current flowing through the disc and external circuit will have no appreciable effect on the field magnet.

But let us now suppose the disc to be subdivided, spirally, as indicated by the full or dotted lines, Fig. 4. The difference of potential between a point on the shaft and a point on the periphery will remain unchanged, in sign as well as in amount. The only difference will be that the resistance of the disc will be augmented and that there will be a greater fall of potential from a point on the shaft to a point on the periphery when the same current is traversing the external circuit. But since the current is forced to follow the lines of subdivision, we see that it will tend either to energize or de-energize the field, and this will depend, other things being equal, upon the direction of the lines of subdivision. If the subdivision be as indicated by the full lines in Fig. 4, it is evident that if the current is of the same direction as before, that is, from centre to periphery, its effect will be to strengthen the field magnet; whereas, if the subdivision be as indicated by the dotted lines, the current generated will tend to weaken the magnet. In the former case the machine will be capable of exciting itself when the disc is rotated in the direction of arrow D; in the latter case the direction of rotation must be reversed. Two such discs may be combined, however, as indicated, the two discs rotating in opposite fields, and in the same or opposite direction.

Similar disposition may, of course, be made in a type of machine in which, instead of a disc, a cylinder is rotated. In such unipolar machines, in the manner indicated, the usual field coils and poles may be omitted and the machine may be made to consist only of a cylinder or of two discs enveloped by a metal casting.

Instead of subdividing the disc or cylinder spirally, as indicated in Fig. 4, it is more convenient to interpose one or more turns between the disc and the contact ring on the periphery, as illustrated in Fig. 5.

A Forbes dynamo may, for instance, be excited in such a manner. In the experience of the writer it has been found that instead of taking the current from two such discs by sliding contacts, as usual, a flexible conducting belt may be employed to advantage. The discs are in such case provided with large flanges, affording a very great contact surface. The belt should be made to bear on the flanges with spring pressure to take up the expansion. Several machines with belt contact were constructed by the writer two years ago, and worked satisfactorily; but for want of time the work in that direction has been temporarily suspended. A number of features pointed out above have also been used by the writer in connection with some types of alternating current motors.

6

ON ROENTGEN RAYS(1)*

One can not help looking at that little bulb of Crookes with a feeling akin to awe, when he considers all that it has done for scientific progress — first, the magnificent results obtained by its originator; next, the brilliant work of Lenard, and finally the wonderful achievements of Roentgen. Possibly it may still contain a grateful Asmodeus, who will be let out of his narrow prison cell by a lucky student. At times it has seemed to me as though I myself heard a whispering voice, and I have searched eagerly among my dusty bulbs and bottles. I fear my imagination has deceived me, but there they are still, my dusty bulbs, and I am still listening hopefully.

After repeating Professor Roentgen's beautiful experiments, I have devoted my energies to the investigation of the nature of the radiations and to the perfecting of the means for their production. The following is a brief statement which, I hope, will be useful, of the methods employed and of the most notable results arrived at in these two directions.

In order to produce the most intense effects we have first to consider that, whatever their nature, they depend necessarily on the intensity of the cathode streams. These again being dependent on the magnitude of the potential, it follows that the highest attainable electrical pressure is desirable.

To obtain high potentials we may avail ourselves of an ordinary induction coil, or of a static machine, or of a disruptive discharge coil. I have the impression that most of the results in Europe have been arrived at through the employment of a static machine or Ruhmkorff coil. But since these appliances can produce only a comparatively small potential, we are naturally thrown on the use of the disruptive discharge coil as the most effective apparatus. With this there is practically no limit to the spark length, and the only requirement is that the experimenter should possess a certain knowledge and skill in the adjustments of the circuits, particularly as to resonance, as I have pointed out in my earlier writings on this subject.

After constructing a disruptive coil suitable for any kind of current supply, direct or alternating the experimenter comes to the consideration as to what kind of bulb to employ. Clearly, if we put two electrodes in a bulb, or use one inside and another outside electrode, we limit the potential, for the presence not only of the anode but of any conducting object has the effect of reducing the practicable potential on the cathode. Thus, to secure the result aimed at, one is driven to the acceptance of a single electrode bulb, the other terminal being as far remote as possible.

Obviously, an inside electrode should be employed to get the highest velocity of the cathode streams, for the bulbs without inside terminals are much less efficient for this special object in consequence of the loss through the glass. A popular error seems to exist in regard to the concentration of the rays by concave electrodes. This, if anything, is a disadvantage. There are certain specific arrangements of the disruptive coil and

* Electrical Review, March 11, 1896.

circuits, condensers and static screens for the bulb, on which I have given full particulars on previous occasions.

Having selected the induction apparatus and type of bulb, the next important consideration is the vacuum. On this subject I am able to make known a fact with which I have long been acquainted, and of which I have taken advantage in the production of vacuum jackets and all sorts of incandescent bulbs, and which

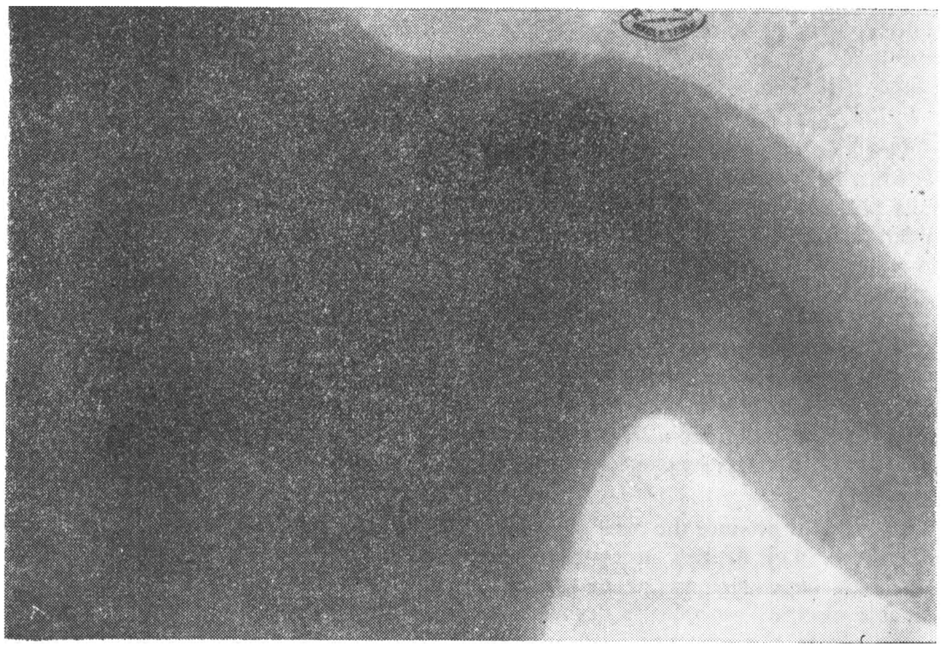


Fig. 1.

I subsequently found to be of the utmost importance, not to say essential, for the production of intense Roentgen shadows. I refer to a method of rarefaction by electrical means to any degree desirable far beyond that obtainable by mechanical appliances.

Though this result can be reached by the use of a static machine as well as of an ordinary induction coil giving a sufficiently high potential, I have found that by far the most suitable apparatus, and one which secures the quickest action, is a disruptive coil. It is best to proceed in this way: The bulb is first exhausted by means of an ordinary vacuum pump to a rather high degree, though my experiences have shown that this is not absolutely necessary, as I have also found it possible to rarefy, beginning from low pressure. After being taken down from the pump, the bulb is attached to the terminal of the disruptive coil, preferably of high frequency of vibration, and usually the following phenomena are noted. First, there is a milky light spreading through the bulb, or possibly for a moment the glass becomes phosphorescent, if the bulb has been exhausted to a high degree. At any rate, the phosphorescence generally subsides quickly and the white light settles around the electrode, whereupon a dark space forms at some distance from the latter. Shortly afterward the light assumes a reddish color and the terminal grows very hot. This heating, however, is observed only with powerful apparatus. It is well to watch the bulb carefully and regulate the potential at this stage, as the electrode might be quickly consumed.

After some time the reddish light subsides, the streams becoming again white, whereupon they get weaker and weaker, wavering around the electrode until they finally disappear. Meanwhile, the phosphorescence of the glass grows more and more intense, and the spot where the stream strikes the wall becomes very hot, while the phosphorescence around the electrode ceases and the latter cools down to such an extent that the glass near it may be actually ice cold to the touch. The gas in the bulb has then reached the required degree of rarefaction. The process may be hastened by repeated heating and cooling and by the employment of a small electrode. It should be added that bulbs with external electrodes may be treated in the same way. It may be also of interest to state that under certain conditions, which I am investigating more closely, the pressure of the gas in a vessel may be augmented by electrical means.

I believe that the disintegration of the electrode, which invariably takes place, is connected with a notable diminution of the temperature. From the point on, when the electrode gets cool, the bulb is in a very good condition for producing the Roentgen shadows. Whenever the electrode is equally, if not hotter than the glass, it is a sure indication that the vacuum is not high enough, or else that the electrode is too small. For very effective working, the inside surface of the wall, where the cathode stream strikes, should appear as if the glass were in a fluid state.

As a cooling medium I have found best to employ jets of cold air. By this means it is possible to operate successfully a bulb with a very thin wall, while the passage of the rays is not materially impeded.

I may state here that the experimenter need not be deterred from using a glass bulb, as I believe the opacity of glass as well as the transparency of aluminum are somewhat exaggerated, inasmuch as I have found that a very thin aluminum sheet throws a marked shadow, while, on the other hand, I have obtained impressions through a thick glass plate.

The above method is valuable not only as a means of obtaining the high vacua desired, but it is still more important, because the phenomena observed throw a light on the results obtained by Lenard and Roentgen.

Though the phenomenon of rarefaction under above conditions admits of different interpretations, the chief interest centers on one of them, to which I adhere — that is, on the actual expulsion of the particles through the walls of the bulb. I have lately observed that the latter commences to act properly upon the sensitive plate only from the point when the exhaustion begins to be noticeable, and the effects produced are the strongest when the process of exhaustion is most rapid, even though the phosphorescence might not appear particularly bright. Evidently, then, the two effects are closely connected, and I am getting more and more convinced that we have to deal with a stream of material particles, which strike the sensitive plate with great velocities. Taking as a basis the estimate of Lord Kelvin on the speed of projected particles in a Crookes' bulb, we arrive easily by the employment of very high potentials to speeds of as much as a hundred kilometres a second. Now, again, the old question arises: Are the particles from the electrode or from the charged surface generally, including the case of an external electrode, projected through the glass or aluminum walls, or do they merely hit the inner surface and cause particles from the outside of the wall to fly off, acting in a purely mechanical way, as when a row of ivory balls is struck? So far, most of the phenomena indicate that they are projected through the wall of the bulb, of whatever material it may be, and I am seeking for still more conclusive evidence in this direction.

It may not be known that even an ordinary streamer, breaking out suddenly and under great pressure from the terminal of a disruptive coil, passes through a thick glass plate as though the latter were not present. Unquestionably, with such coils pressures are practicable which will project the particles in straight lines even under atmospheric pressure. I have obtained distinct impressions in free air, not by streamers, as some experimenters have done, using static machines or induction coils, but by actual projection, the formation of streamers being absolutely prevented by careful static screening.

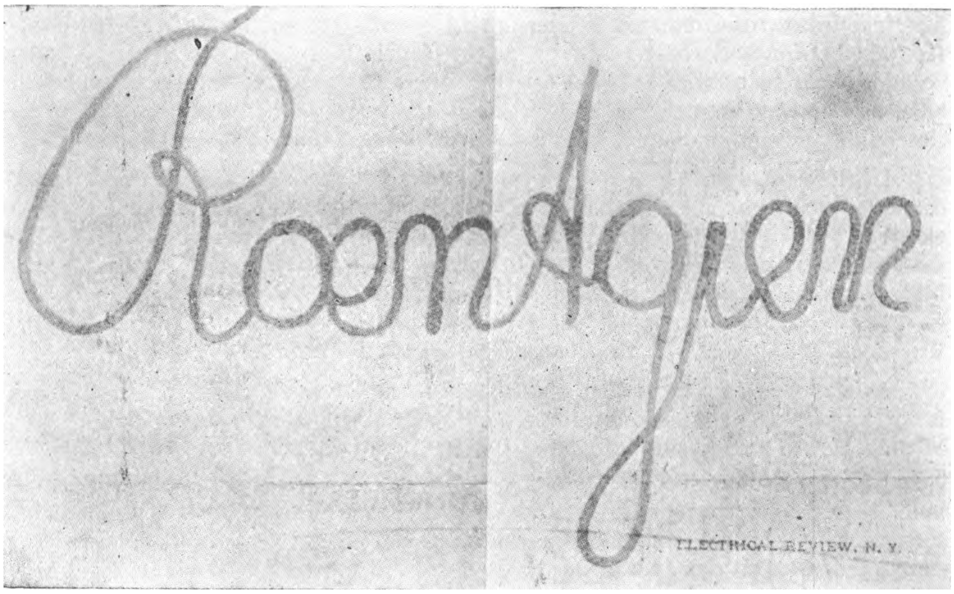


Fig. 2.

A peculiar thing about the Roentgen rays is that from low frequency to the highest obtainable there seems to be no difference in the quality of the effects produced, except that they are more intense when the frequency is higher, which is very likely due to the fact that in such case the maximum pressures on the cathode are likewise higher. This is only possible on the assumption that the effects on the sensitive plate are due to projected particles, or else to vibrations far beyond any frequency which we are able to obtain by means of condenser discharges. A powerfully excited bulb is enveloped in a cloud of violet light, extending for more than a foot around it, but outside of this visible phenomenon there is no positive evidence of the existence of waves similar to those of light. On the other hand, the fact that the opacity bears some proportion to the density of the substance speaks strongly for material streams, and the same may be said of the effect discovered by Prof. J. J. Thomson. It is to be hoped that all doubts will shortly be dispelled.

A valuable evidence of the nature of the radiations and progress in the direction of obtaining strong impressions on the plate might be arrived at by perfecting plates especially sensitive to mechanical shock or impact. There are chemicals suitable for this, and the development in this direction may lead to the abandonment of the present plate. Furthermore, if we have to deal with streams of material particles, it seems not impossible to project upon the plate a suitable substance to insure the best chemical action.

With apparatus as I have described, remarkable impressions on the plate are produced. An idea of the intensity of the effects may be gained when I mention that it is easy to obtain shadows with comparatively short exposures at distances of many feet, while at small distances and with thin objects, exposures of a few seconds are practicable. The annexed print is a shadow of a copper wire projected at a distance of 11 feet through a wooden cover over the sensitive plate. This was the first shadow taken with my improved apparatus in my laboratory. A similar impression was obtained through the body of the experimenter, a plate of glass, nearly three-sixteenths of an inch thick, a thickness of wood of fully two inches and through a distance of about four feet. I may remark, however, that when these impressions were taken, my apparatus was working under extremely unfavorable conditions, which admitted of so great improvements that I am hopeful to magnify the effects many times.

The bony structure of birds, rabbits and the like is shown within the least detail, and even the hollow of the bones is clearly visible. In a plate of a rabbit under exposure of an hour, not only every detail of the skeleton is visible, but likewise a clear outline of the abdominal cavity and the location of the lungs, the fur and many other features. Prints of even large birds show the feathers quite distinctly.

Clear shadows of the bones of human limbs are obtained by exposures ranging from a quarter of an hour to an hour, and some plates have shown such an amount of detail that it is almost impossible to believe that we have to deal with shadows only. For instance, a picture of a foot with a shoe on it was taken, and every fold of the leather, trousers, stocking, etc., is visible, while the flesh and bones stand out sharply. Through the body of the experimenter the shadows of small buttons and like objects are quickly obtained, while with an exposure of from one to one and a half hour the ribs, shoulder-bones and the bones of the upper arm appear clearly, as is shown in the annexed print. It is now demonstrated beyond any doubt that small metallic objects or bony or chalky deposits can be infallibly detected in any part of the body.

An outline of the skull is easily obtained with an exposure of 20 to 40 minutes. In one instance an exposure of 40 minutes gave clearly not only the outline, but the cavity of the eye, the chin and cheek and nasal bones, the lower jaw and connections to the upper one, the vertebral column and connections to the skull, the flesh and even the hair. By exposing the head to a powerful radiation strange effects have been noted. For instance, I find that there is a tendency to sleep and the time seems to pass away quickly. There is a general soothing effect, and I have felt a sensation of warmth in the upper part of the head. An assistant independently confirmed the tendency to sleep and a quick lapse of time. Should these remarkable effects be verified by men with keener sense of observation, I shall still more firmly believe in the existence of material streams penetrating the skull. Thus it may be possible by these strange appliances to project a suitable chemical into any part of the body.

Roentgen advanced modestly his results, warning against too much hope. Fortunately his apprehensions were groundless, for, although we have to all appearance to deal with mere shadow projections, the possibilities of the application of his discovery are vast. I am happy to have contributed to the development of the great art he has created.

ON ROENTGEN RAYS(2)*

— latest results —

To the Editor of Electrical Review

Permit me to say that I was slightly disappointed to note in your issue of March 11 the prominence you have deemed to accord to my youth and talent, while the ribs and other particulars of Fig. 1, which, with reference to the print accompanying my communication, I described as clearly visible, were kept modestly in the background. I also regretted to observe an error in one of the captions, the more so, as I must ascribe it to my own text. I namely stated on page 135, third column, seventh line: "A similar impression was obtained through the body of the experimenter, etc., through a distance of four feet." The impression here referred to was a similar one to that shown in Fig. 2, whereas the shadow in Fig. 1 was taken through a distance of 18 inches. I state this merely for the sake of correctness of my communication, but, as far as the general truth of the fact of taking such a shadow at the distance given is concerned, your caption might as well stand, for I am producing strong shadows at distances of 40 *feet.* I repeat, 40 feet and even more. Nor is this all. So strong are the actions on the film that provision must be made to guard the plates in my photographic department, located on the floor above, a distance of fully 60 feet, from being spoiled by long exposure to the stray rays. Though during my investigations I have performed many experiments which seemed extraordinary, I am deeply astonished observing these unexpected manifestations, and still more so, as even now I see before me the possibility, not to say certitude, of augmenting the effects with my apparatus at least tenfold! What may we then expect? We have to deal here, evidently, with a radiation of astonishing power, and the inquiry into its nature becomes more and more interesting and important. Here is an unlooked-for result of an action which, though wonderful in itself, seemed feeble and entirely incapable of such expansion, and affords a good example of the fruitfulness of original discovery. These effects upon the sensitive plate at so great a distance I attribute to the employment of a bulb with a single terminal, which permits the use of practically any desired potential and the attainment of extraordinary speeds of the projected particles. With such a bulb it is also evident that the action upon a fluorescent screen is proportionately greater than when the usual kind of tube is employed, and I have already observed enough to feel sure that great developments are to be looked for in this direction. I consider Roentgen's discovery, of enabling us to see, by the use of a fluorescent screen, through an opaque substance, even a more beautiful one than the recording upon the plate.

Since my previous communication to you I have made considerable progress, and can presently announce one more result of importance. I have lately obtained shadows by *reflected rays only,* thus demonstrating beyond doubt that the Roentgen rays possess this property. One of the experiments may be cited here. A thick copper tube, about a foot long, was taken and one of its ends tightly closed by the plate-holder containing

* Electrical Review, March 18, 1896

a sensitive plate, protected by a fiber cover as usual. Near the open end of the copper tube was placed a thick plate of glass at an angle of 45 degrees to the axis of the tube. A single-terminal bulb was then suspended above the glass plate at a distance of about eight inches, so that the bundle of rays fell upon the latter at an angle of 45 degrees, and the supposedly reflected rays passed along the axis of the copper tube. An exposure of 45 minutes gave a clear and sharp shadow of a metallic object. This shadow was produced by the reflected rays, as the direct action was absolutely excluded, it having been demonstrated that even under the severest tests with much stronger actions no impression whatever could be produced upon the film through a thickness of copper equal to that of the tube. Concluding from the intensity of the action by comparison with an equivalent effect due to the direct rays, I find that approximately two per cent of the latter were reflected from the glass plate in this experiment. I hope to be able to report shortly and more fully on this and other subjects.

In my attempts to contribute my humble share to the knowledge of the Roentgen phenomena, I am finding more and more evidence in support of the theory of moving material particles. It is not my intention, however, to advance at present any view as to the bearing of such a fact upon the present theory of light, but I merely seek to establish the fact of the existence of such material streams in so far as these isolated effects are concerned. I have already a great many indications of a bombardment occurring outside of the bulb, and I am arranging some crucial tests which, I hope, will be successful. The calculated velocities fully account for actions at distances of as much as 100 feet from the bulb, and that the projection through the glass takes place seems evident from the process of exhaustion, which I have described in my previous communication. An experiment which is illustrative in this respect, and which I intended to mention, is the following: If we attach a fairly exhausted bulb containing an electrode to the terminal of a disruptive coil, we observe small streamers breaking through the sides of the glass. Usually such a streamer will break through the seal and crack the bulb, whereupon the vacuum is impaired; but, if the seal is placed above the terminal, or if some other provision is made to prevent the streamer from passing through the glass at that point, it often occurs that the stream breaks out through the side of the bulb, producing a fine hole. Now, the extraordinary thing is that, in spite of the connection to the outer atmosphere, the air can not rush into the bulb as long as the hole is very small. The glass at the place where the rupture has occurred may grow very hot — to such a degree as to soften; but it will not collapse, but rather bulge out, showing that a pressure from the inside greater than that of the atmosphere exists. On frequent occasions I have observed that the glass bulges out and the hole, through which the streamer rushes out, becomes so large as to be perfectly discernible to the eye. As the matter is expelled from the bulb the rarefaction increases and the streamer becomes less and less intense, whereupon the glass closes again, hermetically sealing the opening. The process of rarefaction, nevertheless, continues, streamers being still visible on the heated place until the highest degree of exhaustion is reached, whereupon they may disappear. Here, then, we have a positive evidence that matter is being expelled through the walls of the glass.

When working with highly strained bulbs I frequently experience a sudden, and sometimes even painful, shock in the eye. Such shocks may occur so often that the eye gets inflamed, and one can not be considered overcautious if he abstains from watching the bulb too closely. I see in these shocks a further evidence of larger particles being thrown off from the bulb.

7

ON REFLECTED ROENTGEN RAYS*

In previous communications in regard to the effects discovered by Roentgen, I have confined myself to giving barely a brief outline of the most noteworthy results arrived at in the course of my investigations. To state truthfully, I have ventured to express myself, the first time, after some hesitation and consequent delay, and only when I had gained the conviction that the information I had to convey was a needful one; for, in common with others, I was not quite able to free myself of a certain feeling which one must experience when he is trespassing on ground not belonging to him. The discoverer would naturally himself arrive at most of the facts in due time, and a courteous restraint in the announcement of the results on the part of his co-workers would not be amiss. How many have sinned against me by proclaiming their achievements just as I was good and ready to do it myself! But these discoveries of Roentgen, exactly of the order of the telescope and microscope, his seeing through a great thickness of an opaque substance, his recording on a sensitive plate of objects otherwise invisible, were so beautiful and fascinating, so full of promise, that all restraint was put aside, and every one abandoned himself to the pleasures of speculation and experiment. Would but every new and worthy idea find such an echo! One single year would then equal a century of progress. A delight it would be to live in such age, but a discoverer I would not wish to be.

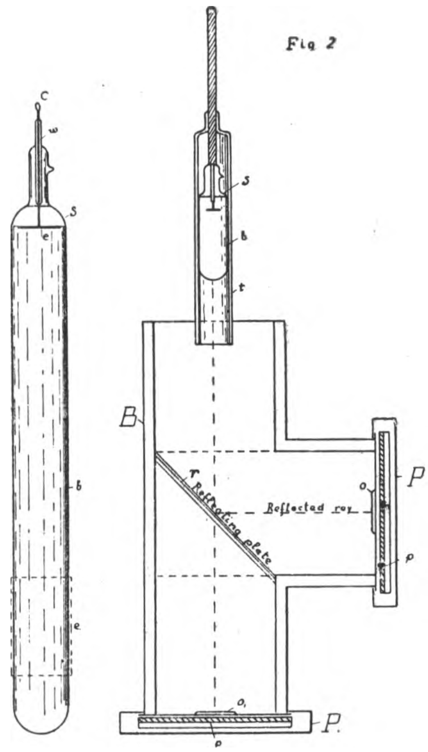
Amongst the facts, which I have had the honor to bring to notice, is one claiming a large share of scientific interest, as well as of practical importance. I refer to the demonstration of the property of reflection, on which I have dwelt briefly.

Having had opportunities to make many observations during my experience with vacuum bulbs and tubes, which could not be accounted for in any plausible way on any theory of vibration as far as I could judge, I began these investigations — disinclined, but expectant to find that the effects produced are due to a stream of material: particles. I had many evidences of the existence of such streams. One of these I mentioned, describing the method of electrically exhausting a tube. Such exhaustion, I have found, takes place much quicker when the glass is very thin than when the walls are thick, I presume because of the easier passage of the ions. While a few minutes are sufficient when the glass is very thin, it often takes half an hour or more if the glass be thick or the electrode very large. In accordance with this idea I have, with a view of obtaining the most efficient action, selected the apparatus, and have found at each step my supposition confirmed and my conviction strengthened.

A stream of material particles, possessing a great velocity, must needs be reflected, and I was therefore quite prepared — assuming my original idea to be true — to demonstrate sooner or later this property. Considering that the reflection should be the more complete the smaller the angle of incidence, I adopted from the outset of my investigations a tube or bulb *b* of the form shown in Fig. 1. It was made of very thick glass, with a bottom blown as thin as possible, with the two obvious objects

* Electrical Review, April 1, 1896.

of restricting the radiation to the sides and facilitating the passage through the bottom. A single electrode *e,* in the form of a round disk of a diameter slightly less than that of the tube, was placed about an inch below the narrow neck *n* on the top. The leading-in conductor *c* was provided with a long wrapping *w*, so as to prevent cracking, by the formation of sparks at the point where the wire enters the bulb. It was found advantageous for a number of reasons to extend the wrapping a good distance beyond the neck, on the inside and outside as well, and to place the seal-off in the narrow neck. On other occasions I have dwelt on the employment of an electrostatic screen in connection with such single-terminal bulbs. In the present instance the screen was preferably formed by a bronze painting *s*, slightly above the aluminum electrode and extending to just a little below the wrapping of the wire, so as to allow seeing constantly the end of the wrapping. Or else a small aluminum plate *s,* Fig. 2, was supported in the inside of the bulb above the electrode. This static screen practically doubles the effect, as it prevented all action above it. Considering, further, that the radiation sideways was restricted by the use of a very thick glass and most of it was thrown to the bottom by reflection, as I then surmised, it became evident that such a tube should prove much more efficient than one of ordinary form. Indeed, I quickly found that its power upon the sensitive plate was very nearly four times as great as that of a spherical bulb with an equivalent area of impact. This kind of tube is also very well adapted for use with two terminals by placing an external electrode e_1 as indicated by the dotted lines in Fig. 1. When the glass is taken thick the stream is sensibly parallel and concentrated. Furthermore, by making the tube as long as one desired, it was possible to employ very high potentials, otherwise impracticable with short bulbs.



Figs. 1 and 2.

The use of high potentials is of great importance, as it allows shortening considerably the time of exposure, and affecting the plate at much greater distances.
I am endeavoring to determine more exactly the relation of the potential to the effect produced upon the sensitive plate. I deem it necessary to remark that the electrode should be of aluminum, as a platinum electrode, which is still persistently employed, gives inferior results and the bulb is disabled in comparatively short time. Some experimenters might find trouble in maintaining a fairly constant vacuum, owing to a peculiar process of absorption in the bulb, which has been pointed out early by Crookes, in consequence of which, by continued use, the vacuum may increase. A convenient way to prevent this I have found to be the following: The screen or aluminum plate *s,* Fig. 2, is placed directly upon the wrapping of the leading-in conductor *c,* but some distance back from the end. The right distance can be only determined by experience. If it is properly chosen, then, during the action of the bulb, the wrapping gets warmer, and a small bright spark jumps from time to time from the wire *c* to the aluminum plate *s* through the wrapping *w.* The passage of this

spark causes gases to be formed, which slightly impair the vacuum, and in this manner, by a little skillful manipulation, the proper vacuum may be constantly maintained. Another way of getting the same result in a tube shown in Fig. 1 is to extend the wrapping so far inside that, when the bulb is normally working, the wrapping is heated sufficiently to free gases to the required amount. It is for this purpose convenient to let the screen of bronze painting *s* extend just a little below the wrapping, so that the spark may be observed. There are, however, many other ways of overcoming this difficulty, which may cause some annoyance to those working with inadequate apparatus.

In order to insure the best action the experimenter should note the various stages which I have pointed out before, and through which the bulb has to pass during the process of exhaustion. He will first observe that when the Crookes phenomena show themselves most prominently there is a reddish streamer issuing from the electrode, which in the beginning covers the latter almost entirely. Up to this point the bulb practically does not affect the sensitive plate, although the glass is very hot at the point of impact. Gradually the reddish streamer disappears, and just before it ceases to be visible the bulb begins to show better action, but still the effect upon the plate is very weak. Presently a white or even bluish stream is observed, and after some time the glass on the bottom of the bulb gets a glossy appearance. The heat is still more intense and the phosphorescence through the entire bulb is extremely brilliant. One should think that such a bulb must be effective, but appearances are often deceitful, and the beautiful bulb still does not work. Even when the white or bluish stream ceases, and the glass on the bottom is so hot as to be nearly melting, the effect on the plate is very weak. But at this stage there appears suddenly at the bottom of the tube a star-shaped changing design, as if the electrode would throw off drops of liquid. From this moment on the power of the bulb is tenfold, and at this stage it must always be kept to give the best results.

I may remark, however, that while it may be generally stated the Crookes vacuum is not high enough for the production of the Roentgen phenomena, this is not literally true. Nor are the Crookes phenomena produced at a particular degree of exhaustion, but manifest themselves even with poor vacua, provided the potential is high enough. This is likewise true of the Roentgen effects. Naturally, to verify this, provision must be made not to overheat the bulb when the potential is raised. This is easily done by reducing the number of impulses or their duration, when raising the potential. For such experiments, it will be found of advantage to use in connection with the ordinary induction coil a rotating commutator, instead of a vibrating brake. By changing the speed of the commutator, and also regulating the duration of contact, one is enabled to adjust the conditions to suit the degree of vacuum and potential employed.

In my experiments on reflection, presently considered, I have used the apparatus shown in Fig. 2. It consists of a T-shaped box throughout, of a square cross-section. The walls are made of lead over one-eighth of an inch thick, which, under the conditions of the experiments, was found to be entirely impervious, even by long exposures to the rays. On the top end was supported firmly the bulb *b,* inclosed in a glass tube *t* of thick Bohemian glass, which reached some distance into the lead box. The lower end of the box was tightly closed by a plate-holder P_1, containing the sensitive film p_1, protected as usual. Finally the side end was closed by a similar plate-holder P, with the sensitive protected film *p.* To obtain sharp images the objects *o* and o_1 exactly alike, were placed in the center of the fiber cover, protecting the sensitive plates. In the central portion of the box, provision was made for inserting a plate *r* of material, the reflective power of which was to be tested, and the dimensions of the box were such that the reflected ray and the direct one had to go through the same distance, the reflecting plate being at an angle of 45 degrees to the incident as well as reflected ray. Care was taken to exclude all possibility of action upon the plate *p*, except by reflected rays, and the reflecting plate *r* was made to fit tight all around in the lead box, so that no rays could reach the film p_1, except by passing through the plate to be tested. In my earliest experiments on reflection I observed only the effects of reflected rays, but in this instance, on the suggestion of Prof. Wm. A. Anthony, I provided the above means for simultaneously examining the action of the direct rays, which eventually passed through the reflecting plate. In this manner it was possible to compare the amount of the transmitted and reflected radiation. The glass tube *t* surrounding the bulb *b* served to render the stream parallel and more intense. By taking impressions at various distances I found that through a considerable distance there was but little spreading of the bundle of rays or stream of particles.

To reduce the error which is caused unavoidably by too long exposures and very small distances, I reduced the exposure to an hour, and the total distance through which the rays had to pass before reaching the sensitive plates was 20 inches, the distance from the bottom of the bulb to the reflecting plate being 13 inches.

It is needless to remark that all the precautions in regard to the sensitive plates — constancy of potential, uniform working of the bulbs, and maintenance of the same conditions in general during these tests have been taken, as far as it was practicable. The plates to be tested were made of uniform size, so as to fit the space provided in the lead box. Of the conductors the following were tested: Brass, tool steel, zinc, aluminum, copper, lead, silver, tin, and nickel, and of the insulators, lead-glass, ebonite, and mica. The summary of the observations is given in the following table:

Reflecting body.	Impression by transmitted rays.	Impression by reflected rays.
Brass.	Strong.	Fairly strong.
Tool steel.	Barely perceptible.	Very feeble.
Zinc.	None.	Very strong.
Aluminum.	Very strong.	None.
Copper.	None.	Fairly strong, but much less than zinc.
Lead.	None.	Very strong, but a little weaker than zinc.
Silver.	Strong, a thin plate being used.	Weaker than copper.
Tin.	None.	Very strong; about like lead.
Nickel.	None.	About like copper.
Lead-glass.	Very strong.	Feeble.
Mica.	Very strong.	Very strong; about like lead.
Ebonite.	Strong.	About like copper.

By comparing, as in previous experiments, the intensity of the impression by reflected rays with an equivalent impression due to a direct exposure of the same bulb and at the same distance — that is, by calculating from the times of exposure under assumption that the action upon the plate was proportionate to the time — the following approximate results were obtained:

Reflecting body.	Impression by direct action.	Impression by reflected rays.
Brass	100	2
Tool steel	100	0,5
Zinc	100	3
Aluminum	100	0
Copper	100	2
Lead	100	2,5
Silver	100	1,75
Tin	100	2,5
Nickel	100	2
Lead-glass	100	1
Mica	100	2,5
Ebonite	100	2

While these figures can be but rough approximations, there is, nevertheless, a fait probability that they are correct, in so far as the relative values of the impressions by reflected rays for the various bodies are concerned. Arranging the metals according to these values, and leaving for the moment the alloys or impure bodies out of question, we arrive at the following order: Zinc, lead, tin, copper, silver. The tin appears) to reflect fully as well as lead, but, allowing for an error in the observation, we may assume that it reflects less, and in this case we find that this order is precisely the contact series of metals in air. If this proves true we shall be confronted with the most extraordinary fact. Why is zinc, for instance, the best reflector among the metals tested and why, at the same time, is it one of the foremost in the contact series? I have not as yet tried magnesium. The truth is that I was somewhat excited over these results. Magnesium should be even a better reflector than zinc, and sodium still better than magnesium. How can this singular relationship be explained? The only possible explanation seems to me at present that the bulb throws out streams of matter in some primary condition, and that the reflection of these streams is dependent upon some fundamental and electrical property of the metals. This would seem to lead to the inference that these streams must be of uniform electrification; that is, that they must be anodic or cathodic in character, but not both. Since the announcement, I believe in France for the first time, that the streams are anodic, I have investigated the subject and find that I can not agree with this contention. On the contrary, I find that anodic and cathodic streams both affect the plate, and, furthermore, I have been led to the conviction that the phosphorescence of the glass has nothing whatever to do with the photographic impressions. An obvious proof is that such impressions are produced with aluminum vessels when there is no phosphorescence, and, as regards the anodic or cathodic character, the simple fact that we can produce impressions by a luminous discharge excited by induction of a closed vessel, when there is neither anode nor cathode, would seem to dispose effectually of the assumption that the streams are issuing solely from one of the electrodes. It may, perhaps, be useful to point out here a simple fact in relation to the induction coils, which may lead an experimenter into an error. When a vacuum tube is attached to the terminals of an induction coil, both of the terminals are acted upon alike as long as the tube is not very highly exhausted. At a high degree of exhaustion both the electrodes act practically independently, and since they behave as bodies possessing considerable capacity, the consequence is that the coil is unbalanced. If the cathode, for instance, is very large, the pressure on the anode may rise considerably, and if the latter is made smaller, as is frequently the case, the electric density may be many times that on the cathode. It results from this that the anode gets very hot, while the cathode may be cool. Quite the opposite occurs if both of them are made exactly alike. But assuming the above conditions to exist, the hotter anode emits a more intense stream than the cool cathode, since the velocity of the particles is dependent on the electrical density, and likewise on the temperature.

From the previous tests an interesting observation can also be made in regard to the opacity. For instance, a brass plate one-sixteenth inch thick proved fairly transparent while plates of zinc and copper of the same thickness showed themselves to be entirely opaque.

Since I have investigated reflection and arrived to results in this direction, I have been able to produce stronger effects by employing proper reflectors. By surrounding a bulb with a very thick glass tube the effect may be augmented very considerably. The employment of a zinc reflector in one instance showed an increase of about 40 per cent in the impression produced. I attach great practical value to the employment of proper reflectors, because by means of them we can employ any quantity of bulbs, and so produce any intensity of radiation required.

One disappointment in the course of these investigations has been the entire failure of my efforts to demonstrate refraction. I have employed lenses of all kinds and tried a great many experiments, but could not obtain any positive result.

8

ON ROENTGEN RADIATIONS*

Having observed the unexpected behavior of the various metals in regard to the reflection of these radiations, (see Electrical Review of April 1, 1896) I have endeavored to settle several still doubtful points. As, for the present, it appeared chiefly desirable to establish the exact order of the metals, or conductors, in regard to their powers of reflection, leaving for further investigation the determination of the magnitude of the effects, I modified slightly the apparatus and procedure described in my communication just referred to. The reflecting plates were not made each of one metal, as before, but of two metals, the reflective power of which was to be compared. This was done by fastening upon a plate of lead the two metal plates to be investigated, so that the reflecting surface was divided in two halves by the joining line. Furthermore, to prevent any spreading and mingling of the rays reflected from both halves, I divided the lead box into two compartments by a thick lead plate through the middle. Care was taken that the density of the rays falling upon the reflecting surfaces was as uniform as possible, and with this object in view the glass tube surrounding the bulb was lifted up so as to just expose the half-spherical bottom of the latter. The bulb was placed as exactly as it was practicable in the center, so that both halves of the reflecting plate were equally exposed to the radiations.

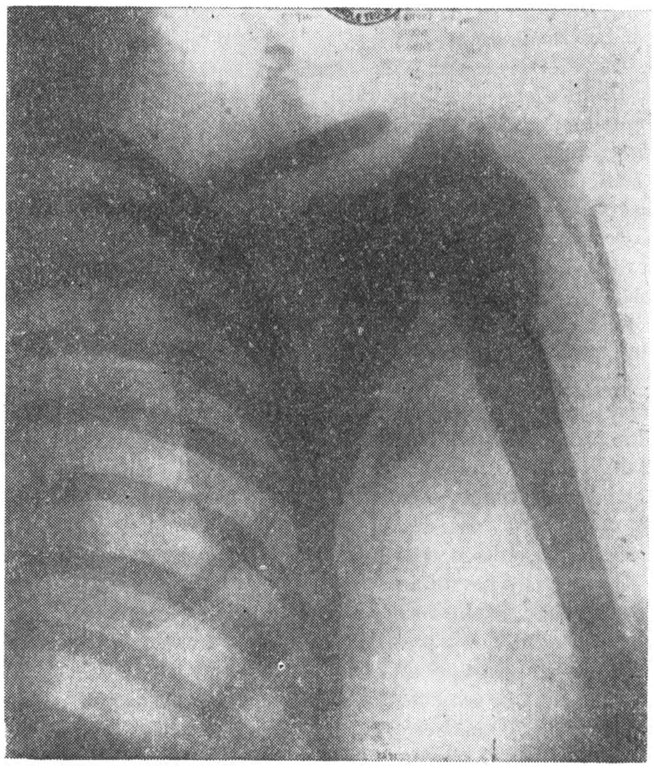
Having failed to obtain, in former experiments, a record for iron owing to an oversight, I tried to ascertain its position in the series by comparing it with copper, using a plate made up of iron and copper. The experiments showed that iron reflected about as much as copper, but which metal reflected better was impossible to determine with safety by this method. Next I endeavored to find whether tin or lead was a better reflector, by the same method. Three experiments were performed, and in each case the metals behaved nearly alike, but tin appeared just a trifle better. Finally I investigated the properties of magnesium as compared with zinc. In fact, the experiments showed that magnesium reflected a little better.

I am not yet satisfied, in view of the importance of this relation of the metals with the means employed, and will try to devise an apparatus which will do away with all the defects of the present. The time of the exposure I have found practicable to reduce to a few minutes by the help of a fluorescent paper.

In my previous communications I have barely hinted at the practical importance of the use of suitable reflectors. One would be apt to conclude that, since under the conditions of the previously described experiments, zinc, for instance, reflected only three per cent of the incident rays, the gain secured by the employment of such zinc reflector would be small. This, of course, would be an erroneous conclusion. First of all it should be remembered that in the instances mentioned before the angle of incidence was 45 degrees, and that for larger angles a much greater portion of the rays would be reflected. The exact law of reflection is still to be determined. Now, let us

* Electrical Review, April 8, 1896.

suppose the shadow of an object is taken at a distance, D. In order to get a sharp shadow we must take this distance not less than two feet, and I am finding it more and more necessary to adopt a still greater distance. If, for the sake of simplicity, we assume a spherical bulb and electrode, the radiation will be uniform on all sides, and any element of a surface of a sphere of radius *D,* drawn around the electrode, will receive an equal quantity of rays. The total surface of this sphere will be $4\pi D_2$. The object, the shadow of which is to be taken, may have a small area *a,* which gets only an



insignificant part of the total rays emitted, this part being given by the proportion $\frac{a}{4\pi D^2}$. In reality we can not assume less than $\frac{a}{D^2\pi}$ as effective ratio, but even then, if *D* is very large and the object, that is, the area *a,* small, this ratio may be still so small that evidently, by the use of a proper reflector, we can easily concentrate upon the area *a* an amount of rays several times exceeding that which would fall upon it without the use of a reflector, in spite of the fact that we are able to reflect only a few per cent of the *total* incident rays.

As an evidence of the effectiveness of such a reflector, the annexed print of the shoulder and ribs of a man is shown. A funnel-shaped zinc reflector, two feet high, with an opening of five inches on the bottom and 23 inches at the top, was used in the experiment. A tube, similar in every respect to those previously described, was suspended in the funnel, so that just the static screen of the tube was above the former. The exact distance from the electrode to the sensitive plate was four and one-half feet. The distance from the end of the tube to the plate was three and one-half feet. The exposure lasted 40 minutes. The plate showed very strongly and clearly every bone, and shoulder and ribs, but I can not tell how clearly they will appear in the print. I selected the same object as in my first report in your columns on this investigation, so as to give a better idea of the progress made. The advance will be best appreciated by stating that the distance in this case was much more than double, while the time of exposure was less than one-half. The chief importance of a reflector consists, however, in this, that it allows the use of many bulbs without sacrifice of precision and clearness, and also the concentration of a great quantity of radiation upon a very small area.

Since the use of phosphorescent or fluorescent bodies in connection with the sensitive film has been suggested by Professors Henry and Salvioni, I have found it an easy matter to shorten the time of exposure to a few minutes, or even seconds. So far, it seems that the tungstate of calcium, recently introduced by Edison, and manufactured by Messrs. Aylsworth & Jackson, is the most sensitive body. I obtained a sample of it and used it in a series of tests. It fluoresces decidedly better than barium-platino-cyanide, but, owing to the size of the crystals and necessarily uneven distribution on the paper, it does not leave a clean impression. For use in connection with the sensitive films, it should be ground very fine, and some way should be adopted of distributing it uniformly. The paper also must adhere firmly to the film all over the plate, so as to get fairly sharp outlines. The fluorescence of this body seems to depend on a peculiar radiation, because I tested several bulbs, which otherwise worked excellently, without producing a very good result, and I almost gained a false impression. One or two of the bulbs, however, effected it very powerfully. An impression of the hand was taken at a distance of about six feet from the bulb with an exposure of less than one minute, and even then it was found that the plate was overexposed. I then took an impression of the chest of a man at a distance of 12 feet from the end of the tube, exposing five minutes. The developed plate showed the ribs clearly, but the outlines were not sharp. Next, I employed a tube with a zinc reflector, as before described, taking an impression of the chest of an assistant at a distance of four feet from the bulb. The latter was strained a little too much in this experiment and exploded, in consequence of the great internal pressure against the bombarded spot. This accident will frequently occur when the bulb is strained too high, the preceding outward sign being an increased activity and vaporlike appearance of the gas in the bulb and rapid heating of the latter. The process causing the abnormal increase in the internal pressure against the glass wall seems to be due to some action opposite to that noted by Crookes and Spottiswoode, and is very rapid, and for this reason the experimenter should watch carefully for these ominous signs and instantly reduce the potential. Owing to the untimely end of the bulb in this last described experiment, the exposure lasted only one minute. Nevertheless, a very strong impression of the skeleton of the chest, showing the right and left ribs and other details, was obtained. The outlines, however, were again much less sharp than when the ordinary process without the phosphorescent intensifier was followed, although care was taken to press the fluorescent paper firmly against the film. From the foregoing it is evident that, when using the above means for shortening the time of exposure, the thickness of the object is not of very much consequence.

I obtained a still better idea of the quality of tungstate of calcium by observing the effect upon a fluorescent screen made of this chemical. Such a screen, together with a paper box, has been termed with the fanciful name “fluoroscope”. It is really Salvioni’s Cryptoscope with the lens omitted, which is a great disadvantage. To appreciate the performances of such a screen, it is necessary to work at night, when the eye has for a long time been used to the darkness, and made capable of noting the faint effects on the screen. In one instance the performance of this screen was particularly noteworthy. It was illuminated at a distance of 20 feet, and even at a distance of 40 feet I could still observe a faint shadow passing across the field of vision, when moving the hand in front of the instrument. Looking at a distance of about three feet from the bulb through the body of an assistant, I could distinguish easily the spinal column in the upper part of the body, which was more transparent. In the lower part of the body the column and the rest were practically not perceptible. The ribs were only very faintly seen. The bones of the neck were plainly noticeable, and I could see through the body of the assistant very easily a square plate of copper, as it was moved up and down in front of the bulb. When looking through the head I could observe only the outline of the skull and the chin-bone, yet the field of vision was still bright. Everything else appeared indistinct. This shows that improving of fluorescence will not aid us very much in the examination of the internal parts of the body. The solution rather will come through the production of very powerful radiations, capable of producing very strong shadows. I believe I have indicated the right way to secure this result. Although it must be admitted that the performance of such a screen is remarkable with the appliances I have used, I have, nevertheless, convinced myself of its still limited value for the purpose of examination. We can distinguish the bones in the limbs, but not nearly as clearly as a photographic impression shows it. Eventually, however, with the help of strong radiations and good reflectors, such fluorescent screens may become valuable instruments for investigation. A few weeks ago, when I observed a small screen of barium-platino-cyanide flare up at a great distance from the bulb, I told some friends that it might be possible to observe by the aid of such a screen objects passing through a street. This possibility seems to me much nearer at present than it appeared then. Forty feet is a fair width for a street, and a screen lights up faintly at that distance from a single bulb. I mention this odd idea only as an illustration of how these scientific developments may even affect our morals and customs. Perhaps we shall shortly get so used to this state of things that nobody will feel the slightest embarrassment while he is conscious that his skeleton and other particulars are being scrutinized by indelicate observers.

Fluorescent screens afford some help in getting an idea of the condition of the bulb when working. I hoped to find some evidence of refraction by means of such a screen, placing a lens between it and the bulb, and varying the focal distance. To my disappointment, although the shadow of the lens was observable at a distance of 20 feet, I could see no trace of refraction. The use of the screen for the purpose of noting the effects of reflection and diffraction proved likewise futile.

9

ROENTGEN RAY INVESTIGATIONS*

Further investigations concerning the behavior of the various metals in regard to reflection of these radiations have given additional support to the opinion which I have before expressed; namely, that Volta's electric contact series in air is identical with that which is obtained when arranging the metals according to their powers of reflection, the most electro-positive metal being the best reflector. Confining myself to the metals easily experimented upon, this series is magnesium, lead, tin, iron, copper, silver, gold and platinum. The last named metal should be found to be the poorest, and sodium one of the best, reflectors. This relation is rendered still more interesting and suggestive when we consider that this series is approximately the same which is obtained when arranging the metals according to their energies of combination with oxygen, as calculated from their chemical equivalents.

Should the above relation be confirmed by other physicists, we shall be justified to draw the following conclusions: *First,* the highly exhausted bulb emits material streams which, impinging on a metallic surface, are reflected; *second,* these streams are formed of matter in some primary or elementary condition; *third,* these material streams are probably the same agent which is the cause of the electro-motive tension between metals in close proximity or actual contact, and they may possibly, to some extent, determine the energy of combination of the metals with oxygen; *fourth,* every metal or conductor is more or less a source of such streams; *fifth,* these streams of radiations must be produced by some radiations which exist in the medium; and *sixth,* streams resembling the cathodic must be emitted by the sun and probably also by other sources of radiant energy, such as an arc light or Bunsen burner.

The first of these conclusions, assuming the above-cited fact to be correct, is evident and uncontrovertible. No theory of vibration of any kind would account for this singular relation between the powers of reflection and electric properties of the metals. Streams of projected matter coming in actual contact with the reflecting metal surface afford the only plausible explanation.

The second conclusion is likewise obvious, since no difference whatever is observed by employing various qualities of glass for the bulb, electrodes of different metals and any kind of residual gases. Evidently, whatever the matter constituting the streams may be, it must undergo a change in the process of expulsion, or, generally speaking, projection — since the views in this regard still differ — in such a way as to lose entirely the characteristics which it possessed when forming the electrode, or wall of the bulb, or the gaseous contents of the latter.

The existence of the above relation between the reflecting and contact series forces us likewise to the third conclusion, because a mere coincidence of that kind is, to say the least, extremely improbable. Besides, the fact may be cited that there is always a

* Electrical Review, April 22, 1896.

difference of potential set up between two metal plates at some distance and in the path of the rays issuing from an exhausted bulb.

Now, since there exists an electric pressure of difference of potential between two metals in close proximity or contact, we must, when considering all the foregoing, come to the fourth conclusion, namely, that the metals emit similar streams, and I therefore anticipate that, if a sensitive film be placed between two plates, say, of magnesium and copper, a true Roentgen shadow picture would be obtained after a very long exposure in the dark. Or, in general, such picture could be secured whenever the plate is placed near a metallic or conducting body, leaving for the present the insulators out of consideration. Sodium, one of the first of the electric contact series, but not yet experimented upon, should give out more of such streams than even magnesium.

Obviously, such streams could not be forever emitted, unless there is a continuous supply of radiation from the medium in some other form; or possibly the streams which the bodies themselves emit are merely reflected streams coming from other sources. But since all investigation has strengthened the opinion advanced by Roentgen that for the production of these radiations some impact is required, the former of the two possibilities is the more probable one, and we must assume that the radiations existing in the medium and giving rise to those here considered partake something of the nature of cathodic streams.

But if such streams exist all around us in the ambient medium, the question arises, whence do they come? The only answer is: From the sun. I infer, therefore, that the sun and other sources of radiant energy must, in a less degree, emit radiations or streams of matter similar to those thrown off by an electrode in a highly exhausted inclosure. This seems to be, at this moment, still a point of controversy. According to my present convictions a Roentgen shadow picture should, with very long exposures, be obtained from all sources of radiant energy, provided the radiations are permitted first to impinge upon a metal or other body.

The preceding considerations tend to show that the lumps of matter composing a cathodic stream in the bulb are broken up into incomparably smaller particles by impact against the wall of the latter, and, owing to this, are enabled to pass into the air. All evidence which I have so far obtained points rather to this than to the throwing off of particles of the wall itself under the violent impact of the cathodic stream. According to my convictions, then, the difference between Lenard and Roentgen rays, if there be any, lies solely in this, that the particles composing the latter are incomparably smaller and possess a higher velocity. To these two qualifications I chiefly attribute the non-deflectibility by a magnet which I believe will be disproved in the end. Both kinds of rays, however, affect the sensitive plate and fluorescent screen, only the rays discovered by Roentgen are much more effective. We know now that these rays are produced under certain exceptional conditions in a bulb, the vacuum being extremely high, and that the range of greatest activity is rather small.

I have endeavored to find whether the reflected rays possess certain distinctive features, and I have taken pictures of various objects with this purpose in view, but no marked difference was noted in any case. I therefore conclude that the matter composing the Roentgen rays does not suffer further degradation by impact against bodies. One of the most important tasks for the experimenter remains still to determine what becomes of the energy of these rays. In a number of experiments with rays reflected from and transmitted through a conducting of insulating plate, I found that only a small part of the rays could be accounted for. For instance, through a zinc plate, one-sixteenth of an inch thick, under an incident angle of 45 degrees, about two and one-half per cent were reflected and about three per cent transmitted through the plate, hence over 94 per cent of the total radiation remain to be accounted for. All the tests which I have been able to make have confirmed Roentgen's statement that these rays are incapable of raising the temperature of a body. To trace this lost energy and account for it in a plausible way will be equivalent to making a new discovery.

Since it is now demonstrated that all bodies reflect more or less, the diffusion through the air is easily accounted for. Observing the tendency to scatter through the air, I have been led to increase the efficiency of reflectors by providing not one, but separated successive layers for reflection, by making the reflector of thin sheets of metal, mica or other substances. The efficiency of mica as a reflector I attribute chiefly to the fact that it is composed of many superimposed layers which reflect individually. These many successive reflections are, in my opinion, also the cause of the scattering through the air.

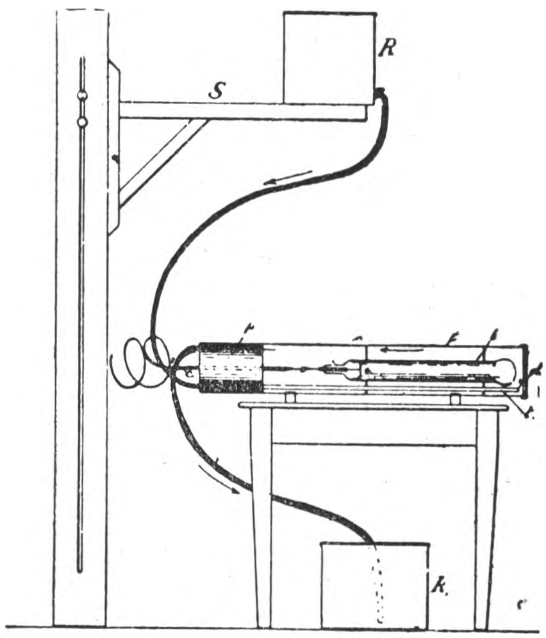
In my communication to you of April 1, I have for the first time stated that these rays are composed of matter in a “primary” or elementary condition or state. I have chosen this mode of expression in order to avoid the use of the word “ether”, which is usually understood in the sense of the Maxwellian interpretation, which would not be in accord with my present convictions in regard to the nature of the radiations.

An observation which might be of some interest is the following: A few years ago I described on one occasion a phenomenon observed in highly exhausted bulbs. It is a brush or stream issuing from a single electrode under certain conditions, which rotates very rapidly in consequence of the action of the earth’s magnetism. Now I have recently observed this same phenomenon in several bulbs which were capable of impressing the sensitive film and fluorescent screen very strongly. As the brush is rapidly twirling around I have conjectured that perhaps also the Lenard and Roentgen streams are rotating under the action of the earth’s magnetism, and I am endeavoring to obtain an evidence of such motion by studying the action of a bulb in various positions with respect to the magnetic axis of the earth.

In so far as the vibrational character of the rays is concerned, I still hold that the vibration is merely that which is conditioned by the apparatus employed. With the ordinary induction coil we have almost exclusively to deal with a very low vibration impressed by the commutating device or brake. With the disruptive coil we usually have a very strong superimposed vibration in addition to the fundamental one, and it is easy to trace sometimes as much as the fourth octave of the fundamental vibration. But I can not reconcile myself with the idea of vibrations approximating or even exceeding those of light, and think that all these effects could be as well produced with a steady electrical pressure as from a battery, with the exclusion of all vibration which may occur, even in such instance, as has been pointed out by De La Rive. In my experiments I have tried to ascertain whether a greater difference between the shadows of the bones and flesh could be obtained by employing currents of extremely high frequency, but I have been unable to discover any such effect which would be dependent on the frequency of the currents, although the latter were varied between as wide limits as was possible. But it is a rule that the more intense the action the sharper the shadows obtained, provided that the distance is not too small. It is furthermore of the greatest importance for the clearness of the shadows that the rays should be passed through some tubular reflector, which renders them sensibly parallel.

In order then to bring out as much detail as possible on a sensitive plate, we have to proceed in precisely the same way as if we had to deal with flying bullets hitting against a wall composed of parts of different density with the problem before us of producing as large as possible a difference in the trajectories of the bullets which pass through the various parts of the wall. Manifestly, this difference will be the greater the greater the velocity of the bullets; hence, in order to bring out detail, very strong radiations are required. Proceeding on this theory I have employed exceptionally thick films and developed very slowly, and in this way clearer pictures have been obtained. The importance of slow development has been first pointed out by Professor Wright, of Yale. Of course, if Professor Henry's suggestion of the use of a fluorescent body in contact with the sensitive film is made use of, the process is reduced to an ordinary quick photographic procedure, and the above consideration does not apply.

It being desirable to produce as powerful a radiation as possible, I have continued to devote my attention to this problem and have been quite successful. First of all, there existed limitations in the vacuum tube which did not permit the applying of as high a potential as I desired; namely, when a certain high degree of exhaustion was reached a spark would form behind the electrode, which would prevent straining the



tube much higher. This inconvenience I have overcome entirely by making the wire leading to the electrode very long and passing it through a narrow channel, so that the heat from the electrode could not cause the formation of such sparks. Another limitation was imposed by streamers which would break out at the end of the tube when the potential was excessive. This latter inconvenience I have overcome either by the use of a cold blast of air along the tube, as I have mentioned before, or else by immersion of the tube in oil. The oil, as it is now well known, is a means of rendering impossible the formation of streamers by the exclusion of all air. The use of the oil in connection with the production of these radiations has been early advocated in this country by Professor Trowbridge. Originally I employed a wooden box made thoroughly tight with wax and filled with oil or other liquid, in which the tube was immersed. Observing certain specific actions, I modified and improved the apparatus, and in my later investigations I have employed an arrangement as shown in the annexed cut: A bulb *b,* of the kind described before, with a leading-in wire and neck much longer than here shown, was inserted into a large and thick glass tube *t.* The tube was closed in front by a diaphragm *d* of pergament, and by a rubber plug P in the back. The plug was provided with two holes, into the lower one of which a glass tube t_1, reaching to very nearly the end of the bulb, was inserted. Oil of some kind was made to flow through rubber tubes *r r* from a large reservoir R, placed on an adjustable support S, to the lower reservoir R_1 the path of the oil being clearly observable from the drawing.

By adjusting the difference of the level between the two reservoirs it was easy to maintain a permanent condition of working. The outer glass tube *t* served in part as a reflector, while at the same time it permitted the observation of the bulb *b* during the action. The plug P, in which the conductor *c* was tightly sealed, was so arranged that it could be shifted in and out of the tube *t,* so as to vary the thickness of the oil traversed by the rays.

I have obtained some results with this apparatus which clearly show the advantage of such disposition. For instance, at a distance of 45 feet from the end of the bulb my assistants and myself could observe clearly the fingers of the hand through a screen of tungstate of calcium, the rays traversing about two and one half inches of oil and the diaphragm *d.* It is practicable with such apparatus to make photographs of small objects at a distance of 40 feet, with only a few minutes exposure, by the help of Professor Henry's method. But, even without the use of a fluorescent powder, short exposures are practicable, so that I think the use of the above method is not essential for quick procedure. I rather believe that in the practical development of this principle, if it shall be necessary, Professor Salvioni's suggestion of a fluorescent emulsion, combined with a film, will have to be adopted. This is bound to give better results than an independent fluorescent screen, and will very much simplify the process. I may say, however, that, since my last communication, considerable improvement has been made in the screens. The manufacturers of Edison's tungstate of calcium are now furnishing screens which give fairly clean pictures. The powder is fine and it is more uniformly distributed. I consider, also, that the employment of a softer and thicker paper than before is of advantage. It is just to remark that the tungstate of calcium has also proved to be an excellent fluorescent in the bulb. I tested its qualities for such use immediately and find it so far unexcelled. Whether it will be so for a long time remains to be seen. News reaches us that several fluorescent bodies, better than the cyanides, have been discovered abroad.

Another improvement with a view of increasing the sharpness of the shadows has been proposed to me by Mr. E. R. Hewitt. He assumed that the absence of sharpness of the outlines in the shadows on the screen was due to the spread of the fluorescence from crystal to crystal. He proposed to avoid this by using a thin aluminum plate with many parallel grooves. Acting on this suggestion, I made some experiments with wire gauze and, furthermore, with screens made of a mixture of a fluorescent with a non-fluorescent powder. I found that the general brightness of the screen was diminished, but that with a strong radiation the shadows appeared sharper. This idea might be found capable of useful application.

By the use of the above apparatus I have been enabled to examine much better than before the body by means of the fluorescent screen. Presently the vertebral column can be seen quite clearly, even in the lower part of the body. I have also clearly noted the outlines of the hip bones. Looking in the region of the heart I have been able to locate in unmistakably. The background appeared much brighter, and this difference in the intensity of the shadow and surrounding has surprised me. The ribs I could now see on a number of occasions quite distinctly, as well as the shoulder bones. Of course, there is no difficulty whatever in observing the bones of all limbs. I noted certain peculiar effects which I attribute to the oil. For instance, the rays passed through plates of metal over one-eighth of an inch thick, and in one instance I could see quite clearly the bones of my hand through sheets of copper, iron and brass of a thickness of nearly one-quarter of an inch. Through glass the rays seemed to pass with such freedom that, looking through the screen in a direction at right angles to the axis of the tube, the action was most intense, although the rays had to pass through a great thickness of glass and oil. A glass slab nearly one-half of an inch thick, held in front of the screen, hardly dimmed the fluorescence. When holding the screen in front of the tube at a distance of about three feet, the head of an assistant, thrust between the screen and the tube, cast but a feeble shadow. It appeared some times as if the bones and the flesh were equally transparent to the radiations passing through the oil. When very close to the bulb, the screen was illuminated through the body of an assistant so strongly that, when a hand was moved in front, I could clearly note the motion of the hand through the body. In one instance I could even distinguish the bones of the arm.

Having observed the extraordinary transparence of the bones in some instances, I at first surmised that the rays might be vibrations of high pitch, and that the oil had in some way absorbed a part of them. This view, however, became untenable when I found that at a certain distance from the bulb I obtained a sharp shadow of the bones. This latter observation led me to apply usefully the screen in taking impressions on the plate. Namely, in such case it is of advantage to first determine by means of the screen the proper distance at which the object is to be placed before taking the impression. It will be found that often the image is much clearer at a greater distance. In order to avoid any error when observing with the screen, I have surrounded the box with thick metal plates, so as to prevent the fluorescence, in consequence of the radiations, reaching the screen from the sides. I believe that such an arrangement is absolutely necessary if one wishes to make correct observations.

During my study of the behavior of oils and other liquid insulators, which I am still continuing, it has occurred to me to investigate the important effect discovered by Prof. J. J. Thomson. He announced some time ago that all bodies traversed by Roentgen radiations become conductors of electricity. I applied a sensitive resonance test to the investigation of this phenomenon in a manner pointed out in my earlier writings on high frequency currents. A secondary, preferably not in very close inductive relation to the primary circuit, was connected to the latter and to the ground, and the vibration through the primary was so adjusted that true resonance took place. As the secondary had a considerable number of turns, very small bodies attached to the free terminal produced considerable variations of potential on the latter. Placing a tube in a box of wood filled with oil and attaching it to the terminal, I adjusted the vibration through the primary so that resonance took place without the bulb radiating Roentgen rays to an appreciable extent. I then changed the conditions so that the bulb became very active in the production of the rays. The oil should have now, according to Prof. J. J. Thomson's statement, become a , conductor and a very marked change in the vibration should have occurred. This was found not to be the case, so that we must see in the phenomenon discovered by J. J. Thomson only a further evidence that we have to deal here with streams of matter which, traversing the bodies, carry away electrical charges. But the bodies do not become conductors in the common acceptance of the term. The method I have followed is so delicate that a mistake is almost an impossibility.

10

AN INTERESTING FEATURE OF X-RAY RADIATIONS*

The following observations, made with bulbs emitting Roentgen radiations, may be of value in throwing additional light upon the nature of these radiations, as well as illustrating better properties already known. In the main these observations agree with the views which have forced themselves upon my mind from the outset, namely, that the rays consist of streams of minute material particles projected with great velocity. In numerous experiments I have found that the matter which, by impact within the bulb, causes the formation of the rays may come from either of the electrodes. Inasmuch as the latter are by continued use disintegrated to a marked degree, it seems more plausible to assume that the projected matter consists of parts of the electrodes themselves rather than of the residual gas. However, other observations, upon which I can not dwell at present, lead to this conclusion. The lumps of projected matter are by impact further disintegrated into particles so minute as to be able to pass through the walls of the bulb, or else they tear off such particles from the walls, or generally bodies, against which they are projected. At any rate, an impact and consequent shattering seems absolutely necessary for the production of Roentgen rays. The vibration, if there be any, is only that which is impressed by the apparatus, and the vibrations can only be longitudinal.

The principal source of the rays is invariably the place of first impact within the bulb, whether it be the anode, as in some forms of tube, or an inclosed insulated body, or the glass wall. When the matter thrown off from an electrode, after striking against an obstacle, is thrown against another body, as the wall of the bulb, for instance, the place of second impact is a very feeble source of the rays.

These and other facts will be better appreciated by referring to the annexed figure, in which a form of tube is shown used in a number of my experiments. The general form is that described on previous occasions. A single electrode *e,* consisting of a massive aluminium plate, is mounted on a conductor *c,* provided with a glass wrapping *w* as usual, and sealed in one of the ends of a straight tube *b,* about five centimetres in diameter and 30 centimetres long. The other end of the tube is blown out into a thin bulb of a slightly larger diameter, and near this end is supported on a glass stem *s* a funnel *f* of thin platinum sheet. In such bulbs I have used a number of different metals for impact with a view of increasing the intensity of the rays and also for the purpose of reflecting and concentrating them. Since, however, in a later contribution, Professor Roentgen has pointed out that platinum gives the most intense rays, I have used chiefly this metal, finding a marked increase in the effect upon the screen or sensitive plate. The particular object of the presently described construction was to ascertain whether the rays generated at the inner surface of the platinum funnel *f* would be brought to a focus outside of the bulb, and further, whether they would proceed in straight lines from that point. For this purpose the apex of the platinum cone was arranged to be about two centimetres outside of the bulb at *o.*

* Electrical Review, July 8, 1896.

When the bulb was properly exhausted and set in action, the glass wall below the funnel *f* became strongly phosphorescent, but not uniformly, as there was a narrow ring *r r* on the periphery brighter than the rest, this ring being evidently due to the rays reflected from the platinum sheet.

Placing a fluorescent screen in contact or quite close to the glass wall below the funnel, the portion of the screen in the immediate neighborhood of the phosphorescent patch was brightly illuminated, the outlines being entirely indistinct. Receding now with the screen from the bulb, the strongly illuminated spot became smaller and the outlines sharper, until, when the point o was reached, the luminous part had dwindled down to a small point. Moving the screen a few millimetres beyond o caused a small dark spot to appear, which widened into a circle and became larger and larger in the same measure as the distance from the bulb was increased (see S), until, at a sufficiently

Diagram Illustrating The Experiment.

large distance, the dark circle covered the entire screen. This experiment illustrated in a beautiful way the propagation in straight lines, which Roentgen originally proved by pinhole photographs. But, besides this, an important point was noted; namely, that the fluorescent glass wall emitted practically no rays, whereas, had the platinum not been present, it would have been, under similar conditions, an efficient source of the rays, for the glass, even by weak excitation of the bulb, was strongly heated. I can only explain the absence of the radiation from the glass by assuming that the matter proceeding from the surface of the platinum sheet was already in a finely divided state when it reached the glass wall. A remarkable fact is, also, that, at least by a weak excitation of the bulb, the edges of the dark circle were very sharp, which speaks strongly against diffusion. By exciting the bulb very strongly, the background became brighter and the shadow S fainter, though it continued to be plainly visible even then.

From the preceding it is evident that, by a suitable construction of the bulb, the rays emanating from the latter may be concentrated upon any small area at some distance, and a practical advantage may be taken of this fact when producing impressions upon a plate or examining bodies by means of a fluorescent screen.

11

ROENTGEN RAYS OR STREAMS*

In the original report of his epochal discoveries, Roentgen expressed his conviction that the phenomena he observed were due to certain novel disturbances in the ether. This opinion deserves to be considered the more as it was probably formed in the first enthusiasm over the revelations, when the mind of the discoverer was capable of a much deeper insight into the nature of things.

It was known since long ago that certain dark radiations, capable of penetrating opaque bodies, existed, and when the rectilinear propagation, the action on a fluorescent screen and on a sensitive film was noted, an obvious and unavoidable inference was that the new radiations were transverse vibrations, similar to those known as light. On the other hand, it was difficult to resist certain arguments in favor of the less popular theory of material particles, especially as, since the researches of Lenard, it has become very probable that material streams, resembling the cathodic, existed in free air. Furthermore, I myself have brought to notice the fact that similar material streams — which were subsequently, upon Roentgen's announcement, found capable of producing impressions on a sensitive film — were obtainable in free air, even without the employment of a vacuum bulb, simply by the use of very high potentials, suitable for imparting to the molecules of the air or other particles a sufficiently high velocity. In reality, such puffs or jets of particles are formed in the vicinity of every highly charged conductor, the potential of which is rapidly varying, and I have shown that, unless they are prevented, they are fatal to every condenser or high-potential transformer, no matter how thick the insulation. They also render practically valueless any estimate of the period of vibration of an electro-magnetic system by the usual mode of calculation or measurement in a static condition in all cases in which the potential is very high and the frequency excessive.

It is significant that, with these and other facts before him, Roentgen inclined to the conviction that the rays he discovered were longitudinal waves of ether.

After a long and careful investigation, with apparatus excellently suited for the purpose, capable of producing impressions at great distances, and after examining the results pointed out by other experimenters, I have come to the conclusion which I have already intimated in my former contributions to your esteemed journal, and which I now find courage to pronounce without hesitation, that the original hypothesis of Roentgen will be confirmed in two particulars; first, in regard to the longitudinal character of the disturbances; second, in regard to the medium concerned in their propagation. The present expression of my views is made solely for the purpose of preserving a faithful record of what, to my mind, appears to be the true interpretation of these new and important manifestations of energy.

Recent observations of some dark radiations from novel sources by Becquerel and others, and certain deductions of Helmholtz, seemingly applicable to the explanation

* Electrical Review, August 12, 1896.

of the peculiarities of the Roentgen rays, have given additional weight to the arguments on behalf of the theory of transverse vibrations, and accordingly this interpretation of the phenomena is held in favor. But this view is still of a purely speculative character, being, as it is at present, unsupported by any conclusive experiment. Contrarily, there is considerable experimental evidence that some matter is projected with great velocity from the bulbs, this matter being in all probability the only cause of the actions discovered by Roentgen.

There is but little doubt at present that a cathodic stream within a bulb is composed of small particles of matter, thrown off with great velocity from the electrode. The velocity probably attained is estimable, and fully accountable for the mechanical and heating effects produced by the impact against the wall or obstacle within the bulb. It is, furthermore, an accepted view that the projected lumps of matter act as inelastic bodies, similarly to ever so many small lead bullets. It can be easily shown that the velocity of the stream may be as much as 100 kilometers a second, or even more, at least in bulbs with a single electrode, in which the practicable vacua and potentials are much higher than in the ordinary bulbs with two electrodes. But, now, matter moving with such great velocity must surely penetrate great thicknesses of the obstruction in its path, if the laws of mechanical impact are at all applicable to a cathodic stream. I have presently so much familiarized myself with this view that, if I had no experimental evidence, I would not question the fact that some matter is projected through the thin wall of a vacuum tube. The exit from the latter is, however, the more likely to occur, as the lumps of matter must be shattered into still much smaller particles by the impact. From my experiments on reflection of the Roentgen rays, before reported, which, with powerful radiations, may be shown to exist under all angles of incidence, it appears that the lumps or molecules are indeed shattered into fragments or constituents so small as to make them lose entirely some physical properties possessed before the impact. Thus, the material composing the electrode, the wall of the bulb or obstruction of any kind placed within the latter, are of absolutely no consequence, except in so far as the intensity of the radiations is concerned. It also appears, as I have pointed out, that no further disintegration of the lumps is attendant upon a second impact. The matter composing the cathodic stream is, to all evidence, reduced to matter of some primary form, heretofore not known, as such velocities and such violent impacts have probably never been studied or even attained before these extraordinary manifestations were observed. Is it not possible that the very ether vortexes which, according to Lord Kelvin's ideal theory, compose the lumps, are dissolved, and that in the Roentgen phenomena we may witness a transformation of ordinary matter into ether? It is in this sense that, I think, Roentgen's first hypothesis will be confirmed. In such case there can be, of course, no question of waves other than the longitudinal assumed by him, only, in my opinion, the frequency must be very small — that of the electro-magnetic vibrating system — generally not more than a few millions a second. If such process of transformation does take place, it will be difficult, if not impossible, to determine the amount of energy represented in the radiations, and the statement that this amount is very small should be received with some caution.

As to the rays exhaustively studied by Lenard, which have proved to be the nucleus of these great realizations, I hold them to be true cathodic streams, projected through the wall of the tube. Their deflectibility by a magnet shows to my mind simply that they differ but little from those within the bulb. The lumps of matter are probably large and the velocity small as compared with that of the Roentgen rays. They should, however be capable in a minor degree of all the actions of the latter. These actions I consider to be purely mechanical and obtainable by other means. So, for instance, I think that if a gun loaded with mercury were fired through a thin board, the projected mercury vapor would cast a shadow of an object upon a film made especially sensitive to mechanical impact, or upon a screen of material capable of being rendered fluorescent by such impact.

The following observations made by myself and others speak more or less for the existence of the streams of matter.

I — PHENOMENA OF EXHAUSTION

On this subject I have expressed myself on another occasion. It is only necessary to once more point out that the effect observed by me should not be confounded with that noted by Spottiswoode and Crookes. I explain the latter phenomenon as follows: The first fluorescence appearing when the current is turned on, is due to some organic matter almost always introduced in the bulb in the process of manufacture. A minute layer of such matter on the wall produces invariably this first fluorescence, and the latter never takes place when the bulb has been exhausted under application of a high degree of heat or when the organic matter is otherwise destroyed. Upon the disappearance of the first fluorescence the rarefaction increases slowly, this being a necessary result of particles being projected from the electrode and fastening themselves upon the wall. These particles absorb a large portion of the residual gas. The latter can be again freed by the application of heat to the bulb or otherwise. So much of the effects observed by these investigators. In the instance observed by myself, there must be actual expulsion of matter, and for this speak following facts: (a) the exhaustion is quicker when the glass is thin; (b) when the potential is higher; (c) when the discharges are more sudden; (d) when there is no obstruction within the bulb; (e) the exhaustion takes place quickest with an aluminum or platinum electrode, the former metal giving particles moving with greatest velocity, the latter particles of greatest weight; (f) the glass wall, when softened by the heat, does not collapse, but bulges outwardly; (g) the exhaustion takes place, in some cases, even if a small perceptible hole is pierced through the glass; (h) all causes tending to impart a greater velocity to the particles hasten the process of exhaustion.

II — RELATION BETWEEN OPACITY AND DENSITY

The important fact pointed out early by Roentgen and confirmed by subsequent research, namely, that a body is the more opaque to the rays the denser it is, can not be explained as satisfactorily under any other assumption as that of the rays being streams of matter, in which case such simple relation between opacity and density would necessarily exist. This relation is the more important in its bearing upon the nature of the rays, as it does not at all exist in light-giving vibrations, and should consequently not be found to so marked a degree and under *all conditions with vibrations,* presumably similar to and approximating in frequency the light vibrations.

III — DEFINITION OF SHADOWS ON SCREEN OR PLATE

When taking impressions or observing shadows while varying the intensity of the radiations, but maintaining all other conditions as nearly as possible alike, it is found that the employment of more intense radiations secures little, if any, advantage, as regards the definition of the details. At first it was thought that all there was needed was to produce very powerful rays. But the experience was disappointing, for, while I succeeded in producing rays capable of impressing a plate at distances of certainly not less than 30 metres, I obtained but slightly better results. There was one advantage in using such intense rays, and this was that the plate could be further removed from the source, and consequently a better shadow was obtained. But otherwise nothing to speak of was gained. The screen in the dark box would be at times rendered so bright as to allow reading at some distance plainly, but the shadow was not more distinct for all that. In fact, often a very strong radiation gave a poorer impression than a weak one. Now, a fact which I have repeatedly observed and to which I attach great importance in this connection, is the following: When taking impressions at a small distance with a tube giving very intense rays, no shadow, unless a scarcely perceptible one, is obtained. Thus, for instance, the flesh and bones of the hand appear equally transparent. Increasing presently gradually the distance, it is found that the bones cast a shadow, while the flesh leaves no impression. The distance still increased, the shadow of the flesh appears, while that of the bones grows deeper, and in this neighborhood a place can be found at which the definition of the shadow is clearest. If the distance is still further continually increased, the detail is lost, and finally only a vague shadow is perceptible, showing apparently the outlines of the hand.

This often-noted fact disagrees entirely with any theory of transverse vibrations, but can be easily explained on the assumption of material streams. When the hand is near and the velocity of the stream of particles very great, both bone and flesh are easily penetrated, and the effect due to the difference in the retardation of the particles passing through the heterogeneous parts can not be observed. The screen can fluoresce only up to a certain limited intensity, and the film can be affected only to a certain small degree. When the distance is increased, or, what is equivalent, when the intensity of the radiation is reduced, the more resisting bones begin to throw the shadow first. Upon a further increase of the distance the flesh begins likewise to stop enough of the particles to leave a trace on the screen. But in all cases, at a certain distance, manifestly that which under the conditions of the experiment gives the greatest difference in the trajectories of the particles within *the range perceptible on the screen or film,* the clearest shadow is secured.

IV — THE RAYS ARE ALL OF ONE KIND

The preceding explains the apparent existence of rays of different kind; that is, of different rates of vibration, as it is asserted. In my opinion, the velocity and possibly the size of the particles both are different, and this fully accounts for the discordant results obtained in regard to the transparency of various bodies to these rays. I found, for example, in many cases that aluminum was less transparent than glass, and in some instances brass appeared to be very transparent as compared with other metallic bodies. Such observations showed that it was necessary, in making the comparison, to take rigorously equal thicknesses of the bodies and place them as closely together as possible. They also showed the fallacy of comparing results obtained with different bulbs.

V — ACTION ON THE FILMS

Many experiments with films of different thicknesses show that decidedly more detail is obtainable with a thick film than with a thin one. This appears to me to be a further evidence in support of the above views, as the result can be easily explained when considering the preceding remarks.

VI — THE BEHAVIOR OF VARIOUS BODIES IN REFLECTING THE RAYS,

on which I have previously dwelt, will, if verified by other experimenters, leave no room for a doubt that the radiations are streams of some matter, or possibly of ether, as before observed.

VII — THE ENTIRE ABSENCE OF REFRACTION

and other features possessed by the light waves has, since Roentgen's announcement, not yet been satisfactorily explained. A trace at least of such an effect would be found if the rays were transverse vibrations.

VIII — THE DISCHARGE OF CONDUCTORS

by the rays shows, in so far as I have been able to follow the researches of others, that the electrical charge is taken off by the bodily carriers. It is also found that the opacity plays an important part, and the observations are mostly in accord with the above views.

IX — THE SOURCE OF THE RAYS

is, I find, always the place of the first impact of the cathodic stream, a second impact producing little or no rays. This fact would be difficult to account for unless streams of matter are assumed to exist.

X — SHADOWS IN SPACE OUTSIDE OF THE BULB

An almost crucial test of the existence of material streams is afforded by the formation of shadows in space at a distance from the bulb, to which I have called attention quite recently. I will presently refer to my preceding communication on this subject, and will only point out that such shadows could not be formed under the conditions described, except by streams of matter.

XI — ALL BODIES ARE TRANSPARENT TO VERY STRONG RAYS

Experiments establish this fact beyond any doubt. With very intense radiations, I obtain, easily, impressions through what may be considered a great thickness of any metal. It is impossible to explain this on any theory of transverse vibrations. We can show how one or other body might allow the rays to pass through, but such explanations are not applicable to *all* bodies without exception. On the contrary, assuming material streams, such a result is unavoidable.

A great many other observations and facts might be added to the above, as further evidence in support of the above views. I have noted certain peculiarities of bodies obstructing a cathodic stream within the bulb. I have observed that the same rays are produced at all degrees of exhaustion and using bodies of vastly different physical properties, and have found a number of features in regard to the pressure, the vacuum, the residual gas, the material of the electrode, etc., all of which observations are more or less in accord with what I have stated before. I hope, however, that there is enough in the present lines to enlist the attention of others.

12

ON THE ROENTGEN STREAMS.*

The following lines may contain some useful information for physicists and physicians. Those who, in the exercise of their professional duties are applying the discoveries of Roentgen to the relief of the suffering by determining the position of foreign objects or ascertaining the condition of local troubles of malformations in the organism, are apt to be disappointed in many instances. While it is perfectly easy to find the position of a foreign object in the head, neck and all soft tissues of the body, and detect some far gone trouble in the lungs, often the location of even such a large and opaque object as a bullet, when imbedded in certain bony parts of the trunk of the patient, may be attended with difficulties. Success will be invariably attained if the suggestions which are given below, and which are the outcome of a number of observations of such cases, are strictly followed.

In order to make the present statements self-contained and more useful, I deem it of advantage to say a few words in regard to the Roentgen rays. According to all evidences so far obtained by me, I entertain the view, which I have expressed on other occasions, that these rays are formed by streams of some matter projected with great velocity, and generally intermittently, from the walls of the tube. The intermittent character is only due to this feature of the apparatus usually employed for the production of the rays; but the oscillatory or intermittent discharge is not absolutely necessary, as I have produced unidirectional currents of high tension which are likewise capable of generating strong rays, and as a static machine may be used with a like result. The mode of formation of these rays or streams is, for the present purposes, of little importance. The small particles within the bulb, which are the original cause, may be ions, formed by a process of electrolysis, or they may be comparatively larger particles of the electrode, or perhaps molecules of the residual gas. At any rate, it is probable that the particles are very minute, and that, therefore, the velocities of the cathodic streams within the vessel are such and the impacts so violent as to cause a further disintegration of the cathodic matter to state probably never before studied by physicists. We may have to deal, as I have already suggested, with an actual breaking up of the ether-vortexes, which, according to Lord Kelvin's theory, compose the material particles, or we may be confronted with a dissolution of matter into some unknown primary form, the Akasa of the old Vedas. Experiments show that this matter is reflected, sometimes very well, sometimes poorly; but in all cases the various metals behave in a curious manner, which I have studied, and the results obtained, though probably not free of error, because of the great difficulties in getting an exact estimate in such an investigation, were, nevertheless, sufficiently positive as to lead me to the conviction that the same medium or element which is concerned in the setting up of the electro motive tension between metals in contact is present in the streams of Roentgen. It might have been proper to say; in the spirit of more modern views on contact electricity, that these streams

* Electrical Review, December 1, 1896.

are formed by ether, but I have preferred to use the term “primary matter”, for, although the expression “ether” conveys a perfectly definite idea to the scientific mind, there exists, nevertheless, much vagueness as to the structure of this medium. The matter projected is not revealed by spectral analysis, and it does not seem to produce any appreciable mechanical nor even heating effects, nor is it deflected by a magnet, all of which facts tend to show that it can not be composed of molecules of any known substance. The streams exercise a powerful action upon a photographic plate or fluorescent screen, but I look upon these results as obvious consequences of the energetic impact.

Of the various more or less plausible views in regard to the formation of these streams outside of the vessel, the simplest, to my mind, is to assume an actual projection through the walls of the bulb of the disintegrated cathodic matter. Granted that there are particles sufficiently small within the bulb, then all velocities, up to many thousands of kilometers per second, are not only possible, but also probable; and, even if the particles would not be further disintegrated by the impact against the wall or other comparatively opaque body within the bulb, they surely would penetrate through great thicknesses of most substances. My experiments in this direction have shown that all the disintegration is practically accomplished in the first impact against the more or less impenetrable obstacle within the bulb, the second impact having seemingly little effect, as might be inferred from well established mechanical principles. I have also found that the place of first and most energetic impact, be it the anode, cathode or wall of the vessel, is invariably the principal source of the rays or streams. Again, quite in accordance with mechanical principles, the penetrative power of the streams is the greater the more complete the disintegration. Thus, for instance, rays which have traversed thick opaque objects, and are presumably further disintegrated, pass more freely through dense substances. An observation to this effect has likewise been made by Professor Wright, who was the first to publish definite results in the United States. I find that bulbs with thick walls give rays of greater penetrating power. It should be, of course, understood that I do not mean by this a greater outward effect. It is principally the above fact which makes it appear more probable that the matter projected is not a homogeneous stream, but consists of particles of varied magnitude moving with different velocities, for, were the former the case, the penetrative power would depend chiefly on the velocity. In the practical use of the Roentgen streams it would, therefore, seem very important to find a method of filtering and rendering them homogeneous, for only by such a method can we hope to obtain exact results in their investigation. Streams of perfectly uniform velocity and character, if produced, would no doubt be more suitable for the purposes of research.

Since the disintegration of the electrodes, especially if they are of aluminum, is so slow that no appreciable diminution of the weight results even after long use; it follows that the matter conveyed by the Roentgen streams is so minute as to escape detection. Some bulbs, which I have used for a number of months, showed that the bombarded spot of the glass was entirely permeated with particles of the aluminum electrode, but it would probably require years of constant use to accumulate any appreciable amount of matter outside. Referring to a tube with an electrode of aluminum, it is a noteworthy fact that, if properly managed, it does not impair in quality, but, on the contrary, seems to improve; whereas, when a platinum electrode is used, the life of the bulb is very short, owing to the conductor being deposited on the walls, which deposit, as I have explained on another occasion, renders difficult the passage of the discharge. Namely, as soon as some of the projected particles strike the conducting layer, they impart a similar electrification to the latter, and a repulsion is exerted upon the particles following. The result is an apparent increase in the resistance of the tube. The above defect of the platinum electrode, despite of its effectiveness, must, in my opinion, lead to its abandonment.

It has been suggested that the Roentgen rays may be due simply to a propagation of electro-static stress; but, on this assumption, it is difficult to conceive how rays could be produced in instances when the glass wall is at a high temperature and consequently conducting, or when the impact plate or inclosure is of metal and connected to the ground. Stokes has recently considered the possibility that the impact of the cathodic stream on one side of a partition might give rise to a molecular motion on the other side without necessarily there being a transit through the partition. According to this view, which I have likewise considered some time ago, it would appear that the material streams might start on the outer side of the wall of the tube, in which case only the air would be responsible for the effects, and the futility of a spectral analysis test would be in a certain measure accounted for. But is it not more probable to assume an actual passage and shattering of matter as all evidences point in this direction? Assuming that, as Professor Stokes now thinks it probable, the disturbance is non-periodic and still capable of producing effects characteristic of transverse vibrations of extremely high frequency, it seems to me a serious question whether, the old Newtonian views on light should not be reconsidered rather than the conclusion drawn that the novel manifestations observed by Roentgen are due to transverse vibrations, when there is no experimental evidence to this effect, nor even a satisfactory explanation found how the cathodic impact might give rise to waves of a higher frequency than those of light.

Being, as I am, firmly convinced of the existence of material streams, I look upon the unsuccess of the attempts of demonstrating an actual transit of matter as being due to either the minuteness of the amount or else to the state of the matter, but rather, to the former cause, as all peculiarities of the streams point in this direction. In my opinion, no experimenter need be deterred from carrying on an investigation of the Roentgen rays for fear of poisonous or generally deleterious action, for it seems reasonable to conclude that it would take centuries to accumulate enough of such matter as to interfere seriously with the process of life of a person. But I look confidently to the demonstration of actions of a purely qualitative nature. For instance, despite of the danger of such an assertion by encouragement which might be given to quacks I would say that I expect with the utmost confidence the demonstration of a germicidal action. In addition to the physiological effects, to which I have early drawn attention, I have more recently observed with powerful tubes that a sensation of pain is produced in the forehead above the eyes just as soon as the current is turned on. This sensation is very similar to that one frequently experiences when stepping from a dark room into the glare of bright sunlight, or when walking for some time over fields of fresh-fallen snow.

As to the hurtful actions on the skin, which have been variously reported, I note that they are misinterpreted. These effects have been known to me for some time, but I have been unable, on account of pressing matters, to dwell on the subject. They are not due to the Roentgen rays, but merely to the ozone generated in contact with the skin. Nitrous acid may also be responsible, to a small extent. The ozone, when abundantly produced, attacks the skin and many organic substances most energetically, the action being no doubt heightened by the heat and moisture of the skin. After exposing the hand, for instance, for some time, the skin loses its elasticity, which causes a tension and pain, and subsequently an inflammation and blistering. This occurs mostly only at short range, but may be produced by a single terminal bulb, or generally by a very highly exhausted bulb, in which the terminals act independently, at greater distance. Owing to this, I have always taken the precaution, when getting impressions with the rays, to guard the person by a screen made of aluminum wires which is connected to the ground, preferably through a condenser. The radical means, however, of preventing such actions is to make impossible the access of the air to the skin while exposing, as, for instance, by immersing in oil. As this would be inconvenient in most cases, a metallic screen should be resorted to. The action of the ozone on some substances, when placed near the bulb in such a way that the gas is generated on their surfaces, is so powerful that the substances are practically destroyed in a few minutes. When a wire heavily insulated with rubber is connected to the terminal of a high-frequency coil, sometimes an exposure of barely a minute is sufficient to completely wreck the rubber insulation. There are certain commercial insulating compounds which are even more quickly destroyed, but which I will not enumerate, because of a possible disadvantage to the manufacturers. Gutta-percha, beeswax and paraffine stand the attack very well, and such wires should be used with high-frequency coils. This powerful action of the ozone was observed by me first about two years ago, when performing an experiment which was shown to many persons in my laboratory. The experiment consisted of charging a person, standing on an insulated stand, with a potential approximating one and one-half million volts, which was alternated several hundred thousand times a second. Under such conditions luminous streams break out on all parts of the body, especially abundantly on the feet, hands, hair, nose and ears. I subjected myself a number of times to this experiment, which seemed to offer no other danger except the possible rupture of a blood vessel, if the skin was very dry and non-conducting. I then noted on myself and others after effects resembling much those attributed to the Roentgen rays. With currents produced by perfected electrical oscillators, such as were described in the Electrical Review, September 30, 1896, the production of the ozone is so abundant that it is sufficient to merely turn on the current for a few seconds and ozonize strongly the atmosphere of a large hall. These currents are also capable of bringing about chemical combinations, of which the chief is that of the nitrogen with the oxygen of the atmosphere, and an immense possibility, which I have been following up for a long time, is opened up; namely, the combination of the nitrogen of the atmosphere on an industrial scale by practically no other means than mechanical power. If merely fertilizers of the soil would be manufactured in this manner, the benefits to humanity derived therefrom would be incalculable. From the above named action of the ozone, it follows that the experimenter should use the indicated precaution, for while ozone in small quantities is a most beneficial disinfectant, when generated in large quantities it is not free of danger.

It is an unpleasant duty to say on this occasion a few words on the subject of "making the blind see" by means of the Roentgen rays. This sensational topic has been given a wide circulation in the journals. Is it not cruel to raise such hopes when there is so little ground for it? For, first of all, the rays are not demonstrated to be transverse vibrations. If they were, we would have to find means for refracting them to make possible the projection of a sufficiently small image upon the retina. As it is, only a shadow of a very small object can be projected. What possible good can result from the application of these rays to such purposes? The shape of the small object might eventually be recognized by impressing the retina, but the sense of touch is more than sufficient to convey such impressions. Luminous sensations are well known to be excited in two ways; namely, by mechanical shock and electrical transmission. Both of these, I think, are present in the Roentgen streams, and hence such an effect on the optic nerve might be expected. I may say, however, that I can not confirm some of the experiments reported. For instance, when a hand is put before the closed eyes it is easy to distinguish the shadow, much the same as before the light of a candle; but when the tube is closed, and all light from the same excluded, I fail to get such an impression. The latter is, therefore, chiefly due to ordinary light, or else my tubes act differently from those experimented with by others. It may be proper to recall here that in ordinary bright sunlight, especially in the southern climates, it is easy to distinguish the shadow of objects, and even their rough outlines, with the eyes shut.

Proceeding on the assumption that we have in reality to deal with material streams, it is important to inquire which are the best conditions to be maintained when taking impressions with the sensitive screen or plate. First, the experimenter will easily observe that there are two causes which, with a given bulb and coil, tend to increase the intensity of the impressions. One of these may be said to lie in the bulb, the other in the coil. The latter, being most generally made of many turns of fine wire, is very sensitive to changes in the capacity of bodies attached to its terminals. The capacity of these bodies, therefore, in such a coil largely determines the difference of potential. At a certain degree of exhaustion this capacity assumes such a value that the pressure rises to a maximum, this tending to give the highest velocity to the cathodic stream, and, consequently, to give rise to the most intense rays. But at that degree of exhaustion it may happen, and usually does happen, that the cathodic streams are not most abundant. To produce the best result it is necessary that both of these causes should be made to cooperate by a careful proportioning of the dimensions of the bulb, which, in practice, is very difficult, inasmuch as the experimenter has to avail himself of commercial bulbs which may or may not be best suitable for his coil. This simple consideration shows the great advantage of the use of a coil which contains no fine wire and is capable of giving a heavy current through the secondary far in excess of what even the largest bulb requires.

Assuming the physician has learned how to manipulate his apparatus to best advantage, he will next notice that, to secure the clearest definition, he will have to maintain a certain pressure on the terminals of the tube, dependent chiefly on the distance and degree of opacity of the object investigated. It goes without saying that the definition is the better the smaller the spot from which the rays are emanating, but this is true only when impressions are taken at very small distances. When the distances are large, it is a disadvantage to use a too small radiating surface, as then the density is diminished to such a degree that the action is too weak. Discarding this consideration, it is clear that, if the rays are intense, the more opaque portions of the body are likewise penetrated and much detail is lost, whereas, when the rays are less intense, the impression might be altogether too weak to bring out sufficient detail.

To illustrate in a popular manner the best way to proceed, I shall avail myself of a simple illustration. Suppose that there would be imbedded between two panels of cloth a foreign object, such as a coin, and it is desired to locate it. We may accomplish this by placing behind the cloth a cardboard, for instance, and then firing from a certain distance a load of fine shot through the cloth in the region where the coin is supposed to be located. The shot will penetrate the cloth on all points except on the place where the coin is located, and on the cardboard behind, this place will be plainly indicated by the absence of the marks. Exactly in this way we proceed in applying the Roentgen rays to the location of such a body. Roentgen gave us a gun to fire — a wonderful gun, indeed, projecting missiles of a thousandfold greater penetrative power than that of a cannon ball, and carrying them probably to distances of many miles, with velocities not producible in any other way we know of. These missiles are so small that we may fire them through our tissues for days, weeks, months and years, apparently, without any hurtful consequence. Instead of the cardboard to indicate the path of the missiles, he gave us what is properly called a Roentgen screen, which becomes luminous on all places where it is hit by the missiles. Where the latter are prevented from hitting the screen by the intervention of the opaque body, the screen does not glow and we observe the shadow of the object. It is simple enough to project the shadow of an object in this way but when it is required to show the finer detail of the structure of the object, the difficulty begins. It will at once appear that, to produce such a result to best advantage, two conditions will have to be more or less realized. Firstly, the screen should be composed of such material that it is capable of becoming luminous by the faintest impact; and, secondly, the missiles should all be of uniform size, and should move with uniform velocity. Neither of these two conditions has so far been realized in practice, for all the bodies we know require a violent impact to become luminous, and no way has been found as yet to produce a uniformity in velocity and magnitude of the supposed projectiles. But a little thought leads immediately to the conclusion that there will be a certain velocity of the missiles which will give, under all conditions, the best definition. This velocity is easily ascertained by trial. Evidently the definition will be best when the bullets which pass through the densest parts of the body strike the screen so feebly as to not make it light up, whereas, those passing through portions of slightly smaller density hit it sufficiently strong as to make it light up feebly. The more sensitive the screen to impact, that is, the weaker an impact is required to make the screen light up, the more detail will be revealed. It therefore follows that, in the application of the Roentgen rays, not the body which fluoresces strongest, but the one which is most sensitive, is best suited for finer work.

The above considerations have led me to adopt the following procedure, which, in practice, has proved very successful. The Roentgen screen is first applied to the body to be investigated, the pressure at the terminals of the tube being very much reduced. The pressure is then slowly and gradually raised. It will be presently observed that, at a certain pressure, the shadow of the object examined is clearest. But as the vacuum is increasing, the pressure generally rises, and the image gets blurred in spite of the screen getting much brighter. Just as soon as the clearness is slightly diminished, the experimenter should for a few moments reverse the current, lowering a little the vacuum in this manner. The current being again given the direction it had at first, namely, that which causes a slow and steady increase of the vacuum, the shadow gets again clear, and by such easy manipulation the best result may be secured. An additional advantage, however, is gained, because the frequent reversals produce a brighter phosphorescence of the screen. When taking a photograph, the bulb should be watched through the screen and the switches manipulated in the above manner.

To give a practical example of the effectiveness of this procedure, I need only mention one of the instances which have come to my notice. A few months ago I investigated the case of Mr Cornelius Mack, of Watertown, Mass. Mr. Mack, while performing his duties many years ago, was struck by a bullet which lodged somewhere in the chest and could not be located. I apply the screen vainly a number of times for although the streams penetrated the body with such ease as to make the screen behind appear bluish white, and reveal all the bones of the body, I could not observe the missile. I then resorted to the above indicated means, and immediately, and easily the exact location of the projectile, between the shoulder blade and one of the ribs, was ascertained and the bullet successfully extracted.

13

ON THE HURTFUL ACTIONS OF LENARD AND ROENTGEN TUBES*

The rapidly extending use of the Lenard and Roentgen tubes or Crookes bulbs as implements of the physician, or as instruments of research in laboratories, makes it desirable, particularly in view of the possibility of certain hurtful actions on the human tissues, to investigate the nature of these influences, to ascertain the conditions under which they are liable to occur and — what is most important for the practitioner — to render all injury impossible by the observance of certain rules and the employment of unfailing remedies.

As I have stated in a previous communication (see Electrical Review of December 2, 1896) no experimenter need be deterred from using freely the Roentgen rays for fear of a poisonous or deleterious action, and it is entirely wrong to give room to expressions of a kind such as may tend to impede the progress and create a prejudice against an already highly beneficial and still more promising discovery; but it can not be denied that it is equally uncommendable to ignore dangers now when we know that, under certain circumstances, they actually exist. I consider it the more necessary to be aware of these dangers, as I foresee the coming into general use of novel apparatus, capable of developing rays of incomparably greater power. In scientific laboratories the instruments are usually in the hands of persons skilled in their manipulation and capable of approximately estimating the magnitude of the effects, and the omission of necessary precautions is, in the present state of our knowledge, not so much to be apprehended; but the physicians, who are keenly appreciating the immense benefits derived from the proper application of the new principle, and the numerous amateurs who are fascinated by the beauty of the novel manifestations, who are all passionately bent upon experimentation in the newly opened up fields, but many of whom are naturally not armed with the special knowledge of the electrician — all of these are much in need of reliable information from experts, and for these chiefly the following lines are written. However, in view of the still incomplete knowledge of these rays, I wish the statements which follow to be considered as devoid of authoritativeness, other than that which is based on the conscientiousness of my study and the faith in the precision of my senses and observations.

Ever since Professor Roentgen's discovery was made known I have carried on investigations in the directions indicated by him, and with perfected apparatus, producing rays of much greater intensity than it was possible to obtain with the usual appliances. Commonly, my bulbs were capable of showing the shadow of a hand on a phosphorescent screen at distances of 40 or 50 feet, or even more, and to the actions of these bulbs myself and several of my assistants were exposed for hours at a time, and although the exposures took place every day, not the faintest hurtful action was noted — as long as certain precautions were taken. On the contrary, be it a coincidence, or an effect of the rays, or the result of some secondary cause present in the operation of the bulbs —

* Electrical Review, May 5, 1897.

as, for example, the generation of ozone — my own health, and that of two persons who were daily under the influence of the rays, more or less, has materially improved, and, whatever be the reason, it is a fact that a troublesome cough with which I was constantly afflicted has entirely disappeared, a similar improvement being observed on another person.

In getting the photographic impressions or studying the rays with a phosphorescent screen, I employed a plate of thin aluminum sheet or a gauze of aluminum wires, which was interposed between the bulb and the person, and connected to the ground directly or through a condenser. I adopted this precaution because it was known to me, a long time before, that a certain irritation of the skin is caused by very strong streamers, which, mostly at small distance, are formed on the body of a person through the electrostatic influence of a terminal of alternating high potential. I found that the occurrence of these streamers and their hurtful consequence was completely prevented by the employment of a conducting object, as a sheet of wire gauze placed and connected as described. It was observed, however, that the injurious effects mentioned did not seem to diminish gradually with the distance from the terminal, but ceased abruptly, and I could give no other explanation for the irritation of the skin which would be as plausible as that which I have expressed; namely, that the effect was due to ozone, which was abundantly produced. The latter peculiarity mentioned was also in agreement with this view, since the generation of ozone ceases abruptly at a definite distance from the terminal, making it evident that a certain intensity of action is absolutely required, as in a process of electrolytic decomposition.

In carrying further my investigations, I gradually modified the apparatus in several ways, and immediately I had opportunities to observe hurtful influences following the exposures. Inquiring now what changes I had introduced, I found that I had made three departures from the plan originally followed; First, the aluminum screen was not used; second, a bulb was employed which, instead of aluminum, contained platinum, either as electrode or impact plate; and third, the distances at which the exposures took place were smaller than usual.

It did not require a long time to ascertain that the interposed aluminum sheet was a very effective remedy against injury, for a hand could be exposed for a long time behind it without the skin being reddened, which otherwise invariably and very quickly occurred. This fact impressed me with the conviction that, whatever the nature of the hurtful influences, it was in a large measure dependent either on an electrostatic action, or electrification, or secondary effects resulting therefrom, such as are attendant to the formation of streamers. This view afforded an explanation why an observer could watch a bulb for any length of time, as long as he was holding the hand in front of the body, as in examining with a fluorescent screen, with perfect immunity to all parts of his body, with the exception of the hand. It likewise explained why burns were produced in some instances on the opposite side of the body, adjacent to the photographic plate, whereas portions on the directly exposed part of the body, which were much nearer to the bulb, and consequently subjected to by far stronger rays, remained unaffected. It also made it easy to understand why the patient experienced a prickling sensation on the exposed part of the body whenever an injurious action took place. Finally, this view agreed with the numerous observations that the hurtful actions occurred when air was present, clothing, however thick, affording no protection, while they practically ceased when a layer of a fluid, quite easily penetrated by the rays, but excluding all contact of the air with the skin, was used as a preventive.

Following, now, the second line of investigation, I compared bulbs containing aluminum only with those in which platinum was used besides, ordinarily as impact body, and soon there were enough evidences on hand to dispel all doubt as to the latter metal being by far the more injurious. In support of this statement, one of the experiences may be cited which, at the same time, may illustrate the necessity — of taking proper precautions when operating bulbs of very high power. In order to carry out comparative tests, two tubes were constructed of an improved Lenard pattern, in size and most other respects alike. Both contained a concave cathode or reflector of nearly two inches in diameter, and both were provided with an aluminum cap or window. In one of the tubes the cathodic focus was made to coincide with the center of the cap, in the other the cathodic stream was concentrated upon a platinum wire supported on a glass stem axially with the tube a little in front of the window, and in each case the metal of the latter was thinned down in the central portion to such an extent as to be barely able to withstand the inward air pressure. In studying the action of the tubes, I exposed one hand to that containing aluminum only, and the other to the tube with the platinum wire. On turning on the former tube, I was surprised to observe that the aluminum window emitted a clear note, corresponding to the rhythmical impact of the cathodic stream. Placing the hand quite near the window, I felt distinctly that something warm was striking it. The sensation was unmistakable, and, quite apart from the warmth felt, differed very much from that prickling feeling produced by streamers or minute sparks. Next I examined the tube with the platinum wire. No sound was emitted by the aluminum window, all the energy of the impact being seemingly spent on the platinum wire, which became incandescent, or else the matter composing the cathodic stream was so far disintegrated that the thin metal sheet offered no material obstruction to its passage. If big lumps are hurled against a wire netting with large meshes, there is considerable pressure exerted against the netting; if, on the contrary — for illustration — the lumps are very small as compared with the meshes, the pressure might not be manifest. But, although the window did not vibrate, I felt, nevertheless, again, and distinctly, that something was impinging against the hand, and the sensation of warmth was stronger than in the previous case. In the action on the screen there was apparently no difference between the two tubes, both rendering it very bright, and the definition of the shadows was the same, as far as it was possible to judge. I had looked through the screen at the second tube a few times, only when something detracted my attention, and it was not until about 20 minutes later, when I observed that the hand exposed to it was much reddened and swollen. Thinking that it was due to some accidental injury, I turned again to the examination of the platinum tube, thrusting the same hand close to the window, and now I felt instantly a sensation of pain, which became more pronounced when the hand was placed repeatedly near the aluminum window. A peculiar feature was that the pain appeared to be seated, not at the surface, but deep in the tissues of the hand, or rather in the bones. Although the aggregate exposure was certainly not more than half a minute, I had to suffer severe pain for a few days afterward, and some time later I observed that all the hair was destroyed and that the nails on the injured hand had grown anew.

The bulb containing no platinum was now experimented with, more care being taken, but soon its comparative harmlessness was manifest, for, while it reddened the skin, the injury was not nearly as severe as with the other tube. The valuable experiences thus gained were: The evidence of something hot striking the exposed member; the pain *instantly* felt; the injury produced *immediately* after the exposure, and the increased violence due, in all probability, to the presence of the platinum.

Some time afterward I observed other remarkable actions at very small distances from powerful Lenard tubes. For instance, the hand being held near the window only for a few seconds, the skin seems to become tight, or else the muscles are stiffened, for some resistance is experienced in closing the fist, but upon opening and closing it repeatedly the sensation disappears, apparently no ill effect remaining. I have, furthermore, observed a decided influence on the nasal discharge organs similar to the effects of a cold just contracted. But the most interesting observation in this respect is the following: When such a powerful bulb is watched for some time, the head of the observer being brought very close, he soon after that experiences a sensation so peculiar that no one will fail to notice it when once his attention is called to it, it being almost as positive as touch. If one imagines himself looking at something like a cartridge, for instance, in close and dangerous proximity, and just about to explode, he will get a good idea of the sensation produced, only, in the case of the cartridge, one can not render himself an account where the feeling exactly resides, for it seems to extend all over the body, this indicating that it comes from a general awareness of danger resulting from previous and manifold experiences, and not from the anticipation of an unpleasant impression directly upon one, of the organs, as the eye or the ear; but, in the case of the Lenard bulb, one can at once, and with precision, locate the sensation; it is in the head. Now, this observation might not be of any value except, perhaps, in view of the peculiarity and acuteness of the feeling, were it not that exactly the same sensation is produced when working for some time with a noisy spark gap, or, in general, when exposing the ear to sharp noises or explosions. Since it seems impossible to imagine how the latter could cause such a sensation in any other way except by directly impressing the organs of hearing, I conclude that a Roentgen or Lenard tube, working in perfect silence as it may, nevertheless produces violent explosions or reports and concussions, which, though they are inaudible, take some material effect upon the bony structure of the head. Their inaudibility may be sufficiently explained by the well founded assumption that not the air, but some finer medium, is concerned in their propagation.

But it was in following up the third line of inquiry into the nature of these hurtful actions, namely, in studying the influence of distance, that the most important fact was unearthed. To illustrate it popularly, I will say that the Roentgen tube acts exactly like a source of intense heat. If one places the hand near to a red-hot stove, he may be instantly injured. If he keeps the hand at a certain small distance, he may be able to withstand the rays for a few minutes or more, and may still be injured by prolonged exposure; but if he recedes only a little farther, where the heat is slightly less, he may withstand the heat in comfort and any length of time without receiving any injury, the radiations at that distance being too weak to seriously interfere with the life process of the skin. This is absolutely the way such a bulb acts. Beyond a certain distance no hurtful effect whatever is produced on the skin, no matter *how long* the exposure. The character of the burns is also such as might be expected from a source of high heat. I have maintained, in all deference to the opinions of others, that those who have likened the effects on the skin and tissues to sunburns have misinterpreted them. There is no similarity in this respect, except in so far as the reddening and peeling of the skin is concerned, which may result from innumerable causes. The burns, when slight, rather resemble those people often receive when working close to a strong fire. But when the injury is severe, it is in all appearances like that received from contact with fire or from a red-hot iron. There may be no period of incubation at all, as is evident from the foregoing remarks, the rays taking effect immediately, not to say instantly. In a severe case the skin gets deeply colored and blackened in places, and ugly, ill-foreboding blisters form; thick layers come off, exposing the raw flesh, which, for a time, discharges freely. Burning pain, feverishness and such symptoms are of course but natural accompaniments. One single injury of this kind, in the abdominal region, to a dear and zealous assistant — the only accident that ever happened to any one but myself in all my laboratory experience — I had the misfortune to witness. It occurred before all these and other experiences were gained, following directly an exposure of five minutes at the fairly safe distance of 11 inches to a very highly-charged platinum tube, the protecting aluminum screen having been unfortunately omitted, and it was such as to fill me with, the gravest apprehensions. Fortunately, frequent warm baths, free application of vaseline, cleaning and general bodily care soon repaired the ravages of the destructive agent, and I breathed again freely. Had I known more than I did of these injurious actions, such unfortunate exposure would not have been made; had I known less than I did, it might have been made at a smaller distance, and a serious, perhaps irremediable, injury might have resulted.

I am using the first opportunity to comply with the bitter duty of recording the accident. I hope that others will do likewise, so that the most complete knowledge of these dangerous actions may soon be acquired. My apprehensions led me to consider, with keener interest than I would have felt otherwise, what the probabilities were in such a case of the internal tissues being seriously injured. I came to the very comforting conclusion that, no matter what the rays are ultimately recognized to be, practically all their destructive energy must spend itself on the surface of the body, the internal tissues being, in all probability, safe, unless the bulb would be placed in very close proximity to the skin, or else, that rays of far greater intensity than now producible were generated. There are many reasons why this should be so, some of which will appear clear from my foregoing statements referring to the nature of the hurtful agencies, but I may be able to cite new facts in support of this view. A significant feature of the case reported may be mentioned. It was observed that on three places, which were covered by thick bone buttons, the skin was entirely unaffected, while it was entirely destroyed under each of the small holes in the buttons. Now, it was impossible for the rays, as investigation showed, to reach these points of the skin in straight lines drawn from the bulb, and this would seem to indicate that not all the injury was due to the rays or radiations under consideration, which unmistakably propagate in straight lines, but that, at least in part, concomitant causes were responsible. A further experimental demonstration of this fact may be obtained in the following manner: The experimenter may excite a bulb to a suitable and rather small degree, so as to illuminate the fluorescent screen to a certain intensity at a distance of, say, seven inches. He may expose his hand at that distance, and the skin will be reddened after a certain duration of exposure. He may now force the bulb up to a much higher power, until, at a distance of 14 inches, the screen is illuminated even stronger than it was before at half that distance. The rays are now evidently stronger at the greater distance, and yet he may expose the hand a very long time, and it is safe to assert that he will not be injured. Of course, it is possible to bring forth arguments which might deprive the above demonstration of force. So, it might be stated, that the actions on the screen or photographic plate do not give us an idea as to the density and other quantitative features of the rays, these actions being entirely of a qualitative character. Suppose the rays are formed by streams of material particles, as I believe, it is thinkable that it might be of no particular consequence, in so far as the visible impression on the screen or film is concerned, whether a trillion of particles per square millimetre strike the sensitive layer or only a million, for example; but with the actions on the skin it is different; these must surely and very materially depend on the quantity of the streams.

As soon as the before-mentioned fact was recognized, namely, that beyond a certain distance even the most powerful tubes are incapable of producing injurious action, no matter how long the exposure may last, it became important to ascertain the safe distance. Going over all my previous experiences, I found that, very frequently, I have had tubes which at a distance of 12 feet, for illustration, gave a strong impression of the chest of a person with an exposure of a few minutes, and many times persons have been subjected to the rays from these tubes at a distance of from 18 to 24 inches, the time of exposure varying from 10 to 45 minutes, and never the faintest trace of an injurious action was observed. With such tubes I have even made long exposures at distances of 14 inches, always, of course, through a thin sheet or wire gauze of aluminum connected to the ground, and, in each case, observing the precaution that the. metal would not give any spark when the person was touching it with the hand, as it might sometimes be when the electrical vibration is of extremely high frequency, in which case a ground connection, through a condenser of proper capacity, should be resorted to. In all these instances bulbs containing only aluminum were used, and I therefore still lack sufficient data to form an exact idea of what distance would have been safe with a platinum tube. From the case previously cited, we see that a grave injury resulted at a distance of 11 inches, but I believe that, had the protecting screen been used, the injury, if any, would have been very slight. Taking all my experiences together, I am convinced that no serious injury can result if the distance is greater than 16 inches and the impression is taken in the manner I have described.

Having been, successful in a number of lines of inquiry pertaining to this new department of science, I am able at present to form a broader view of the actions of the bulbs, which, I hope, will soon assume a quite definite shape. For the present, the following brief statement may be sufficient. According to the evidences I am obtaining, the bulb, when in action, is emitting a stream of small material particles. There are some experiments which seem to indicate that these particles start from the outer wall of the bulb; there are others which seem to prove that there is an actual penetration of the wall, and, in the case of a thin aluminum window, I have now not the least doubt that some of the finely disintegrated cathodic matter is actually forced through. These streams may simply be projected to a great distance, the velocity gradually diminishing without the formation of any waves, or they may give rise to concussions and longitudinal waves. This, for the present consideration, is entirely immaterial, but, assuming the existence of such streams of particles, and disregarding such actions as might be due to the properties, chemical or physical, of the projected matter, we have to consider the following specific actions:

First. There is the thermal effect. The temperature of the electrode or impact body does not in any way give us an idea of the degree of heat of the particles, but, if we consider the probable velocities only, they correspond to temperatures which may be as high as 100,000 degrees centigrade. It may be sufficient that the particles are simply at a high temperature to produce an injurious action, and, in fact, many evidences point in this direction. But against this is the experimental fact that we can not demonstrate such a transference of heat, and no satisfactory explanation is found yet, although, in carrying my investigations in this direction, I have arrived at some results.

Second, there is the purely electrical effect. We have absolute experimental evidence that the particles or rays, to express myself generally, convey an immense amount of electricity, and I have even found a way of how to estimate and measure that amount. Now it is likewise possible that the mere fact of these particles being highly electrified is sufficient to cause the destruction of the tissue. Certainly, on contact with the skin, the electrical charges will be given off, and may give rise to strong and destructive local currents in minute paths of the tissue. Experimental results are in accord with this view, and, in pushing my inquiry in this direction, I have been still more successful than in the first. Yet, while as I have suggested before, this view explains best the action on a sensitive layer, experiment shows that, when the supposed particles traverse a grounded plate, they are not deprived entirely of their electrification, which is not satisfactorily explained.

The *third* effect to be considered is the electro-chemical. The charged particles give rise to an abundant generation of ozone and other gases, and these we know, by experiment, destroy even such a thing as rubber, and are, therefore, the most likely agent in the destruction of the skin, and the evidences are strongest in this direction, since a small layer of a fluid, preventing the contact of gaseous matter with the skin, seems to stop all action.

The *last* effect to be considered is the purely mechanical. It is thinkable that material particles, moving with great speed, may, merely by a mechanical impact and unavoidable heating at such speeds, be sufficient to deteriorate the tissues, and in such a case deeper layers might also be injured, whereas it is very probable that no such thing would occur if any of the former explanations would be found to hold.

Summing up my experimental experiences and the conclusions derived from them, it would seem advisable, first, to abandon the use of bulbs containing platinum; second, to substitute for them a properly constructed Lenard tube, containing pure aluminum only, a tube of this kind having, besides, the advantage that it can be constructed with great mechanical precision, and therefore is capable of producing much sharper impressions; third, to use a protecting screen of aluminum sheet, as suggested, or, instead of this, a wet cloth or a layer of a fluid; fourth, to make the exposures at distances of, at least, 14 inches, and preferably expose longer at a larger distance.

14

ON THE SOURCE OF ROENTGEN RAYS AND THE PRACTICAL CONSTRUCTION AND SAFE OPERATION OF LENARD TUBES*

I have for some time felt that a few indications in regard to the practical construction of Lenard tubes of improved designs, a great number of which I have recently exhibited before the New York Academy of Sciences (April 6, 1897), would be useful and timely, particularly as by their proper construction and use much of the danger attending the experimentation with the rays may be avoided. The simple precautions which I have suggested in my previous communications are seemingly disregarded, and cases of injury to patients are being almost daily reported, and in view of this only, were it for no other reason, the following lines, referring to this subject, would have been written before had not again pressing and unavoidable duties prevented me from doing so. A short and, I may say, most unwelcome interruption of the work which has been claiming my attention makes this now possible. However, as these opportunities are scarce, I will utilize the present to dwell in a few words on some other matters in connection with this subject, and particularly on a result of importance which I have reached some time ago by the aid of such a Lenard tube, and which, if I am correctly informed, I can only in part consider as my own, since it seems that practically it has been expressed in other words by Professor Roentgen in a recent communication to the Academy of Sciences of Berlin. The result alluded to has reference to the much disputed question of the source of the Roentgen rays. As will be remembered, in the first announcement of his discovery, Roentgen was of the opinion that the rays which affected the sensitive layer emanated from the fluorescent spot on the glass wall of the bulb; other scientific men next made the cathode responsible; still others the anode, while some thought that the rays were emitted solely from fluorescent powders of surfaces, and speculations, mostly unfounded, increased to such an extent that, despairingly, one would exclaim with the poet:

> *"O glücklich wer noch hoffen kann,*
> *Aus diesem Meer des Irrtums aufzutauchen!*"

My own experiments led me to recognize that, regardless of the location, the chief source of these rays was the place of the *first* impact of the projected stream of particles within the bulb. This was merely a broad statement, of which that of Professor Roentgen was a special case, as in his first experiments the fluorescent spot on the glass wall was, incidentally, the place of the first impact of the cathodic stream. Investigations carried on up to the present day have only confirmed the correctness of the above opinion, and the place of the first collision of the stream of particles — be it an anode or independent

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* Electrical Review, August 11, 1897.

impact body, the glass wall or an aluminum window — is still found to be the principal source of the rays. But, as will be seen presently, it is not the only source.

Since recording the above fact my efforts were directed to finding answers to the following questions: First, is it necessary that the impact body should be within the tube? Second, is it required that the obstacle in the path of the cathodic stream should

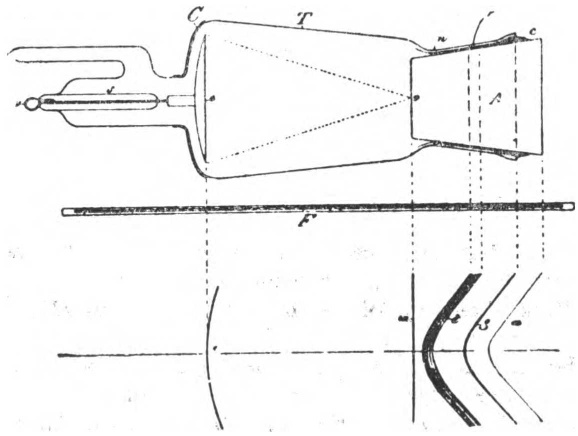

Fig. 1. — Illustrating an Experiment Revealing the Real Source of the Roentgen Rays.

be a solid or liquid? And, third, to what extent is the velocity of the stream necessary for the generation of and influence upon the character of the rays emitted?

In order to ascertain whether a body located outside of the tube and in the path or in the direction of the stream of particles was capable of producing the same peculiar phenomena as an object located inside, it appeared necessary to first show that there is an actual penetration of the particles through the wall, or otherwise that the actions

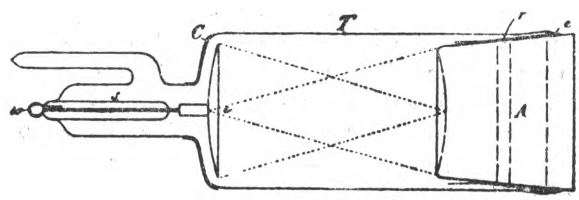

Fig. 2. — Improved Lenard Tube.

of the supposed streams, of whatever nature they might be, were sufficiently pronounced in the outer region close to the wall of the bulb as to produce some of the effects which are peculiar to a cathodic stream. It was not difficult to obtain with a properly prepared Lenard tube, having an exceedingly thin window, many and at first surprising evidences of this character. Some of these have already been pointed out, and it is thought sufficient to cite here one more which I have since observed. In the hollow aluminum cap A of a tube as shown in diagram Fig. 1, which will be described in detail, I placed a half-dollar silver piece, supporting it at a small distance from and parallel to the window or bottom of the cap by strips of mica in such a manner that it was not touching the metal of the tube, an air space being left all around it. Upon exciting the bulb for about 30 to 45 seconds by the secondary discharge of a powerful coil of a novel type now well known, it was found that the silver piece was rendered so hot as to actually scorch the hand; yet the aluminum window, which offered a very insignificant obstacle to the cathodic stream, was only moderately warmed. Thus it was shown that the silver alloy, owing to its density and thickness, took up most of the energy of the impact, being acted upon by the particles almost identically as if it had been inside of the bulb, and, what is more, indications were obtained, by observing the shadows, that it behaved like a second source of the rays, inasmuch as the outlines of the shadows, instead of being sharp and clear as when the half-dollar piece was removed, were dimmed. It was immaterial for the chief object of the inquiry to decide by more exact methods whether the cathodic particles actually penetrated the window, or whether a new and separate stream was projected from the outer side of the window. In my mind there exists not the least doubt that the former was the case, as in this respect I have been able to obtain numerous additional proofs, upon which I may dwell in the near future.

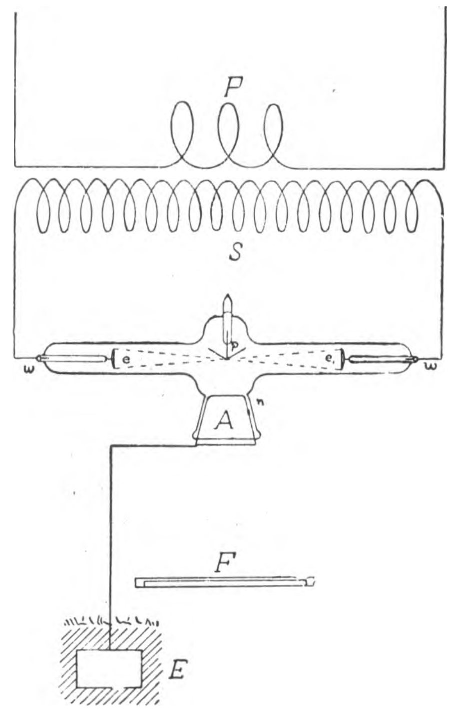

Fig. 3. — Illustrating Arrangement with Improved Double-Focus Tube for Reducing the Injurious Actions.

I next endeavored to ascertain whether it was necessary that the obstacle outside was, as in this case, a solid body, or a liquid, or broadly, a body of measurable dimensions, and it was in investigating in this direction that I came upon the important result to which I referred in the introductory statements of this communication. I namely observed rather accidentally, although I was following up a systematic inquiry, what is illustrated in diagram Fig. 1. The diagram shows a Lenard tube of improved design, consisting of a tube T of thick glass tapering towards the open end, or neck *n,* into which is fitted an aluminum cap A, and a spherical cathode *e,* supported on a glass stem *s,* and platinum wire *w* sealed in the opposite end of the tube as usual. The aluminum cap A, as will be observed, is not in actual contact with the ground-glass wall, being held at a small distance from the latter by a narrow and continuous ring of tinfoil *r.* The outer space between the glass and the cap A is filled with cement *c,* in a manner which I shall later describe. F is a Roentgen screen such as is ordinarily used in making the observations.

Now, in looking upon the screen in the direction from F to T, the dark lines indicated on the lower part of the diagram were seen on the illuminated background. The curved line *e* and the straight line W were, of course, at once recognized as the outlines of the cathode *e* and the bottom of the cap A respectively, although, in consequence of a confusing optical illusion, they appeared much closer together than they actually were. For instance, if the distance between *e* and *o* was five inches, these lines would appear on the screen about two inches apart, as nearly as I could judge by the eye. This illusion may be easily explained and is quite unimportant, except that it might be of some moment to physicians to keep this fact in mind when making examinations with the screen as, owing to the above effect, which is sometimes exaggerated to a degree hard to believe, a completely erroneous idea of the distance of the various parts of the object under examination might be gained, to the detriment of the surgical operation. But while the lines *e* and W were easily accounted for, the curved lines *t, g, a* were at first puzzling. Soon, however, it was ascertained that the faint line *a* was the shadow of the edge of the aluminum cap, the much darker line *g* that of the rim of the glass tube T, and *t* the shadow of the tinfoil ring *r*. These shadows on the screen F clearly showed that the agency which affected the fluorescent material was proceeding from the space outside of the bulb towards the aluminum cap, and chiefly from the region through which the primary disturbances or streams emitted from the tube through the window were passing, which observation could not be explained in a more plausible manner than by assuming that the air and dust particles outside, in the path of the projected streams, afforded an obstacle to their passage and gave rise to impacts and collisions spreading through the air in all directions, thus producing continuously new sources of the rays. It is this fact which, in his recent communication before mentioned, Roentgen has brought out. So, at least, I have interpreted his reported statement that the rays emanate from the irradiated air. It now remains to be shown whether the air, from which carefully all foreign particles are

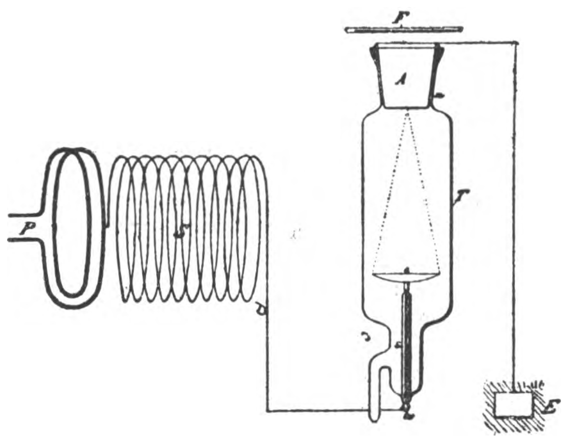

Fig. 4. — Illustrating Arrangement with a Lenard Tube for Safe Working at Close Range.

removed, is capable of behaving as an impact body and source of the rays, in order to decide whether the generation of the latter is dependent on the presence in the air of impact particles of measurable dimensions. I have reasons to think so.

With the knowledge of this fact we are now able to form a more general idea of the process of generation of the radiations which have been discovered by Lenard and Roentgen. It may be comprised in the statement that the streams of minute material particles projected from an electrode with great velocity in encountering obstacles wherever they may be, within the bulb, in the air or other medium or in the sensitive layers themselves, give rise to rays or radiations possessing many of the properties of those known as light. If this physical process of generation of these rays is undoubtedly demonstrated as true, it will have most important consequences, as it will induce physicists to again critically examine many phenomena which are presently attributed to transverse ether waves, which may lead to a radical modification of existing views and theories in regard to these phenomena, if not as to their essence so, at least, as to the mode of their production.

My effort to arrive at an answer to the third of the above questions led me to the establishment, by actual photographs, of the close relationship which exists between the Lenard and Roentgen rays. The photographs bearing on this point were exhibited at a meeting of the New York Academy of Sciences — before referred to — April 6, 1897, but, unfortunately, owing to the shortness of my address, and concentration of thought on other matters, I omitted what was most important; namely, to describe the manner in which these photographs were obtained, an oversight which I was able to only partially repair the day following. I did, however, on that occasion illustrate and describe experiments in which was shown the deflectibility of the Roentgen rays by a magnet, which establishes a still closer relationship, if not identity, of the rays named after these two discoverers. But the description of these experiments in detail, as well as of other investigations and results in harmony with and restricted to the subject I brought before that scientific body, will appear in a longer communication which I am slowly preparing.

To bring out clearly the significance of the photographs in question, I would recall that, in some of my previous contributions to scientific societies, I have endeavored to dispel a popular opinion before existing that the phenomena known as those of Crookes were dependent on and indicative of high vacua. With this object in view, I showed that phosphorescence and most of the phenomena in Crookes bulbs were producible at greater pressures of the gases in the bulbs by the use of much higher or more sudden electro-motive impulses. Having this well demonstrated fact before me, I prepared a tube in the manner described by Lenard in his first classical communication on this subject. The tube was exhausted to a moderate degree, either by chance or of necessity, and it was found that, when operated by an ordinary high-tension coil of a low rate of change in the current, no rays of any of the two kinds could be detected, even when the tube was so highly strained as to become very hot in a few moments. Now, I expected that, if the suddenness of the impulses through the bulb were sufficiently increased, rays would be emitted. To test this I employed a coil of a type which I have repeatedly described, in which the primary is operated by the discharges of a condenser. With such an instrument any desired suddenness of the impulses may be secured, there being practically no limit in this respect, as the energy accumulated in the condenser is the most violently explosive agent we know, and any potential or electrical pressure is obtainable. Indeed, I found that in increasing the suddenness of the electro-motive impulses through the tube — without, however, increasing, but rather diminishing the total energy conveyed to it — phosphorescence was observed and rays began to appear, first the feebler Lenard rays and later, by pushing the suddenness far enough, Roentgen rays of great intensity, which enabled me to obtain photographs showing the finest texture of the bones. Still, the same tube, when again operated with the ordinary coil of a low rate of change in the primary current, emitted practically no rays, even when, as before stated, much more energy, as judged from the heating, was passed through it. This experience, together with the fact that I have succeeded in producing by the use of immense electrical pressures, obtainable with certain apparatus designed for this express purpose, some impressions in free air, have led me to the conclusion that in lightning discharges Lenard and Roentgen rays must be generated at ordinary atmospheric pressure.

At this juncture I realize, by a perusal of the preceding lines, that my scientific interest has dominated the practical, and that the following remarks must be devoted to the primary object of this communication — that is, to giving some data for the construction to those engaged in the manufacture of the tubes and, perhaps, a few useful hints to practicing physicians who are dependent on such information. The foregoing was, nevertheless, not lost for this object, inasmuch as it has shown how much the result obtained depends on the proper construction of the instruments, for, with ordinary implements, most of the above observations could not have been made.

I have already described the form of tube illustrated in Fig. 1, and in Fig. 2 another still further improved design is shown. In this case the aluminum cap A, instead of having a straight bottom as before, is shaped spherically, the center of the sphere coinciding with that of the electrode *e,* which itself, as in Fig. 1, has its focus in the center of the window of cap A, as indicated by the dotted lines. The aluminum cap A has a tinfoil ring *r,* as that in Fig. 1, or else the metal of the cap is spun out on that place so as to afford a bearing of small surface between the metal and the glass. This is an important practical detail as, by making the bearing surface small, the pressure per unit of area is increased and a more perfect joint made. The ring *r* should be first spun out and then ground to fit the neck of the bulb. If a tinfoil ring is used instead, it may be cut out of one of the ordinary tinfoil caps obtainable in the market, care being taken that the ring is very smooth.

In Fig. 3 I have shown a modified design of tube which, as the two types before described, was comprised in the collection I exhibited. This, as will be observed, is a double-focus tube, with impact plates of iridium alloy and an aluminum cap A opposite the same. The tube is not shown because of any originality in design, but simply to illustrate a practical feature. It will be noted that the aluminum caps in the tubes described are fitted inside of the necks and not outside, as is frequently done. Long experience has demonstrated that it is practically impossible to maintain a high vacuum in a tube with an outside cap. The only way I have been able to do this in a fair measure is by cooling the cap by a jet of air, for instance, and observing the following precautions: The air jet is first turned on slightly and upon this the tube is excited. The current through the latter, and also the air pressure, are then gradually increased and brought to the normal working condition. Upon completing the experiment the air pressure and current through the tube are both gradually reduced and both so manipulated that no great differences in temperature result between the glass and aluminum cap. If those precautions are not observed the vacuum will be immediately impaired in consequence of the uneven expansion of the glass and metal.

With tubes, as these presently described, it is quite unnecessary to observe this, precaution if proper care is taken in their preparation. In inserting the cap the latter is cooled down as low as it is deemed advisable without endangering the glass, and it is then gently pushed in the neck of the tube, taking care that it sets straight.

The two most important operations in the manufacture of such a tube are, however, the thinning down of the aluminum window and the sealing in of the cap. The metal of the latter may be one thirty-second or even one-sixteenth of an inch thick, and in such case the central portion may be thinned down by a countersink tool about one-fourth of an inch in diameter as far as it is possible without tearing the sheet. The further thinning down may then be done by hand with a scraping tool; and, finally, the metal should be gently beaten down so as to surely close the pores which might permit a slow leak. Instead of proceeding in this way I have employed a cap with a hole in the center, which I have closed with a sheet of pure aluminum a few thousandths of an inch thick, riveted to the cap by means of a washer of thick metal, but the results were not quite as satisfactory.

In sealing the cap I have adopted the following procedure: The tube is fastened on the pump in the proper position and exhausted until a permanent condition is reached. The degree of exhaustion is a measure of perfection of the joint. The leak is usually considerable, but this is not so serious a defect as might be thought. Heat is now gradually applied to the tube by means of a gas stove until a temperature up to about the boiling point of sealing wax is reached. The space between the cap and the glass is then filled with sealing wax of good quality; and, when the latter begins to boil, the temperature is reduced to allow its settling in the cavity. The heat is then again increased, and this process of heating and cooling is repeated several times until the entire cavity, upon reduction of the temperature, is found to be filled uniformly with the wax, all bubbles having disappeared. A little more wax is then put on the top and the exhaustion carried on for an hour or so, according to the capacity of the pump, by application of moderate heat much below the melting point of the wax.

A tube prepared in this manner will maintain the vacuum very well, and will last indefinitely. If not used for a few months, it may gradually lose the high vacuum, but it can be quickly worked up. However, if after long use it becomes necessary to clean the tube, this is easily done by gently warming it and taking off the cap. The cleaning may be done first with acid, then with highly diluted alkali, next with distilled water, and finally with pure rectified alcohol.

These tubes, when properly prepared, give impressions much sharper and reveal much more detail than those of ordinary make. It is important for the clearness of the impressions that the electrode should be properly shaped, and that the focus should be exactly in the center of the cap or slightly inside. In fitting in the cap, the distance from the electrode should be measured as exactly as possible. It should also be remarked that the thinner the window, the sharper are the impressions, but it is not advisable to make it too thin, as it is apt to melt in a point on turning on the current.

The above advantages are not the only ones which these tubes offer. They are also better adapted for purposes of examination by surgeons, particularly if used in the peculiar manner illustrated in diagrams Fig. 3 and Fig. 4, which are self-explanatory. It will be seen that in each of these the cap is connected to the ground. This decidedly diminishes the injurious action and enables also to take impressions with very short exposures of a few seconds only at close range, inasmuch as, during the operation of the bulb, one can easily touch the cap without any inconvenience, owing to the ground connection. The arrangement shown in Fig. 4 is particularly advantageous with a form of single terminal, which coil I have described on other occasions and which is diagrammatically illustrated, P being the primary and S the secondary. In this instance the high-potential terminal is connected to the electrode, while the cap is grounded. The tube may be placed in the position indicated in the drawing, under the operating table and quite close or even in contact with the body of the patient, if the impression requires only a few seconds as, for instance, in examining parts of the members. I have taken many impressions with such tubes and have observed no injurious action, but I would advise not to expose for longer than two or three minutes at very short distances. In this respect the experimenter should bear in mind what I have stated in previous communications. At all events it is certain that, in proceeding in the manner described, additional safety is obtained and the process of taking impressions much quickened. To cool the cap, a jet of air may be used, as before stated, or else a small quantity of water may be poured in the cap each time when an impression is taken. The water only slightly impairs the action of the tube, while it maintains the window at a safe temperature. I may add that the tubes are improved by providing back of the electrode a metallic coating C, shown in Fig. 3 and Fig. 4.

15

ON CURRENT INTERRUPTERS*

To stimulate the ardor of the zealous experimenters, who believe in the revolutionary character of this discovery, it might be well to suggest one or two such simple devices for interrupting the current. For instance, a very primitive contrivance of this kind comprises a poker — yes, an ordinary poker, connected by means of a flexible cable to one of the mains of the generator, and a bathtub filled with conducting fluid which is connected in any suitable manner, through the primary of an induction coil, to the other pole of the generator. When the experimenter desires to take a Roentgen picture, he brings the end of the poker to white heat, and, thrusting the same into the bathtub, he will at once witness an astonishing phenomenon, the seething and boiling liquid making and breaking the current in rapid succession, and the powerful rays generated will at once convince him of the great practical value of this discovery. I might further suggest that the poker may be conveniently heated by means of a welding machine.

Another device, entirely automatic, and probably suitable for use in suburban districts, comprises two insulated metal plates, supported in any convenient manner, in close proximity to each other. These plates are connected through the primary of an induction coil with the determinals of a generator, and are bridged by two movable contacts joined by a flexible cable. The two contacts are both attached to the legs of a good-sized chicken standing astride on the plates. Heat being applied to the latter, muscular contractions are produced in the legs of the chicken, which thus makes and breaks the current through the induction coil. Any number of such chickens may be provided and the contacts connected in series or multiple arc, as may be desired, thus increasing the frequency of the impulses. In this manner fierce sparks, suitable for most purposes, may be obtained, and vacuum tubes may be operated, and these contrivances will be found a notable improvement on certain circuit-breakers of old, with which two enterprising editors undertook some years ago to revolutionize the systems of electric lighting. The enterprising editors are wiser now. They are to be congratulated, and their readers, scientific societies and the profession, all ought to be congratulated, and — "all is well that ends well". The observant experimenter will not fail to note that the fierce sparks frighten the chickens, which are thus put into more violent spasms and muscular contractions, this again increasing the fierceness of the sparks, which, in return, causes a greater fright of the chickens and increased speed of interruptions; it is, in fact, as Kipling says:

"Interdependence absolute, foreseen, ordained, decreed,
To work, ye'l note, at any tilt an' every rate o'speed."

But to return, in all earnestness, to the "electrolytic interrupter" described, this is a device with which I am perfectly familiar, having carried on extensive experiments with the same two or three years ago. It was one of many devices which I invented in

* Electrical Review, March 15, 1899.

my efforts to produce an economical contrivance of this kind. The name is really not appropriate, inasmuch as any fluid, either conducting or made so in any manner, as by being rendered acid or alkaline, or by being heated, may be used. I have even found it possible, under certain conditions, to operate with mercury. The device is extremely simple, but the great waste of energy attendant upon its operation and certain other defects make it entirely unsuitable for any valuable, practical purpose, and as far as those instances are concerned, in which a small amount of energy is needed, much better results are obtained by a properly designed mechanical circuit-breaker. The experimenters are very likely deceived by finding that an induction coil gives longer sparks when this device is inserted in place of the ordinary break, but this is due merely to the fact that the break is not properly designed. Of the total energy supplied from the mains, scarcely one-fourth is obtainable of that amount, which a well constructed mechanical break furnishes in the secondary, and although I have designed many improved forms, I have found it impossible to increase materially the economy. Two improvements, however, which I found at that time necessary to introduce, I may mention for the benefit of those who are using the device. As will be readily noted, the small terminal is surrounded by a gaseous bubble, in which the makes and breaks are formed, generally in an irregular manner, by the liquid being driven towards the terminal at some point. The force which drives the liquid is evidently the pressure of the fluid column, and by increasing the fluid pressure in any manner the liquid is forced with greater speed towards the terminal and thus the frequency is increased. Another necessary improvement was to make a provision for preventing the acid or alkali from being carried off into the atmosphere, which always happens more or less, even if the liquid column be of some height. During my early experiments with the device I became so interested in it that I neglected this precaution, and I noted that the acid had attacked all the apparatus in my laboratory. The experimenter will conveniently carry out both of these improvements by taking a long glass tube of, say, six to eight feet in length, and arranging the interrupting device close to the bottom of the tube, with an outlet for eventually replacing the liquid. The high column will prevent the fumes from vitiating the atmosphere of the room, and the increased pressure will add materially to the effectiveness of the performance. If the liquid column be, say, nine times as high, the force driving the fluid towards the contact is nine times as great, and this force is capable, under the same conditions, of driving the fluid three times as fast, hence the frequency is increased in that ratio and, in fact, in a somewhat greater ratio, as the gaseous bubble, being compressed, is rendered smaller, and therefore the liquid is made to travel through a smaller distance. The electrode, of course, should be very small to insure the regularity of operation, and it is not necessary to use platinum. The pressure may, however, be increased in other ways, and I have obtained some results of interest, in experiments of this kind.

As before stated, the device is very wasteful, and, while it may be used in some instances, I consider it of little or no practical value. It will please me to be convinced of the contrary, but I do not think that I am erring. My chief reasons for this statement are that there are many other ways in which by far better results are obtainable with devices equally simple, if not more so. I may mention one here, based on a different principle, which is incomparably more effective, more efficient and also simpler on the whole. It comprises a fine stream of conducting fluid which is made to issue, with any desired speed, from an orifice connected with one pole of a generator, through the primary of the induction coil, against the other terminal of the generator placed at a small distance. This device gives discharges of a remarkable suddenness, and the frequency may be brought within reasonable limits, almost to anything desired. I have used this device for a long time in connection with ordinary coils and in a form of my own coil with results greatly superior in every respect to those obtainable with the form of device discussed.

16

ELECTRICAL OSCILLATORS*

Few fields have been opened up the exploration of which has proved as fruitful as that of high frequency currents. Their singular properties and the spectacular character of the phenomena they presented immediately commanded universal attention. Scientific men became interested in their investigation, engineers were attracted by their commercial possibilities, and physicians recognized in them a long-sought means for effective treatment of bodily ills. Since the publication of my first researches in 1891, hundreds of volumes have been written on the subject and many invaluable results obtained through the medium of this new agency. Yet, the art is only in its infancy and the future has incomparably bigger things in store.

From the very beginning I felt the necessity of producing efficient apparatus, *to* meet a rapidly growing demand and during the eight years succeeding my original announcements I developed not less than fifty types of these transformers or electrical oscillators, each complete in every detail and refined to such a degree that I could not materially improve any one of them today. Had I been guided by practical considerations I might have built up an immense and profitable business, incidentally rendering important services to the world. But the force of circumstances and the ever enlarging vista of greater achievements turned my efforts in other directions. And so it comes that instruments will shortly be placed on the market which, oddly enough, were perfected twenty years ago!

These oscillators are expressly intended to operate on direct and alternating lighting circuits and to generate damped and undamped oscillations or currents of any frequency, volume and tension within the widest limits. They are compact, self-contained, require no care for long periods of time and will be found very convenient and useful for various purposes as, wireless telegraphy and telephony; conversion of electrical energy; formation of chemical compounds through fusion and combination; synthesis of gases; manufacture of ozone; lighting; welding; municipal, hospital, and domestic sanitation and sterilization, and numerous other applications in scientific laboratories and industrial institutions. While these transformers have never been described before, the general principles underlying them were fully set forth in my published articles and patents, more particularly those of September 22, 1896, and it is thought, therefore, that the appended photographs of a few types, together with a short explanation, will convey all the information that may be desired.

The essential parts of such an oscillator are: a condenser, a self-induction coil for charging the same to a high potential, a circuit controller, and a transformer which is

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* Electrical Experimenter, July 1919.

energized by the oscillatory discharges of the condenser. There are at least three, but usually four, five or six, circuits in tune and the regulation is effected in several ways, most frequently merely by means of an adjusting screw. Under favorable conditions an efficiency as high as 85% is attainable, that is to say, that percentage of the energy supplied can be recovered in the secondary of the transformer. While the chief virtue of this kind of apparatus is obviously due to the wonderful powers of the condenser, special qualities result from concatenation of circuits under observance of accurate harmonic relations, and minimization of frictional and other losses which has been one of the principal objects of the design.

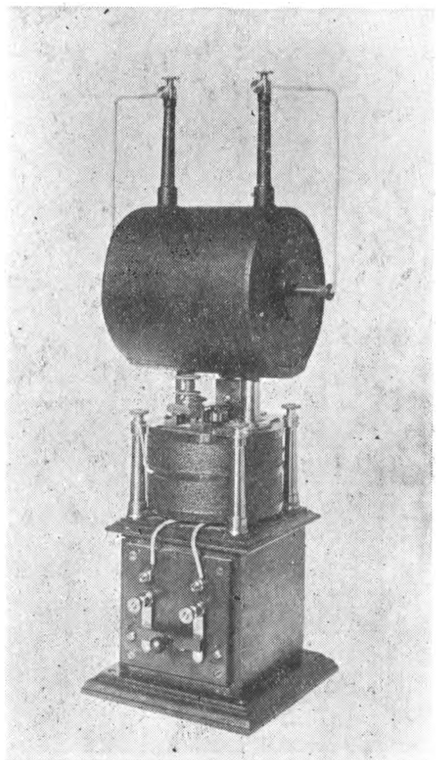


Fig. 1.

Broadly, the instruments can be divided into two classes: one in which the circuit controller comprises solid contacts, and the other in which the make and break is effected by mercury. Figures 1 to 8, inclusive, belong to the first, and the remaining ones to the second class. The former are capable of an appreciably higher efficiency on account of the fact that the losses involved in the make and break are reduced to the minimum and the resistance component of the damping factor is very small. The latter are preferable for purposes requiring larger output and a great number of breaks per second. The operation of the motor and circuit controller of course consumes a certain amount of energy which, however, is the less significant the larger the capacity of the machine.

In Fig. 1 is shown one of the earliest forms of oscillator constructed for experimental purposes. The condenser is contained in a square box of mahogany upon which is mounted the self-induction or charging coil wound, as will be noted, in two sections connected in multiple or series according to whether the tension of the supply circuit is 110 or 220 volts. From the box protrude four brass columns carrying a plate with

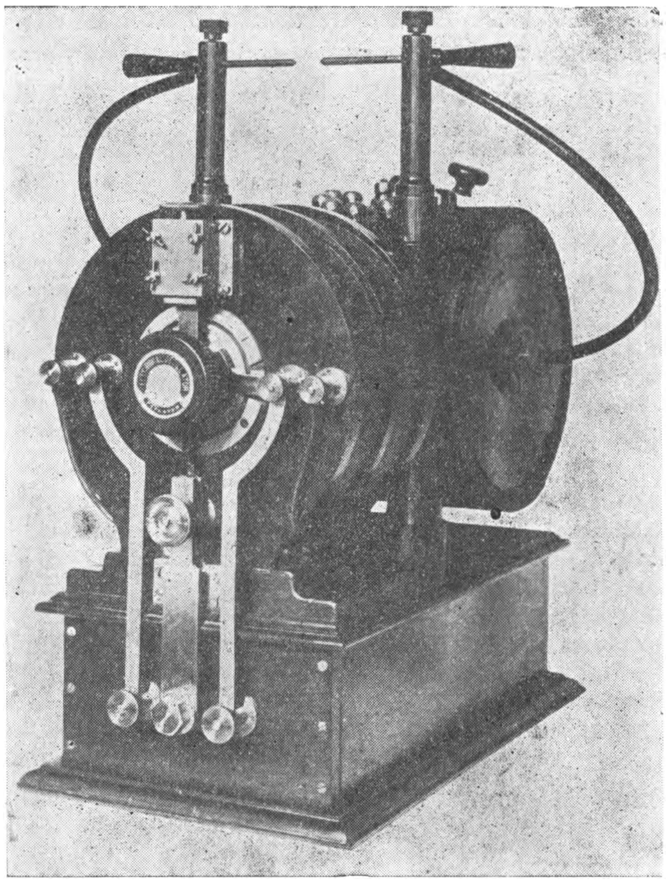


Fig. 2.

the spring contacts and adjusting screws as well as two massive terminals for the reception of the primary of the transformer. Two of the columns serve as condenser connections while the other pair is employed to join the binding posts of the switch in front to the self-inductance and condenser. The primary coil consists of a few turns of copper ribbon to the ends of which are soldered short rods fitting into the terminals referred to. The secondary is made in two parts, wound in a manner to reduce as much as possible the distributed capacity and at the same time enable the coil to withstand a very high pressure between its terminals at the center, which are connected to binding posts on two rubber columns projecting from the primary. The circuit connections may be slightly varied but ordinarily they are as diagrammatically illustrated in the Electrical

Experimenter for May on page 89, relating to my oscillation transformer photograph of which appeared on page 16 of the same number. The operation is as follows: When the switch is thrown on, the current from the supply circuit rushes through the self-induction coil, magnetizing the iron core within and separating the contacts of the controller. The high tension induced current then charges the condenser and upon

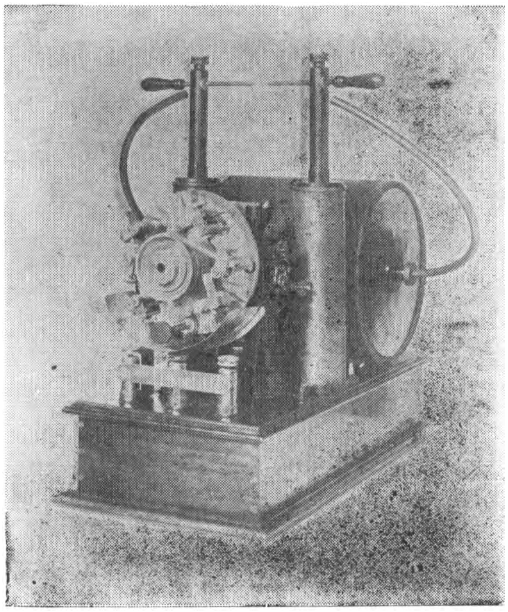


Fig. 3.

closure of the contacts the accumulated energy is released through the primary, giving rise to a long series of oscillations which excite the tuned secondary circuit.

This device has proved highly serviceable in carrying on laboratory experiments of all kinds. For instance, in studying phenomena of impedance, the transformer was removed and a bent copper bar inserted in the terminals. The latter was often replaced by a large circular loop to exhibit inductive effects at a distance or to excite resonant circuits used in various investigations and measurements. A transformer suitable for any desired performance could be readily improvised and attached to the terminals and in this way much time and labor was saved. Contrary to what might be naturally expected, little trouble was experienced with the contacts, although the currents through them were heavy, namely, proper conditions of resonance existing, the great flow occurs only when the circuit is closed and no destructive arcs can develop. Originally I employed platinum and iridium tips but later replaced them by some of meteorite and finally of tungsten. The last have given the best satisfaction, permitting working for hours and days without interruption.

Fig. 2 illustrates a small oscillator designed for certain specific uses. The underlying idea was to attain great activities during minute intervals of time each succeeded by a comparatively long period of inaction. With this object a large self-induction and a quick-acting break were employed owing to which arrangement the condenser was charged to a very high potential. Sudden secondary currents and sparks of great volume were thus obtained, eminently suitable for welding thin wires, flashing lamp filaments, igniting explosive mixtures and kindred applications. The instrument was also adapted for battery use and in this form was a very effective igniter for gas engines on which a patent bearing number 609,250 was granted to me August 16, 1898.

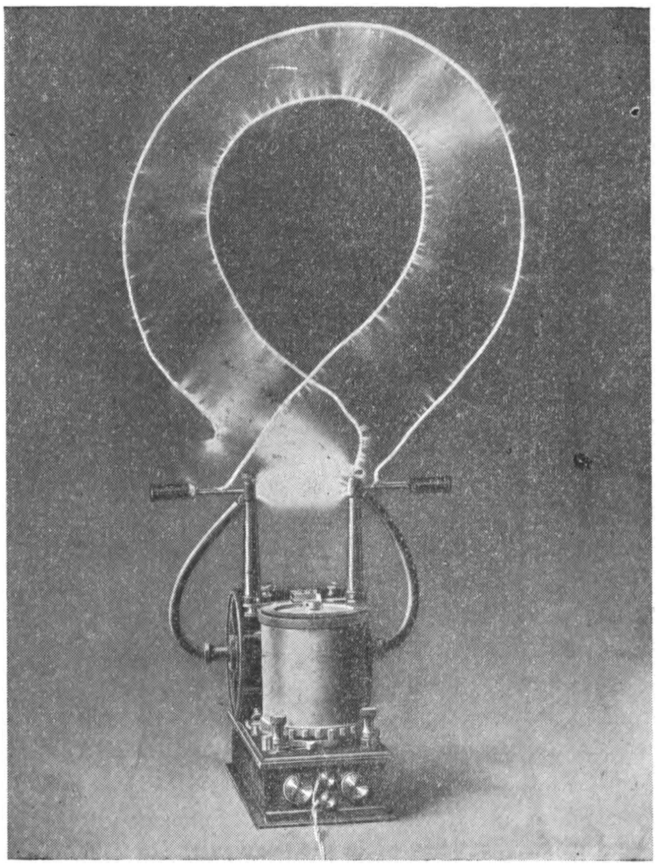


Fig. 4.

Fig. 3 represents a large oscillator of the first class intended for wireless experiments, production of Röntgen rays and scientific research in general. It comprises a box containing two condensers of the same capacity on which are supported the charging coil and transformer. The automatic circuit controller, hand switch and connecting posts are mounted on the front plate of the inductance spool as is also one of the contact springs. The condenser box is equipped with three terminals, the two external ones serving merely for connection while the middle one carries a contact bar with a screw for regulating the interval during which the circuit is closed. The vibrating spring itself, the sole function of which is to cause periodic interruptions, can be adjusted in its strength as well as distance from the iron core in the center of the charging coil by four screws visible on the top plate so that any desired conditions of mechanical control might be secured. The primary coil of the transformer is of copper sheet and taps are made at suitable points for the purpose of varying, at will, the number of turns. As in Fig. 1 the inductance coil is wound in two sections to

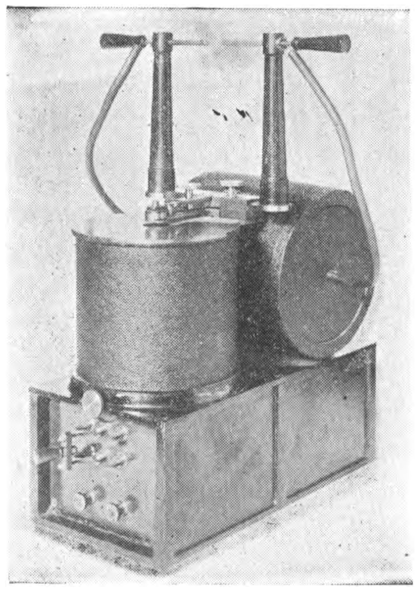


Fig. 5.

adapt the instrument both to 110 and 220 volt circuits and several secondaries were provided to suit the various wave lengths of the primary. The output was approximately 500 watt with damped waves of about 50,000 cycles per second. For short periods of time undamped oscillations were produced in screwing the vibrating spring tight against the iron core and separating the contacts by the adjusting screw *which also performed the function of a key.* With this oscillator I made a number of important observations and it was one of the machines exhibited at a lecture before the New York Academy of Sciences in 1897.

Fig. 4 is a photograph of a type of transformer in every respect similar to the one illustrated in the May, 1919, issue of the Electrical Experimenter to which reference has already been made. It contains the identical essential parts, disposed in like manner, but was specially designed for use on supply circuits of higher tension, from 220 to 500 volts or more. The usual adjustments are made in setting the contact spring and shifting the iron core within the inductance coil up and down by means of two screws. In order to prevent injury through a short-circuit, fuses are inserted in the lines. The instrument was photographed in action, generating undamped oscillations from a 220 volt lighting circuit.

Fig. 5 shows a later form of transformer principally intended to replace Rhumkorf coils. In this instance a primary is employed, having a much greater number of turns

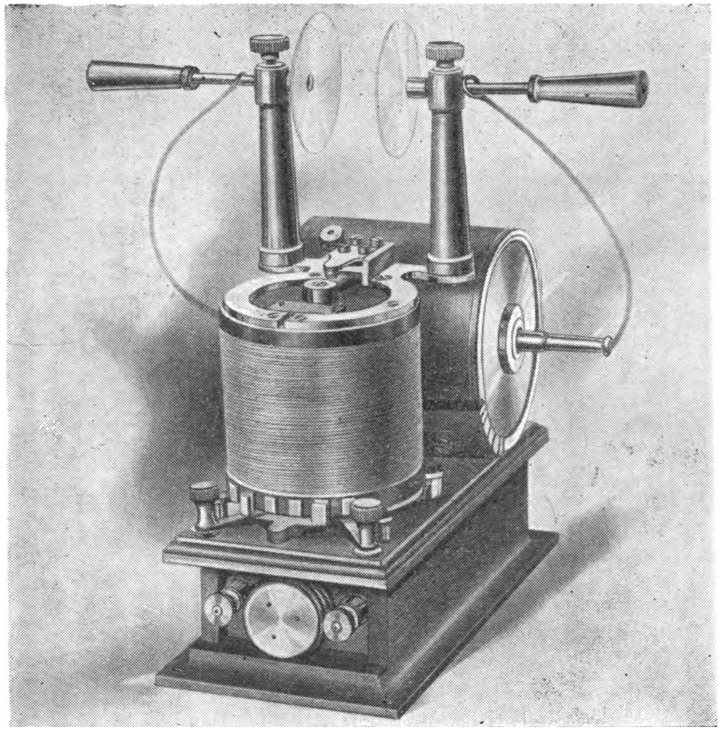


Fig. 6.

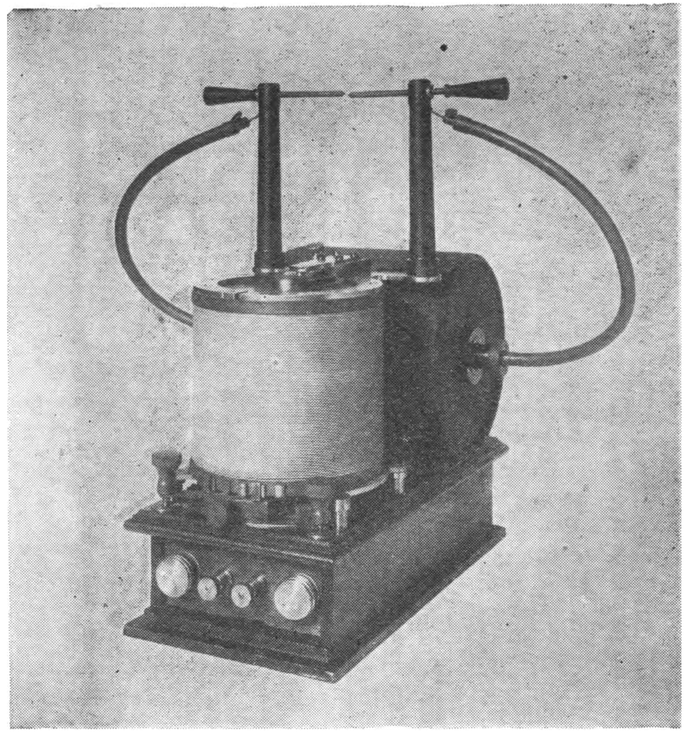


Fig. 7.

and the secondary is closely linked with the same. The currents developed in the latter, having a tension of from 10,000 to 30,000 volts, are used to charge condensers and operate an independent high frequency coil as customary. The controlling mechanism is of somewhat different construction but the core and contact spring are both adjustable as before.

Fig. 6 is a small instrument of this type, particularly intended for ozone production or sterilization. It is remarkably efficient for its size and can be connected either to a 110 or 220 volt circuit, direct or alternating, preferably the former.

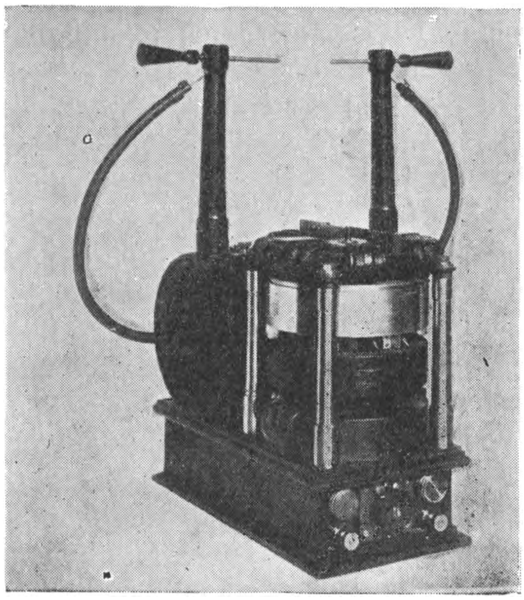


Fig. 8.

In Fig. 7 is shown a photograph of a larger transformer of this kind. The construction and disposition of the parts is as before but there are two condensers in the box, one of which is connected in the circuit as in the previous cases, while the other is in shunt to the primary coil. In this manner currents of great volume are produced in the latter and the secondary effects are accordingly magnified. The introduction of an additional tuned circuit secures also other advantages but the adjustments are rendered more difficult and for this reason it is desirable to use such an instrument in the production of currents of a definite and unchanging frequency.

Fig. 8 illustrates a transformer with rotary break. There are two condensers of the same capacity in the box which can be connected in series or multiple. The charging inductances are in the form of two long spools upon which are supported the secondary terminals. A small direct current motor, the speed of which can be varied within wide limits, is employed to drive a specially constructed make and break. In other features the oscillator is like the one illustrated in Fig. 3 and its operation will be readily understood from the foregoing. This transformer was used in my wireless experiments

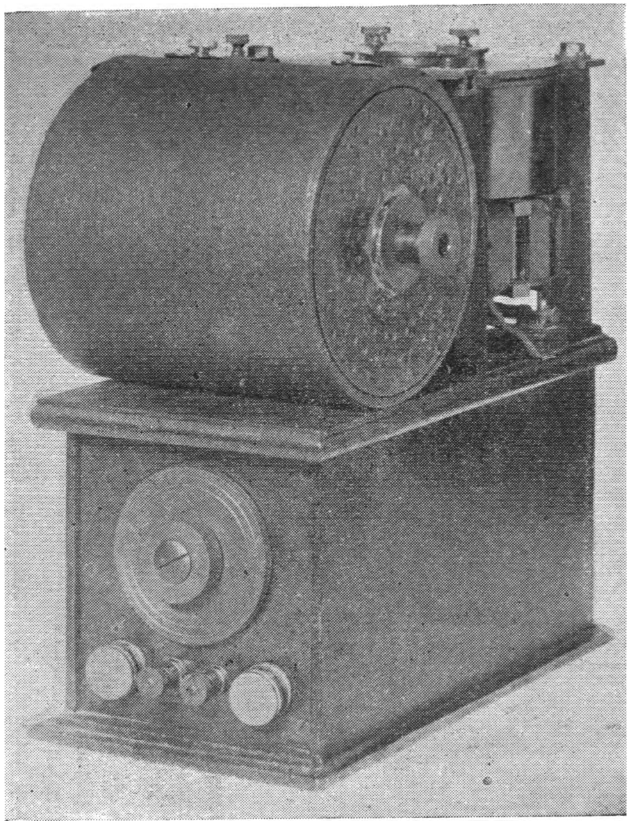


Fig. 9.

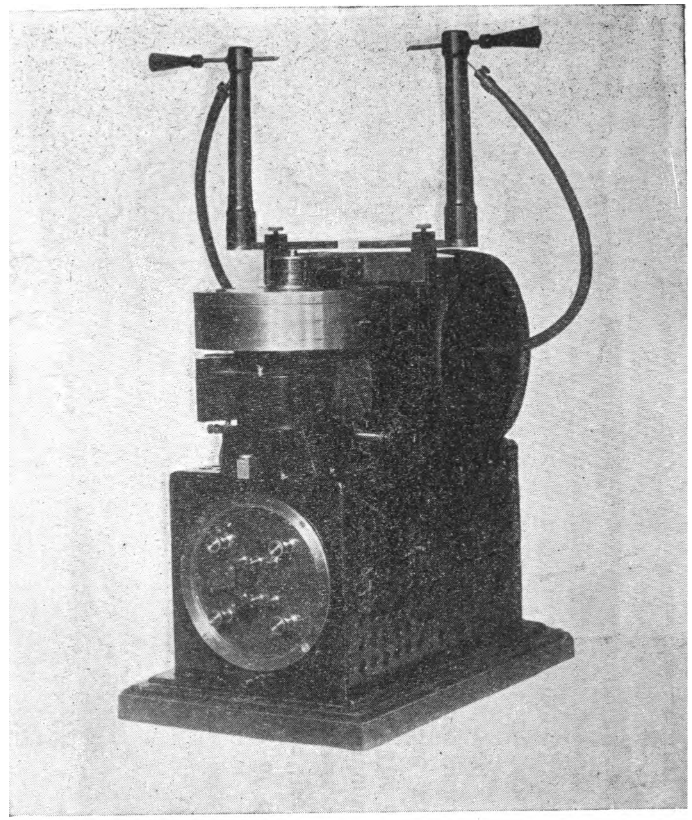


Fig. 10.

and frequently also for lighting the laboratory by my vacuum tubes and was likewise exhibited at my lecture before the New York Academy of Sciences above mentioned.

Coming now to machines of the second class, Fig. 9 shows an oscillatory transformer comprising a condenser and charging inductance enclosed in a box, a transformer and a mercury circuit controller, the latter being of a construction described for the first time in my patent No. 609,251 of August 16, 1898. It consists of a motor driven hollow pulley containing a small quantity of mercury which is thrown outwardly against the walls of the vessel by centrifugal force and entrains a contact wheel which periodically closes and opens the condenser circuit. By means of adjusting screws

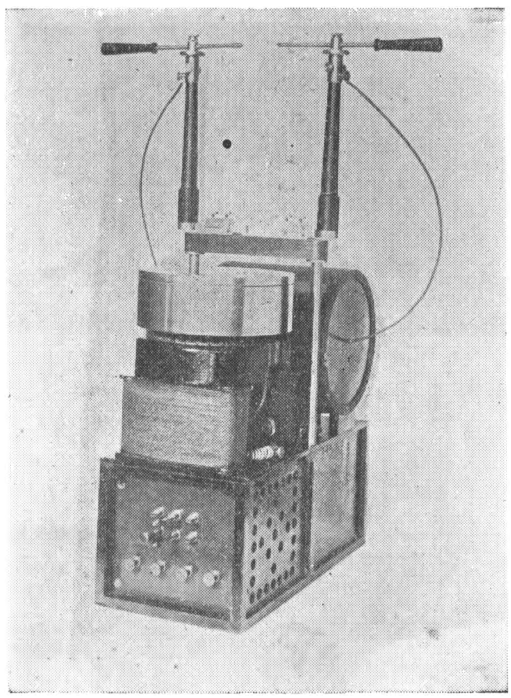


Fig. 11.

above the pulley, the depth of immersion of the vanes and consequently, also, the duration of each contact can be varied at desire and thus the intensity of the effects and their character controlled. This form of break has given thorough satisfaction, working continuously with currents of from 20 to 25 amperes. The number of interruptions is usually from 500 to 1,000 per second but higher frequencies are practicable. The space occupied is about 10" × 8" × 10" and the output approximately ½ kW.

In the transformer just described the break is exposed to the atmosphere and a slow oxidation of the mercury takes place. This disadvantage is overcome in the instrument shown in Fig. 10, which consists of a perforated metal box containing the condenser and charging inductance and carrying on the top a motor driving the break, and a transformer. The mercury break is of a kind to be described and operates on the

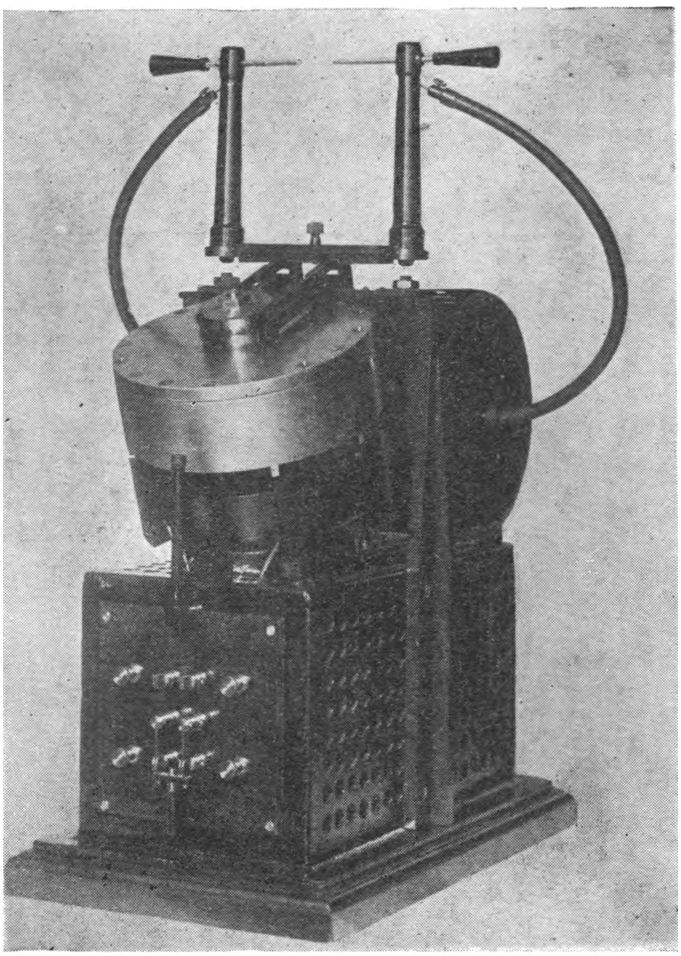


Fig. 12.

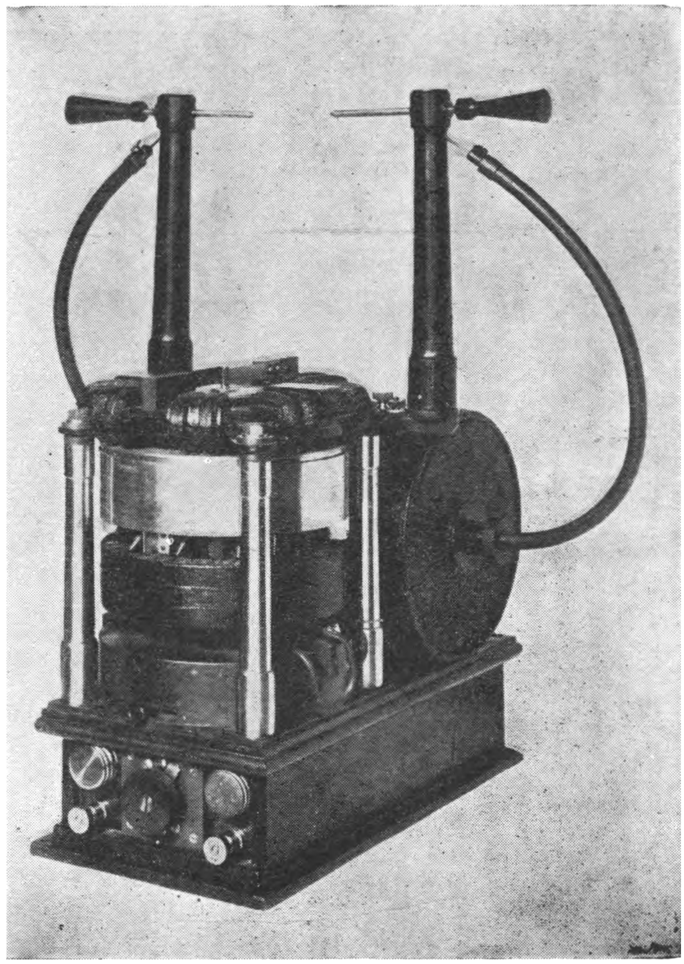


Fig. 13.

principle of a jet which establishes, intermittently, contact with a rotating wheel in the interior of the pulley. The stationary parts are supported in the vessel on a bar passing through the long hollow shaft of the motor and a mercury seal is employed to effect hermetic closure of the chamber enclosing the circuit controller. The current is led into the interior of the pulley through two sliding rings on the top which are in series with the condenser and primary. The exclusion of the oxygen is a decided improvement, the deterioration of the metal and attendant trouble being eliminated and perfect working conditions continuously maintained.

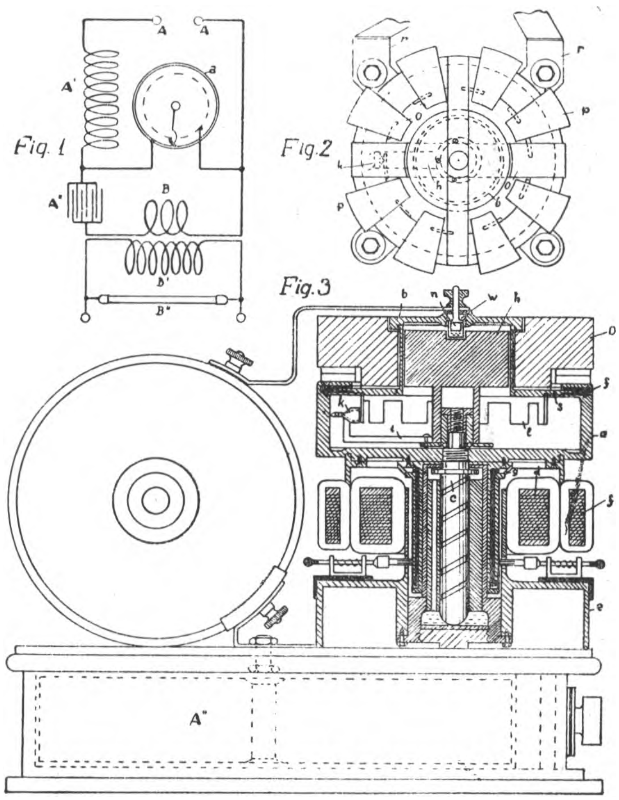


Fig. 14.

Fig. 11 is a photograph of a similar oscillator with hermetically inclosed mercury break. In this machine the stationary parts of the interrupter in the interior of the pulley were supported on a tube through which was led an insulated wire connecting to one terminal of the break while the other was in contact with the vessel. The sliding rings were, in this manner, avoided and the construction simplified. The instrument was designed for oscillations of lower tension and frequency requiring primary currents of comparatively smaller amperage and was used to excite other resonant circuits.

Fig. 12 shows an improved form of oscillator of the kind described in Fig. 10, in which the supporting bar through the hollow motor shaft was done away with, the device pumping the mercury being kept in position by gravity, as will be more fully explained with reference to another figure. Both the capacity of the condenser and primary turns were made variable with the view of producing oscillations of several frequencies.

Fig. 13 is a photographic view of another form of oscillatory transformer with hermetically sealed mercury interrupter, and Fig. 14 diagrams showing the circuit

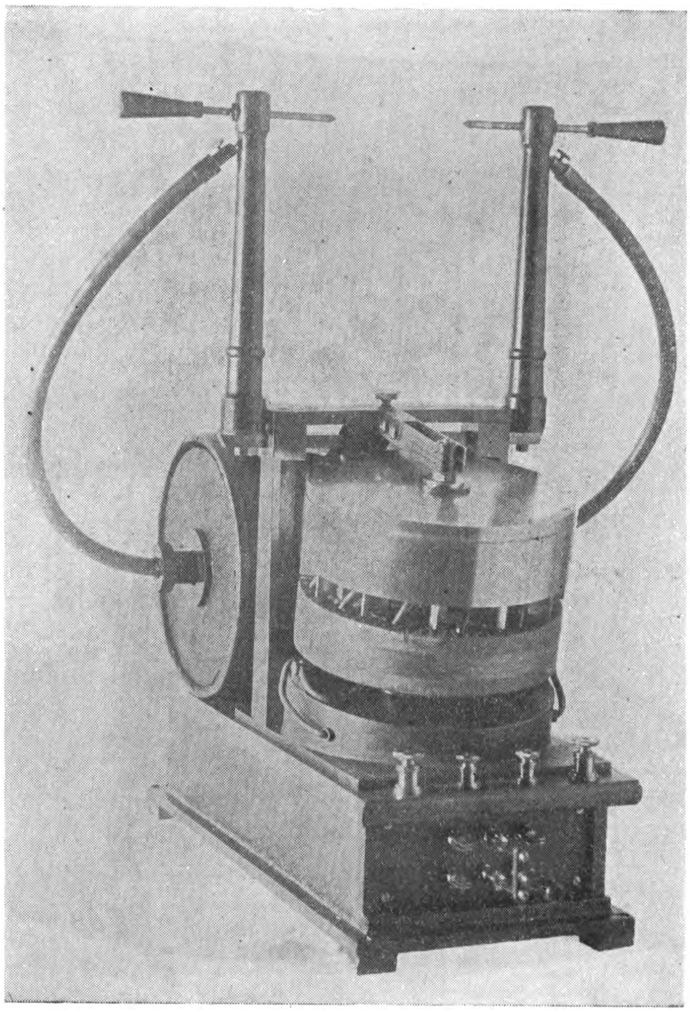


Fig. 15.

connections and arrangement of parts reproduced from my patent, No. 609,245, of August 16, 1898, describing this particular device. The condenser, inductance, transformer and circuit controller are disposed as before, but the latter is of different construction, which will be clear from an inspection of Fig. 14. The hollow pulley *a* is secured to a shaft *c* which is mounted in a vertical bearing passing through the stationary field magnet *d* of the motor. In the interior of the vessel is supported, on frictionless bearings, a body *h* of magnetic material which is surrounded by a dome *b* in the center of a laminated iron ring, with pole pieces *oo* wound with energizing coils *p.* The ring is supported on four columns and, when magnetized, keeps the body *h* in position while the pulley is rotated. The latter is of steel, but the dome is preferably made of German silver burnt black by acid or nickeled. The body *h* carries a short tube *k* bent, as indicated, to catch the fluid as it is whirled around, and project it against the teeth

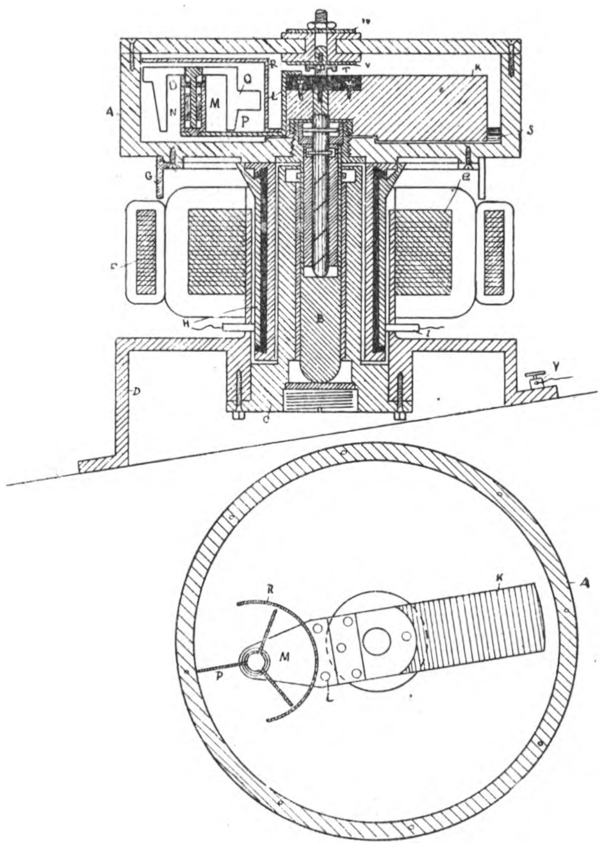


Fig. 16.

of a wheel fastened to the pulley. The wheel is insulated and contact from it to the external circuit is established through a mercury cup. As the pulley is rapidly rotated a jet of the fluid is thrown against the wheel, *thus making and breaking contact about* 1,000 *times per second.* The instrument works silently and, owing to the absence of all deteriorating agents, keeps continually clean and in perfect condition. The number of interruptions per second may be much greater, however, so as to make the currents suitable for wireless telephony and like purposes.

A modified form of oscillator is represented in Figs. 15 and 16, the former being a photographic view and the latter a diagrammatic illustration showing the arrangement

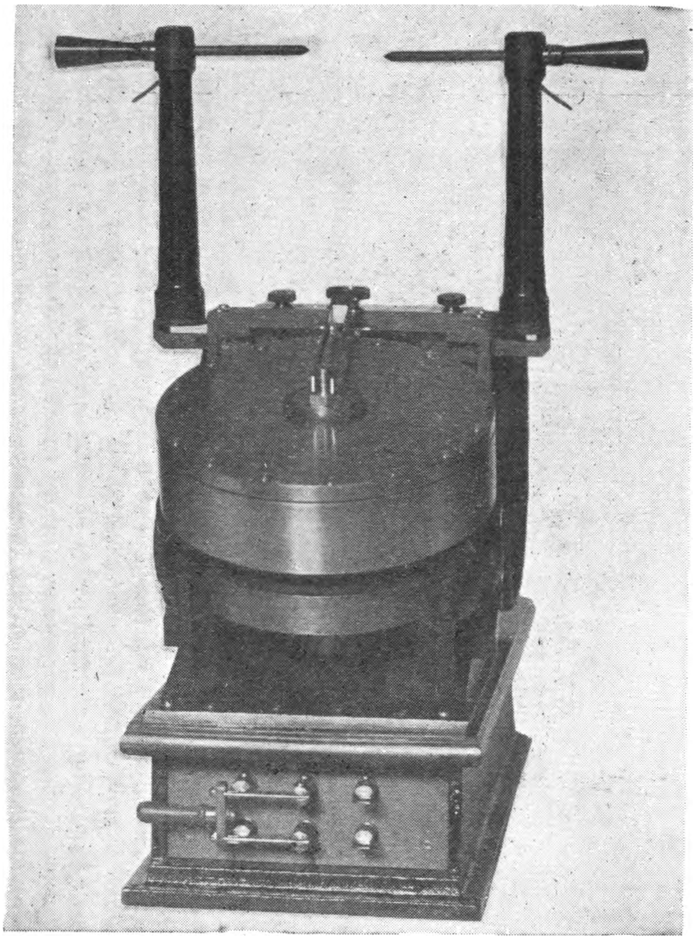


Fig. 17.

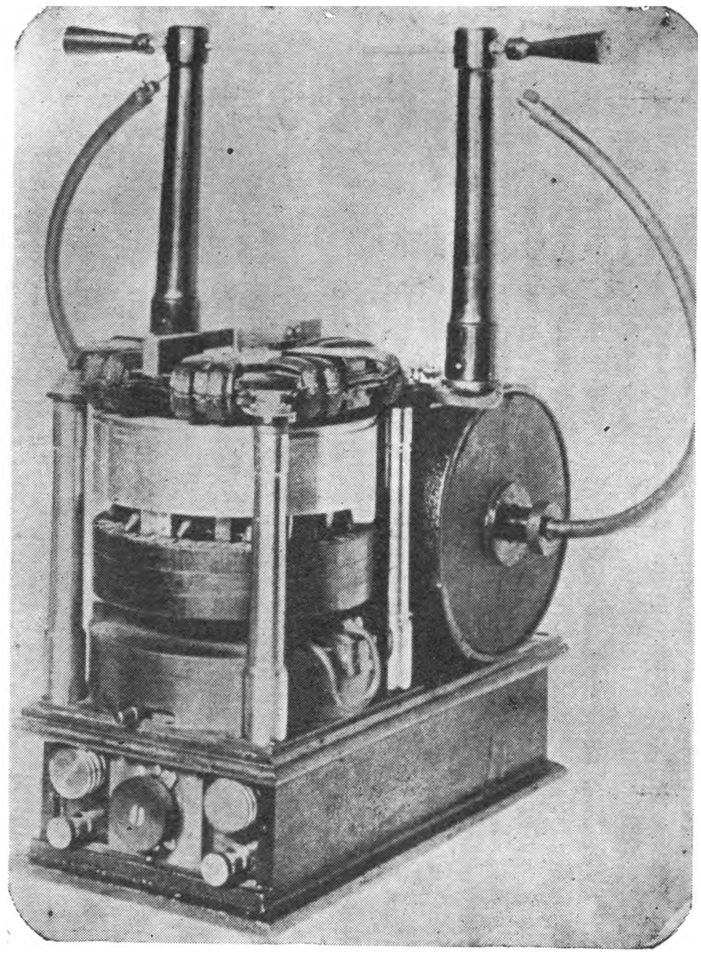


Fig. 18.

of the interior parts of the controller. In this instance the shaft *b* carrying the vessel *a* is hollow and supports, in frictionless bearings, a spindle *j* to which is fastened a weight *k.* Insulated from the latter, but mechanically fixed to it, is a curved arm L upon which is supported, freely rotatable, a break-wheel with projections QQ. The wheel is in electrical connection with the external circuit through a mercury cup and an insulated plug supported from the top of the pulley. Owing to the inclined position of the motor the weight *k* keeps the break-wheel in place by the force of gravity and as the pulley is rotated the circuit, including the condenser and primary coil of the transformer, is rapidly made and broken.

Fig. 17 shows a similar instrument in which, however, the make and break device is a jet of mercury impinging against an insulated toothed wheel carried on an insulated stud in the center of the cover of the pulley as shown. Connection to the condenser circuit is made by brushes bearing on this plug.

Fig. 18 is a photograph of another transformer with a mercury circuit controller of the wheel type, modified in some features on which it is unnecessary to dwell.

These are but a few of the oscillatory transformers I have perfected and constitute only a small part of my high frequency apparatus of which I hope to give a full description, when I shall have freed myself of pressing duties, at some future date.

17

DEVELOPMENTS IN PRACTICE AND ART OF TELEPHOTOGRAPHY*

The recent successful experiments by Edouard Belin of Paris in the transmission of photographs between New York City and St. Louis, a distance of 1000 miles, have naturally aroused new interest in this rather old art. Mr. Belin's apparatus has been examined with a knowledge of previous efforts in that direction, and it must be admitted that the French inventor has achieved a marked improvement. It is true that his apparatus in many of its features is old and well known, but all the details have been worked out skilfully and his photographic reproductions are not only good likenesses of the originals but are expressive in no small degree. In common with other arts the transmission of pictures to a distance has been brought to its present state of perfection by slow and gradual improvements effected in the course of 77 years. The literature on the subject is quite voluminous and difficult to peruse, as the articles are published in various languages and scattered through numerous periodicals. Only one complete and exhaustive work has been published in German by Dr. Arthur Korn of Munich and Dr. Bruno Glatzel.

FIRST PATENTS TAKEN OUT MANY YEARS AGO

The original idea is due to Alexander Bain, a Scotch mechanician, who secured a British patent disclosing the invention in 1843. His plan contemplated the transmission of printed letters, drawings and pictures in the following way: At the sending station a holder with insulated metal points was arranged to glide in the direction of the lines over a frame resting on the printed page to be reproduced at a distance. Within this frame, and at right angles to its plane, a number of short wires were imbedded in sealing wax, their lower ends being in contact with the letters which in turn were all electrically connected. As the holder moved back and forth the insulated metal points would be brought in and out of contact with the upper ends of the short wires, thus controlling the flow of the current through them. Each metal point was joined by a special line to the receiving station where there was a similar holder made to slide over chemically prepared paper laid on a grounded metal plate. When a battery at the transmitting end was connected with one of its poles to the letters and the other to the ground the current impulses traversing the line wires and the chemical paper would cause changes of color in the latter, thus reproducing the characters. A great number of points and line wires were required to attain satisfactory results and, realizing this objection, Bain proposed to avail himself of only one wire, but did not give full information in this regard. Subsequently Bonnelli and other inventors made improvements in his apparatus, reducing the number of the wires to a few. There is no doubt that, despite the manifest crudity of this system, it was quite capable of being used

* Electrical Review, Dec. 11, 1920.

commercially in the transmission of type as well as drawings and pictures and may yet be found valuable.

The first practical success was achieved by an Englishman, Frederick Collier Bakewell, who secured a British patent in 1847 on a process, some features of which have proved to be indispensable in later years. He employed as a transmitter a cylinder on which the characters were written with insulating ink. A metal point bore on the cylinder and advanced slightly with each revolution of the same exactly as in the older form of phonograph. A similar cylinder covered with chemical paper and equipped with a sliding point was provided at the receiving station. The cylinders being grounded and a battery included in the line wire connecting the transmitting and receiving points, the passage of the current resulted in a discoloration of the paper and reproduction of the written characters at the receiving end. Considering the period Bakewell's apparatus was surprisingly perfect, particularly in the feature of maintaining the rotating cylinders in synchronism for which purpose he provided an automatic as well as a hand correction. A controversy was waged between Bakewell and Bain for the honor of priority, but in this respect there can be no mistake. Bain was the originator of the idea while Bakewell was the first to carry it out successfully.

USE OF CHEMICAL PAPER CONSIDERED IMPRACTICAL

The use of chemical paper was considered objectionable, and in 1851 Hipp eliminated it, producing the impressions at the receiver with a magnet actuated by the transmitted impulses. It is curious, though, to observe that the modern art depends entirely on this very device. In 1855 Casselli modified the Bakewell apparatus by employing carefully synchronized pendulums at the transmitting and receiving stations, thus replacing the rotary motion by a to-and-fro movement as in the Bain arrangement. Casselli seems to have had more enterprise than his predecessors, and the apparatus which he perfected in 1860 was actually used with some success for a short time in service between Paris and several other cities in France. Its abandonment was probably due to the slowness of transmission and lack of demand for this kind of facility. It is singular that many treatises on physics and other text books mention Casselli while ignoring Bain and Bakewell.

Shortly after this Meyer perfected a system which was used with success in France, and may be fairly considered as the first thoroughly practical application of ideas in this field. A curious improvement was made by Gérard who, in 1865, proposed the use of flat disks in place of the cylinders of Bakewell. Ever since one wire was adopted for the transmission it became an imperative necessity to maintain perfect synchronism between the transmitter and receiver, and many inventors devoted their energy to this task. D'Arlincourt resorted to tuning forks, and his idea was subsequently carried out in a more perfect manner by Lacour. At about this time the invention reached America, and in 1870 Sawyer brought his ingenuity to bear on the evolution of a process in which he employed zinc clichés. These were very reliable and constituted a signal advance.

In 1880 Edison devised an apparatus on the principle of that used by Sawyer, except that the impressions were produced on paper in bas-relief. This idea was carried further by Dennison in instruments of the reciprocating type. Through the introduction of the Tesla alternating system of power transmission a novel means was afforded for operating transmitters and receivers. The use of synchronous motors was proposed first in 1893 by Sheehy.

DEVELOPMENTS PERMIT USE OF PHOTOGRAPHIC FILMS

In all cases without exception it was necessary to provide an actual print, drawing or sketch to be transmitted until Lenoir introduced photographic films into the art, making possible the transmission of any kind of picture. This was a great step forward, but the honor of the first practical success belongs to an American engineer, N. Amstutz, who used photographic sending clichés in relief for the first time and with complete success. Amstutz was a true pioneer, and his improvement is essential in the carrying out of the modern processes. It is true that as early as 1865, a Frenchman, Hubert, had suggested the use of letters written with thick ink, but this was of little value, and Amstutz was undoubtedly the first to produce and use the clichés on which the up-to-date art vitally depends. Perfectly satisfactory demonstrations were made with his devices in this country more than 20 years ago, when pictures were transmitted over telegraph wires to great distances. Samples of his work have been preserved which clearly show how much be was ahead of his time.

Following Amstutz, Dunlany, Palmer, Mills and other American inventors took up picture transmission with more or less success. By this time the necessity presented itself for increasing the rapidity of the process by greater speed of the devices as well as multiplex transmission. The Belgian inventor, Carbonelle, made an important improvement in this direction when he introduced the telephone diaphragm carrying a stylus for making the impressions.

Of all inventors, however, Dr. Korn was the most successful as well as prolific in the suggestion of improvements, his photographic method of recording carried out in 1903 being the most significant. The general idea of photographic recording had been already advanced by George Little, and a few years later Dillon took out a patent involving the use of sensitized paper and a mirror reflecting a beam of light on the same. But it is obvious that at that time it would have been hardly practicable to use this suggestion, as photography was not sufficiently advanced. In illustration of this it may be mentioned that in 1892 the attention of the scientific world was directed to a wonderfully sensitive receiver, consisting of an electron stream maintained in a delicately balanced condition in a vacuum bulb, by means of which it was proposed to use photography in the transmission of telegraphic and telephonic messages through the Atlantic cables, and later also by wireless. This proposal was met by insurmountable objections to the photographic method. Indeed, the Belin process has been rendered possible largely through the great improvements in the sensitive films which have been evolved in response to the urgent demands of the motion picture and also under the stimulus of the recent war.

SELENIUM CELL AND VACUUM TUBE USED TO TRANSMIT AND RECEIVE

In the apparatus invented by Dr. Korn a selenium cell is used at the transmitter to vary the intensity of the sending current, and at the receiving station he employs a vacuum tube of high intensity which throws its light through a fine slot on a sensitive plate. The tube is excited by high-frequency currents supplied from a Tesla transformer and may be flashed up many thousand times per second. The motion of the receiver element is effected either by a wire galvanometer, oscillograph or telephone diaphragm. The Korn system has been used for some years past with success in Germany and other countries. In fact, it has been operated for some time even by wireless. Patents on this mode of transmission have been granted in 1898 and 1899 to Küster and G. Williams, but the arrangements involved the employment of Hertz waves and were impracticable. Later Frederick Braun, Pansa and Knudsen secured patents which, however, are equally defective. Success in this direction has been achieved so far only by Korn, Berjonneau and T. Baker. Invariably the inventors employ a wire galvanometer which is especially suitable for great speed. Telautographic transmission by similar means through wires as well as wireless is now common and is effected by employing a transmitter of two components, the original idea of which is due to an Englishman, Jones, who made that suggestion as early as 1855.

PRESENT DEVELOPMENTS INVOLVE MANY OLD PRINCIPLES

To this short story of picture transmission Belin has contributed the latest chapter. The process he has finally adopted after many years of persistent effort involves the use of two cylinders rotating in synchronism — one for transmitting and the other for reproducing. The former is of copper and is prepared. for operation by having its surface coated with a thin shellac solution, wrapping a carbon print of the photograph about it with its face to the cylinder and immersing the whole in hot water, this causing the gelatine to adhere to the cylinder surface in proportion to the degree of blackness so that a likeness of the print in bas-relief is obtained. On this cylinder bears the stylus of a microphone diaphragm which is slowly moved forward by the revolution of the cylinder as in a phonograph. In this manner the pressure of the carbon contacts is varied in conformity with the changes of the surface, and the microphone currents pass over the transmitting wire to the receiving station where they cause corresponding deflections of a mirror forming part of a highly sensitive dead-beat oscillograph. A strong beam of light reflected from the mirror traverses a screen graduated from full transparency to opacity and is led through a microscopic opening to the sensitive film wrapped around the receiving cylinder. Special provisions are made to keep the cylinders exactly in step as this is indispensable to good performance. The film is, of course, protected against the external light, and when the operation is completed it is developed as usual so that either a positive or negative print is obtained according to the position of the screen. There is nothing in his apparatus which is fundamentally novel; in fact, every feature of the same has been disclosed in the prior art. Even the gratuated screen, which is one of the most essential parts, has been employed before by Dr. Korn. But Mr. Belin has displayed considerable ingenuity and skill in all the details, and his reproduced photographs are most excellent. There is every reason to believe that his efforts will be rewarded by an extensive practical application of his devices.

TELEVISION TO BE NEXT STEP IN PROGRESS OF TRANSMISSION

The transmission of photographs constitutes only the first step towards the immeasurably greater achievement of television. By this is meant instantaneous transmission of visual impressions to any distance by wire or wireless. It is a subject to which I have devoted more than 25 years of close study. Two of the impediments which years ago seemed insurmountable have been successfully overcome, but great difficulties are still in the way. These are encountered in the inertia of the sensitive cells and the enormous speed required to make possible the vision of persons, objects or scenes as in life. It is the problem of constructing a transmitter analogous to the lens and retina of the eye, providing a medium of conveyance corresponding to the optic nerve, and a receiver organized similarly to the brain. It is a gigantic task, but I am confident that the world will witness its actual accomplishment in the near future.

II
ARTICLES ON SOME GENERAL PROBLEMS

ON ELECTRICITY*

THE ADDRESS ON THE OCCASION OF THE COMMEMORATION OF THE INTRODUCTION OF NIAGARA FALLS POWER IN BUFFALO AT THE ELLICOTT CLUB, JANUARY 12, 1897.

I have scarcely had courage enough to address an audience on a few unavoidable occasions, and the experience of this evening, even as disconnected from the cause of our meeting, is quite novel to me. Although in those few instances, of which I have retained agreeable memory, my words have met with a generous reception, I never deceived myself, and knew quite well that my success was not due to any excellency in the rhetorical or demonstrative art. Nevertheless, my sense of duty to respond to the request with which I was honored a few days ago was strong enough to Overcome my very grave apprehensions in regard to my ability of doing justice to the topic assigned to me. It is true, at times — even now, as I speak — my mind feels full of the subject, but I know that, as soon as I shall attempt expression, the fugitive conceptions will vanish, and I shall experience certain well known sensations of abandonment, chill and silence. I can see already your disappointed countenances and can read in them the painful regret of the mistake in your choice.

These remarks, gentlemen, are not made with the selfish desire of winning your kindness and indulgence on my shortcomings, but with the honest intention of offering you an apology for your disappointment. Nor are they made — as you might be disposed to think — in that playful spirit which, to the enjoyment of the listeners, is often displayed by belated speakers. On the contrary, I am deeply earnest in my wish that I were capable of having the fire of eloquence kindled in me, that I might dwell in adequate terms on this fascinating science of electricity, on the marvelous development which electrical annals have recorded and which, as one of the speakers justly remarked, stamp this age as the Electrical Age, and particularly on the great event we are commemorating this day. Unfortunately, this my desire must remain unfulfilled, but I am hopeful that in my formless and incomplete statements, among the few ideas and facts I shall mention there may be something of interest and usefulness, something befitting this unique occasion.

Gentlemen, there are a number of features clearly discernible in, and characteristic of, human intellectual progress in more recent times — features which afford great comfort to the minds of all those who have really at heart the advancement and welfare of mankind.

First of all, the inquiry, by the aid of the microscope and electrical instruments of precision, into the nature of our organs and senses, and particularly of those through which we commune directly with the outside world and through which knowledge is conveyed to our minds, has revealed their exact construction and mode of action, which

* Electrical Review, Jan. 27, 1897.

is in conformity with simple and well established physical principles and laws. Hence the observations we make and the facts we ascertain by their help are *real* facts and observations, and our knowledge is *true* knowledge. To illustrate: Our knowledge of form, for instance, is dependent upon the positive fact that light propagates in straight lines, and, owing to this, the image formed by a lens is exactly similar to the object seen. Indeed, my thoughts in such fields and directions have led me to the conclusion that most all human knowledge is based on this simple truth, since practically every idea or conception — and therefore all knowledge — presupposes visual impressions. But if light would not propagate in accordance with the law mentioned, but in conformity with any other law which we might presently conceive, whereby not only the image might not bear any likeness to the object seen, but even the images of the same object at different times or distances might not resemble each other, then our knowledge of form would be very defective, for then we might see, for example, a three-cornered figure as a six or twelve-cornered one. With the clear understanding of the mechanism and mode of action of our organs, we remove all doubts as to the *reality* and *truth* of the impressions received from the outside, and thus we bar out — forever, we may hope — that unhealthy speculation and skepticism into which formerly even strong minds were apt to fall.

Let me tell you of another comforting feature. The progress in a measured time is nowadays more rapid and greater than it ever was before. This is quite in accordance with the fundamental law of motion, which commands acceleration and increase of momentum or accumulation of energy under the action of a continuously acting force and tendency, and is the more true as every advance weakens the elements tending to produce friction and retardation. For, after all, what *is* progress, or — more correctly — development, or evolution, if not a movement, infinitely complex and often unscrutinizable, it is true, but nevertheless exactly determined in quantity as well as in quality of motion by the physical conditions and laws governing? This feature of more recent development is best shown in the rapid merging together of the various arts and sciences by the obliteration of the hard and fast lines of separation, of borders, some of which only a few years ago seemed unsurpassable, and which, like veritable Chinese walls, surrounded every department of inquiry and barred progress. A sense of connectedness of the various apparently widely different forces and phenomena we observe is taking possession of our minds, a sense of deeper understanding of nature as a whole, which, though not yet quite clear and defined, is keen enough to inspire us with the confidence of vast realizations in the near future.

But these features chiefly interest the scientific man, the thinker and reasoner. There is another feature which affords us still more satisfaction and enjoyment, and which is of still more universal interest, chiefly because of its bearing upon the welfare of mankind. Gentlemen, there is an influence which is getting strong and stronger day by day, which shows itself more and more in all departments of human activity, an influence most fruitful and beneficial — the influence of the artist. It was a happy day for the mass of humanity when the artist felt the desire of becoming a physician, an electrician, an engineer or mechanician or — whatnot — a mathematician or a financier; for it was he who wrought all these wonders and grandeur we are witnessing. It was he who abolished that small, pedantic, narrow-grooved school teaching which made of an aspiring student a galley-slave, and he who allowed freedom in the choice of subject of study according to one's pleasure and inclination, and so facilitated development.

Some, who delight in the exercise of the powers of criticism, call this an asymmetrical development, a degeneration or departure from the normal, or even a degradation of the race. But they are mistaken. This is a welcome state of things, a blessing, a wise subdivision of labors, the establishment of conditions most favorable to progress. Let one concentrate all his energies in one single great effort, let him perceive a single truth, even though he be consumed by the sacred fire, then millions of less gifted men can easily follow. Therefore it is not as much quantity as quality of work which determines the magnitude of the progress.

It was the artist, too, who awakened that broad philanthropic spirit which, even in old ages, shone in the teachings of noble reformers and philosophers, that spirit which makes men in all departments and positions work not as much for any material benefit or compensation — though reason may command this also — but chiefly for the sake of success, for the pleasure there is in achieving it and for the good they might be able to do thereby to their fellow-men. Through his influence types of men are now pressing forward, impelled by a deep love for their study, men who are doing wonders in their respective branches, whose chief aim and enjoyment is the acquisition and spread of knowledge, men who look far above earthly things, whose banner is Excelsior! Gentlemen, let us honor the artist, let us thank him, let us drink his health!

Now, in all these enjoyable and elevating features which characterize modern intellectual development, electricity, the expansion of the science of electricity, has been a most potent factor. Electrical science has revealed to us the true nature of light, has provided us with innumerable appliances and instruments of precision, and has thereby vastly added to the exactness of our knowledge. Electrical science has disclosed to us the more intimate relation existing between widely different forces and phenomena and has thus led us to a more complete comprehension of Nature and its many manifestations to our senses. Electrical science, too, by its fascination, by its promises of immense realizations, of wonderful possibilities chiefly in humanitarian respects, has attracted the attention and enlisted the energies of the artist; for where is there a field in which his God-given powers would be of greater benefit to his fellow-men than this unexplored, almost virgin, region, where, like in a silent forest, a thousand voices respond to every call?

With these comforting features, with these cheering prospects, we need not look with any feeling of incertitude or apprehension into the future. There are pessimistic men, who, with anxious faces, continuously whisper in your ear that the nations are secretly arming — arming to the teeth; that they are going to pounce upon each other at a given signal and destroy themselves; that they are all trying to outdo that victorious, great, wonderful German army, against which there is no resistance, for every German has the discipline in his very blood — every German is a soldier. But these men are in error. Look only at our recent experience with the British in that Venezuela difficulty. Two other nations might have crashed together, but not the Anglo-Saxons; they are too far ahead. The men who tell you this are ignoring forces which are continually at work, silently but resistlessly — forces which say Peace!

There is the genuine artist, who inspires us with higher and nobler sentiments, and makes us abhor strife and carnage. There is the engineer, who bridges gulfs and chasms, and facilitates contact and equalization of the heterogeneous masses of humanity. There is the mechanic, who comes with his beautiful time and energy-saving appliances, who perfects his flying machine, not to drop a bag of dynamite on a city or vessel, but to facilitate transport and travel. There, again, is the chemist, who opens new resources and makes existence more pleasant and secure; and there is the electrician, who sends his messages of peace to all parts of the globe. The time will not be long in coming when those men who are turning their ingenuity to inventing quick-firing guns, torpedoes and other implements of destruction — all the while assuring you that it is for the love and good of humanity — will find no takers for their odious tools, and will realize that, had they used their inventive talent in other directions, they might have reaped a far better reward than the sestertia received. And then, and none too soon, the cry will be echoed everywhere. Brethren, stop these high-handed methods of the strong, these remnants of barbarism so inimical to progress! Give that valiant warrior opportunities for displaying a more commendable courage than that he shows when, intoxicated with victory, he rushes to the destruction of his fellow-men. Let him toil day and night with a small chance of achieving and yet be unflinching; let him challenge the dangers of exploring the heights of the air and the depths of the sea; let him brave the dread of the plague, the heat of the tropic desert and the ice of the polar region. Turn your energies to warding off the common enemies and dangers, the perils that are all around you, that threaten you in the air you breathe, in the water you drink, in the food you consume. Is it not strange, is it not shame, that we, beings in the highest state of development in this our world, beings with such immense powers of thought and action, we, the masters of the globe, should be absolutely at the mercy of our unseen foes, that we should not know whether a swallow of food or drink brings joy and life or pain and destruction to us! In this most modern and sensible warfare, in which the bacteriologist leads, the services electricity will render will prove invaluable. The economical production of high-frequency currents, which is now an accomplished fact, enables us to generate easily and in large quantities ozone for the disinfection of the water and the air, while certain novel radiations recently discovered give hope of finding effective remedies against ills of microbic origin, which have heretofore withstood all efforts of the physician. But let me turn to a more pleasant theme.

I have referred to the merging together of the various sciences or departments of research, and to a certain perception of intimate connection between the manifold and apparently different forces and phenomena. Already we know, chiefly through the efforts of a bold pioneer, that light, radiant heat, electrical and magnetic actions are closely related, not to say identical. The chemist professes that the effects of combination and separation of bodies he observes are due to electrical forces, and the physician and physiologist will tell you that even life's progress is electrical. Thus electrical science has gained a universal meaning, and with right this age can claim the name "Age of Electricity".

I wish much to tell you on this occasion — I may say I actually burn for desire of telling you — what electricity really *is,* but I have very strong reasons, which my co-workers will best appreciate, to follow a precedent established by a great and venerable philosopher, and I shall not dwell on this purely scientific aspect of electricity.

There is another reason for the claim which I have before stated which is even more potent than the former, and that is the immense development in all electrical branches in more recent years and its influence upon other departments of science and industry. To illustrate this influence I only need to refer to the steam or gas engine. For more than half a century the steam engine has served the innumerable wants of man. The work it was called to perform was of such variety and the conditions in each case were so different that, of necessity, a great many types of engines have resulted. In the vast majority of cases the problem put before the engineer was not, as it should have been, the broad one of converting the greatest possible amount of heat energy into mechanical power, but it was rather the specific problem of obtaining the mechanical power in such form as to be best suitable for general use. As the reciprocating motion of the piston was not convenient for practical purposes, except in very few instances, the piston was connected to a crank, and thus rotating motion was obtained, which was more suitable and preferable, though it involved numerous disadvantages incident to the crude and wasteful means employed. But until quite recently there were at the disposal of the engineer, for the transformation and transmission of the motion Of the piston, no better means than rigid mechanical connections. The past few years have brought forcibly to the attention of the builder the electric motor, with its ideal features. Here was a mode of transmitting mechanical motion simpler by far, and also much more economical. Had this mode been perfected earlier, there can be no doubt that, of the many different types of engine, the majority would not exist, for just as soon as an engine was coupled with an electric generator a type was produced capable of almost universal use. From this moment on there was no necessity to endeavor to perfect engines of special designs capable of doing special kinds of work. The engineer's task became now to concentrate all his efforts upon one type, to perfect one kind of engine — the best, the universal, the engine of the immediate future; namely, the one which is best suitable for the generation of electricity. The first efforts in this direction gave a strong impetus to the development of the reciprocating high-speed engine, and also to the turbine, which latter was a type of engine of very limited practical usefulness, but became, to a certain extent, valuable in connection with the electric generator and motor. Still, even the former engine, though improved in many particulars, is not radically changed, and even now has the same objectionable features and limitations. To do away with these as much as possible, a new type of engine is being perfected in which more favorable conditions for economy are maintained, which expands the working fluid with utmost rapidity and loses little heat on the walls, an engine stripped of all usual regulating mechanism — packings, oilers and other appendages — and forming part of an electric generator; and in this type, I may say, I have implicit faith.

The gas or explosive engine has been likewise profoundly affected by the commercial introduction of electric light and power, particularly in quite recent years. The engineer is turning his energies more and more in this direction, being attracted by the prospect of obtaining a higher thermodynamic efficiency. Much larger engines are now being built, the construction is constantly improved, and a novel type of engine, best suitable for the generation of electricity, is being rapidly evolved.

There are many other lines of manufacture and industry in which the influence of electrical development has been even more powerfully felt. So, for instance, the manufacture of a great variety of articles of metal, and especially of chemical products. The welding of metals by electricity, though involving a wasteful process, has, nevertheless, been accepted as a legitimate art, while the manufacture of metal sheet, seamless tubes and the like affords promise of much improvement. We are coming gradually, but surely, to the fusion of bodies and reduction of all kinds of ores — even of iron ores — by the use of electricity, and in each of these departments great realizations are probable. Again, the economical conversion of ordinary currents of supply into high-frequency currents opens up new possibilities, such as the combination of the atmospheric nitrogen and the production of its compounds; for instance, ammonia and nitric acid, and their salts, by novel processes.

The high-frequency currents also bring us to the realization of a more economical system of lighting; namely by means of phosphorescent bulbs or tubes, and enable us to produce with these appliances light of practically any candle-power. Following other developments in purely electrical lines, we have all rejoiced in observing the rapid strides made, which, in quite recent years, have been beyond our most sanguine expectations. To enumerate the many advances recorded is a subject for the reviewer, but I can not pass without mentioning the beautiful discoveries of Lenard and Roentgen, particularly the latter, which have found such a powerful response throughout the scientific world that they have made us forget, for a time, the great achievement of Linde in Germany, who has effected the liquefaction of air on an industrial scale by a process of continuous cooling: the discovery of argon by Lord Rayleigh and Professor Ramsay, and the splendid pioneer work of Professor Dewar in the field of low temperature research. The fact that the United States have contributed a very liberal share to this prodigious progress must afford to all of us great satisfaction. While honoring the workers in other countries and all those who, by profession or inclination, are devoting themselves to strictly scientific pursuits, we have particular reasons to mention with gratitude the names of those who have so much contributed to this marvelous development of electrical industry in this country. Bell, who, by his admirable invention enabling us to transmit speech to great distances, has profoundly affected our commercial and social relations, and even our very mode of life; Edison, who, had he not done anything else beyond his early work in incandescent lighting, would have proved himself one of the greatest benefactors of the age; Westinghouse, the founder of the commercial alternating system; Brush, the great pioneer of arc lighting; Thomson, who gave us the first practical welding machine, and who, with keen sense, contributed very materially to the development of a number of scientific and industrial branches; Weston, who once led the world in dynamo design, and now leads in the construction of electric instruments; Sprague, who, with rare energy, mastered the problem and insured the success of practical electrical railroading; Acheson, Hall, Willson and others, who are creating new and revolutionizing industries here under our very eyes at Niagara. Nor is the work of these gifted men nearly finished at this hour. Much more is still to come, for, fortunately, most of them are still full of enthusiasm and vigor. All of these men and many more are untiringly at work investigating new regions and opening up unsuspected and promising fields. Weekly, if not daily, we learn through the journals of a new advance into some unexplored region, where at every step success beckons friendly, and leads the toiler on to hard and harder tasks.

But among all these many departments of research, these many branches of industry, new and old, which are being rapidly expanded, there is one dominating all others in importance — one which is of the greatest significance for the comfort and welfare, not to say for the existence, of mankind, and that is the electrical transmission of power. And in this most important of all fields, gentlemen, long afterwards, when time will have placed the events in their proper perspective, and assigned men to their deserved places, the great event we are commemorating to-day will stand out as designating a new and glorious epoch in the history of humanity — an epoch grander than that marked by the advent of the steam engine. We have many a monument of past ages; we have the palaces and pyramids, the temples of the Greek and the cathedrals of Christendom. In them is exemplified the power of men, the greatness of nations, the love of art and religious devotion. But that monument at Niagara has something of its own, more in accord with our present thoughts and tendencies. It is a monument worthy of our scientific age, a true monument of enlightenment and of peace. It signifies the subjugation of natural forces to the service of man, the discontinuance of barbarous methods, the relieving of millions from want and suffering. No matter what we attempt to do, no matter to what fields we turn our efforts, we are dependent on power. Our economists may propose more economical systems of administration and utilization of resources, our legislators may make wiser laws and treaties, it matters little; that kind of help can be only temporary. If we want to reduce poverty and misery, if we, want to give to every deserving individual what is needed for a safe existence of an intelligent being, we want to provide more machinery, more power. Power is our mainstay, the primary source of our many-sided energies. With sufficient power at our disposal we can satisfy most of our wants and offer a guaranty for safe and comfortable existence to all, except perhaps to those who are the greatest criminals of all — the voluntarily idle.

The development and wealth of a city, the success of a nation, the progress of the whole human race, is regulated by the power available. Think of the victorious march of the British, the like of which history has never recorded. Apart from the qualities of the race, which have been of great moment, they own the conquest of the world to — coal. For with coal they produce their iron; coal furnishes them light and heat; coal drives the wheels of their immense manufacturing establishments, and coal propels their conquering fleets. But the stores are being more and more exhausted, the labor is getting dearer and dearer, and the demand is continuously increasing. It must be clear to every one that soon some new source of power supply must be opened up, or that at least the present methods must be materially improved. A great deal is expected from a more economical utilization of the stored energy of the carbon in a battery; but while the attainment of such a result would be hailed as a great achievement, it would not be as much of an advance towards the ultimate and permanent method of obtaining power as some engineers seem to believe. By reasons both of economy and convenience we are driven to the general adoption of a system of energy supply from central stations, and for such purposes the beauties of the mechanical generation of electricity can not be exaggerated. The advantages of this universally accepted method are certainly so great that the probability of replacing the engine dynamos by batteries is, in my opinion, a remote one, the more so as the high-pressure steam engine and gas engine give promise of a considerably more economical thermodynamic conversion. Even if we had this day such an economical coal battery, its introduction in central stations would by no means be assured, as its use would entail many inconveniences and drawbacks. Very likely the carbon could not be burned in its natural form as in a boiler, but would have to be specially prepared to secure uniformity in the current generation. There would be a great many cells needed to make up the electro-motive force usually required. The process of cleaning and renewal, the handling of nasty fluids and gases and the great space necessary for so many batteries would make it difficult, if not commercially unprofitable, to operate such a plant in a city or densely populated district. Again, if the station be erected in the outskirts, the conversion by rotating transformers or otherwise would be a serious and unavoidable drawback. Furthermore, the regulating appliances and other accessories which would have be provided would probably make the plant fully as much, if not more, complicated than the present. We might, of course, place the batteries at or near the coal mine, and from there transmit the energy to distant points in the form of high-tension alternating currents obtained from rotating transformers, but even in this most favorable case the process would be a barbarous one, certainly more so than the present, as it would still involve the consumption of material, while at the same time it would restrict the engineer and mechanic in the exercise of their beautiful art. As to the energy supply in small isolated places as dwellings, I have placed my confidence in the development of a light storage battery, involving the use of chemicals manufactured by cheap water power, such as some carbide or oxygen-hydrogen cell.

But we shall not satisfy ourselves simply with improving steam and explosive engines or inventing new batteries; we have something much better to work for, a greater task to fulfill. We have to evolve means for obtaining energy from stores which are forever inexhaustible, to perfect methods which do not imply consumption and waste of any material whatever. Upon this great possibility, which I have long ago recognized, upon this great problem, the practical solution of which means so much for humanity, I have myself concentrated my efforts since a number of years, and a few happy ideas which came to me have inspired me to attempt the most difficult, and given me strength and courage in adversity. Nearly six years ago my confidence had become strong enough to prompt me to an expression of hope in the ultimate solution of this all dominating problem. I have made progress since, and have passed the stage of mere conviction such as is derived from a diligent study of known facts, conclusions and calculations. I now feel sure that the realization of that idea is not far off. But precisely for this reason I feel impelled to point out here an important fact, which I hope will be remembered. Having examined for a long time the possibilities of the development I refer to, namely, that of the operation of engines on any point of the earth by the energy of the medium, I find that even under the theoretically best conditions such a method of obtaining power can not equal in economy, simplicity and many other features the present method, involving a conversion of the mechanical energy of running water into electrical energy and the transmission of the latter in the form of currents of very high tension to great distances. Provided, therefore, that we can avail ourselves of currents of sufficiently high tension, a waterfall affords us the most advantageous means of getting power from the sun sufficient for all our wants, and this recognition has impressed me strongly with the future importance of the water power, not so much because of its commercial value, though it may be very great, but chiefly because of its bearing upon our safety and welfare. I am glad to say that also in this latter direction my efforts have not been unsuccessful, for I have devised means which will allow us the use in power transmission of electromotive forces much higher than those practicable with ordinary apparatus. In fact, progress in this field has given me fresh hope that I shall see the fulfillment of one of my fondest dreams; namely, the transmission of power from station to station without the employment of any connecting wire. Still, whatever method of transmission be ultimately adopted, nearness to the source of power will remain an important advantage.

Gentlemen, some of the ideas I have expressed may appear to many of you hardly realizable; nevertheless, they are the result of long-continued thought and work. You would judge them more justly if you would have devoted your life to them, as I have done. With ideas it is like with dizzy heights you climb: At first they cause you discomfort and you are anxious to get down, distrustful of your own powers; but soon the remoteness of the turmoil of life and the inspiring influence of the altitude calm your blood; your step gets firm and sure and you begin to look — for dizzier heights. I have attempted to speak to you on “Electricity”, its development and influence, but I fear that I have done it much like a boy who tries to draw a likeness with a few straight lines. But I have endeavored to bring out one feature, to speak to you in one strain which I felt sure would find response in the hearts of all of you, the only one worthy of this occasion — the humanitarian. In the great enterprise at Niagara we see not only a bold engineering and commercial feat, but far more, a giant stride in the right direction as indicated both by exact science and philanthropy. Its success is a signal for the utilization of water powers all over the world, and its influence upon industrial development is incalculable. We must all rejoice in the great achievement and congratulate the intrepid pioneers who have joined their efforts and means to bring it about. It is a pleasure to learn of the friendly attitude of the citizens of Buffalo and of the encouragement given to the enterprise by the Canadian authorities. We shall hope that other cities, like Rochester on this side and Hamilton and Toronto in Canada, will soon follow Buffalo’s lead. This fortunate city herself is to be congratulated. With resources now unequaled, with commercial facilities and advantages such as few cities in the world possess, and with the enthusiasm and progressive spirit of its citizens, it is sure to become one of the greatest industrial centers of the globe.

2

THE PROBLEM OF INCREASING HUMAN ENERGY*

THE ONWARD MOVEMENT OF MAN — THE ENERGY OF THE MOVEMENT — THE THREE WAYS OF INCREASING HUMAN ENERGY

Of all the endless variety of phenomena which nature presents to our senses, there is none that fills our minds with greater wonder than that inconceivably complex movement which, in its entirety, we designate as human life. Its mysterious origin is veiled in the forever impenetrable mist of the past, its character is rendered incomprehensible by its infinite intricacy, and its destination is hidden in the unfathomable depths of the future. Whence does it come? What is it? Whither does it tend? are the great questions which the sages of all times have endeavored to answer.

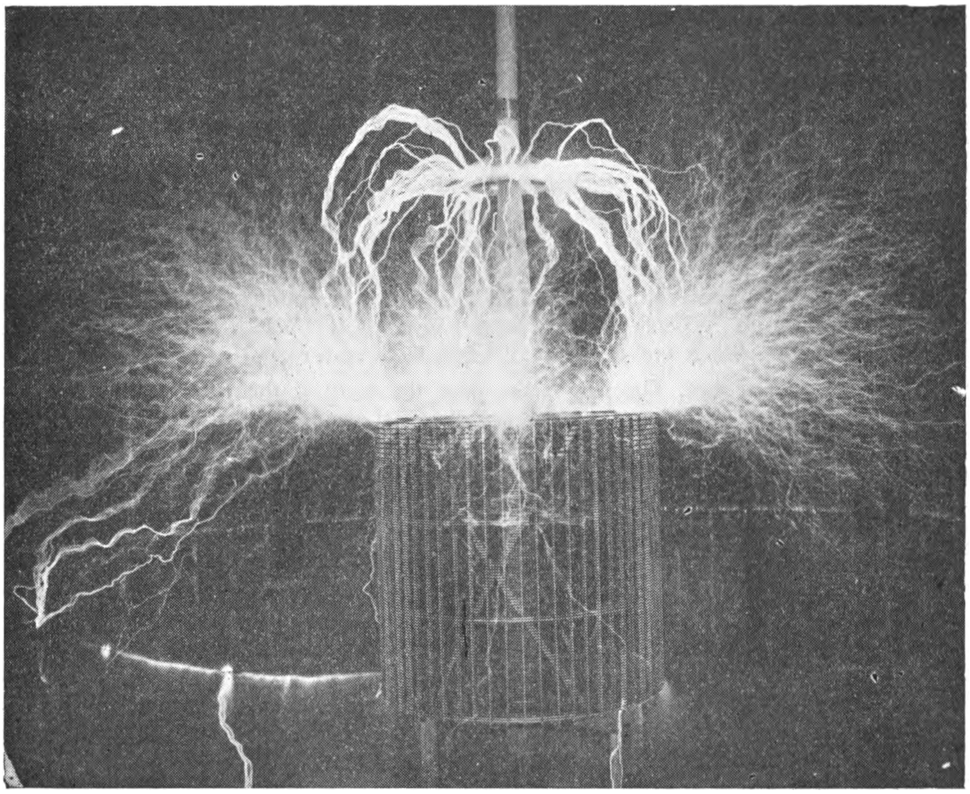
Modern science says: The sun is the past, the earth is the present, the moon is the future. From an incandescent mass we have originated, and into a frozen mass we shall turn. Merciless is the law of nature, and rapidly and irresistibly we are drawn to our doom. Lord Kelvin, in his profound meditations, allows us only a short span of life, something like six million years, after which time the sun's bright light will have ceased to shine, and its life-giving heat will have ebbed away, and our own earth will be a lump of ice, hurrying on through the eternal night. But do not let us despair. There will still be left on it a glimmering spark of life, and there will be a chance to kindle a new fire on some distant star. This wonderful possibility seems, indeed, to exist, judging from Professor Dewar's beautiful experiments with liquid air, which show that germs of organic life are not destroyed by cold, no matter how intense; consequently they may be transmitted through the interstellar space. Meanwhile the cheering lights of science and art, ever increasing in intensity, illuminate our path, and the marvels they disclose, and the enjoyments they offer, make us measurably forgetful of the gloomy future.

Though we may never be able to comprehend human life, we know certainly that it is a movement, of whatever nature it be. The existence of a movement unavoidably implies a body which is being moved and a force which is moving it. Hence, wherever there is life, there is a mass moved by a force. All mass possesses inertia, all force tends to persist. Owing to this universal property and condition, a body, be it at rest or in motion, tends to remain in the same state, and a force, manifesting itself anywhere and through whatever cause, produces an equivalent opposing force, and as an absolute necessity of this it follows that every movement in nature must be rhythmical. Long ago this simple truth was clearly pointed out by Herbert Spencer, who arrived at it through a somewhat different process of reasoning. It is borne out in everything we perceive — in the movement of a planet, in the surging and ebbing of the tide, in the reverberations of the air, the swinging of a pendulum, the oscillations of an electric current, and in the infinitely varied phenomena of organic life. Does not the

* The Century Illustrated Monthly Magazine, June 1900

whole of human life attest it? Birth, growth, old age, and death of an individual, family, race, or nation, what is it all but a rhythm? All life-manifestation, then, even in its most intricate form, as exemplified in man, however involved and inscrutable, is only a movement, to which the same general laws of movement which govern throughout the physical universe must be applicable.

When we speak of man, we have a conception of humanity as a whole, and before applying scientific methods to the investigation of his movement, we must accept this as a physical fact. But can any one doubt to-day that all the millions of individuals and all innumerable types and characters constitute an entirety, a unit? Though free to



Note to Fig. 1. — This result is produced by the discharge of an electrical oscillator giving twelve million volts. The electrical pressure, alternating one hundred thousand times per second, excites the normally inert nitrogen, causing it to combine with the oxygen. The flame-like discharge shown in the photograph measures sixty-five feet across.

think and act, we are held together, like the stars in the firmament, with ties inseparable. These ties we cannot see, but we can feel them. I cut myself in the finger, and it pains me: this finger is a part of me. I see a friend hurt, and it hurts me, too: my friend and I are one. And now I see stricken down an enemy, a lump of matter which, of all the lumps of matter in the universe, I care least for, and still it grieves me. Does this not prove that each of us is only a part of a whole?

For ages this idea has been proclaimed in the consummately wise teachings of religion, probably not alone as a means of insuring peace and harmony among men, but as a deeply founded truth. The Buddhist expresses it in one way, the Christian in another, but both say the same: We are all one. Metaphysical proofs are, however, not the only ones which we are able to bring forth in support of this idea. Science, too, recognizes this connectedness of separate individuals, though not quite in the same sense as it admits that the suns, planets, and moons of a constellation are one body, and there can be no doubt that it will be experimentally confirmed in times to come, when our means and methods for investigating physical and other states and phenomena shall have been brought to great perfection. Still more: this one human being lives on and on. The individual is ephemeral, races and nations come and pass away, but man remains. Therein lies the profound difference between the individual and the whole. Therein, too, is to be found the partial explanation of many of those marvelous phenomena of heredity which are the result of countless centuries of feeble but persistent influence.

Conceive, then, man as a mass urged on by a force. Though this movement is not of a translatory character, implying change of place, yet the general laws of mechanical movement are applicable to it, and the energy associated with this mass can be measured, in accordance with well-known principles, by half the product of the mass with the square of a certain velocity. So, for instance, a cannon-ball which is at rest possesses a certain amount of energy in the form of heat, which we measure in a similar way. We imagine the ball to consist of innumerable minute particles, called atoms or molecules, which vibrate, or whirl around one another. We determine their masses and velocities, and from them the energy of each of these minute systems, and adding them all together, we get an idea of the total heat-energy contained in the ball, which is only seemingly at rest. In this purely theoretical estimate this energy may then be calculated by multiplying half of the total mass — that is, half of the sum of all the small masses — with the square of a velocity which is determined from the velocities of the separate particles. In like manner we may conceive of human energy being measured by half the human mass multiplied with the square of a velocity which we are not yet able to compute. But our deficiency in this knowledge will not vitiate the truth of the deductions I shall draw, which rest on the firm basis that the same laws of mass and force govern throughout nature.

Man, however, is not an ordinary mass, consisting of spinning atoms and molecules, and containing merely heat-energy. He is a mass possessed of certain higher qualities by reason of the creative principle of life with which he is endowed. His mass, as the water in an ocean wave, is being continuously exchanged, new taking the place of the old. Not only this, but he grows, propagates, and dies, thus altering his mass independently, both in bulk and density. What is most wonderful of all, he is capable of increasing or diminishing his velocity of movement by the mysterious power he possesses of appropriating more or less energy from other substance, and turning it into motive energy. But in any given moment we may ignore these slow changes and assume that human energy is measured by half the product of man's mass with the square of a certain hypothetical velocity. However we may compute this velocity, and whatever we may take as the standard of its measure, we must, in harmony with this conception, come to the conclusion that the great problem of science is, and always will be, to increase the energy thus defined. Many years ago, stimulated by the perusal of that deeply interesting work, Draper's "History of the Intellectual Development of Europe", depicting so vividly human movement, I recognized that to solve this eternal problem must ever be the chief task of the man of science. Some results of my own efforts to this end I shall endeavor briefly to describe here.

Let, then, in diagram *a, M* represent the mass of man. This mass is impelled in one direction by a force *f,* which is resisted by another partly frictional and partly negative force *R,* acting in a direction exactly opposite, and retarding the movement of the mass. Such an antagonistic force is present in every movement, and must be taken into consideration. The difference between these two forces is the effective force which imparts a velocity *V* to the mass *M* in the direction of the arrow on the line representing the force *f.* In accordance with the preceding, the human energy will then be given by the product $\frac{1}{2}MV^2 = \frac{1}{2}MV \times V$, in which *M* is the total mass of man in the ordinary interpretation of the term "mass", and *V* is a certain hypothetical velocity, which, in the present state of science, we are unable exactly to define and determine. To increase the human energy is, therefore, equivalent to increasing this product, and there are, as will readily be seen, only three ways possible to attain this result, which are illustrated in the diagram below. The first way, shown in the top figure, is to increase the mass (as indicated by the dotted circle), leaving the two opposing forces the same. The second way is to reduce the retarding force *R* to a smaller value *r,* leaving the mass and the impelling force the same, as diagrammatically

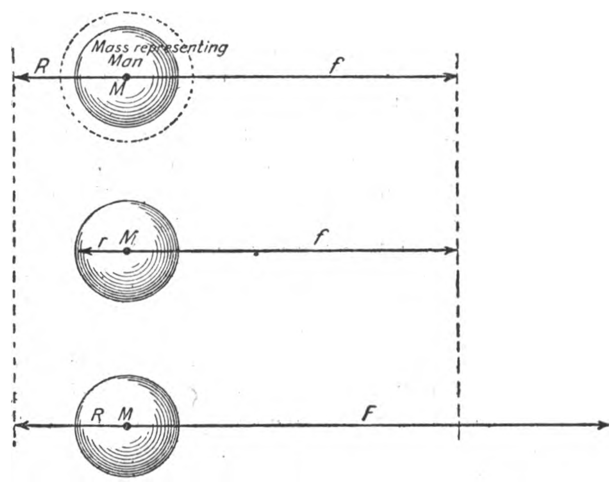


Diagram a. The three ways of increasing human energy.

shown in the middle figure. The third way, which is illustrated in the last figure, is to increase the impelling force *f* to a higher value *F,* while the mass and the retarding force *R* remain unaltered. Evidently fixed limits exist as regards increase of mass and reduction of retarding force, but the impelling force can be increased indefinitely. Each of these three possible solutions presents a different aspect of the main problem of increasing human energy, which is thus divided into three distinct problems, to be successively considered.

THE FIRST PROBLEM: HOW TO INCREASE THE HUMAN MASS — THE BURNING OF ATMOSPHERIC NITROGEN

Viewed generally, there are obviously two ways of increasing the mass of mankind: first, by aiding and maintaining those forces and conditions which tend to increase it; and, second, by opposing and reducing those which tend to diminish it. The mass will be increased by careful attention to health, by substantial food, by moderation, by regularity of habits, by the promotion of marriage, by conscientious attention to the children, and, generally stated, by the observance of all the many precepts and laws of religion and hygiene. But in adding new mass to the old, three cases again present themselves. Either the mass added is of the same velocity as the old, or it is of a smaller or of a higher velocity. To gain an idea of the relative importance of these cases, imagine a train composed of, say, one hundred locomotives running on a track, and suppose that, to increase the energy of the moving mass, four more locomotives are added to the train. If these four move at the same velocity at which the train is going, the total energy will be increased four per cent.; if they are moving at only one half of that velocity, the increase will amount to only one per cent.; if they are moving at twice that velocity, the increase of energy will be sixteen per cent. This simple illustration shows that it is of the greatest importance to add mass of a higher velocity. Stated more to the point, if, for example, the children be of the same degree of enlightenment as the parents, — that is, mass of the "same velocity", — the energy will simply increase proportionately to the number added. If they are less intelligent, or advanced, or mass of "smaller velocity", there will be a very slight gain in the energy; but if they are further advanced, or mass of "higher velocity", then the new generation will add very considerably to the sum total of human energy. Any addition of mass of "smaller velocity", beyond that indispensable amount required by the law expressed in the proverb, "Mens sana in corpore sano", should be strenuously opposed. For instance, the mere development of muscle, as aimed at in some of our colleges, I consider equivalent to adding mass of "smaller velocity", and I would not commend it, although my views were different when I was a student myself. Moderate exercise, insuring the right balance between mind and body, and the highest efficiency of performance, is, of course, a prime requirement. The above example shows that the most important result to be attained is the education, or the increase of the "velocity", of the mass newly added.

Conversely, it scarcely need be stated that everything that is against the teachings of religion and the laws of hygiene is tending to decrease the mass. Whisky, wine, tea, coffee, tobacco, and other such stimulants are responsible for the shortening of the lives of many, and ought to be used with moderation. But I do not think that rigorous measures of suppression of habits followed through many generations are commendable. It is wiser to preach moderation than abstinence. We have become accustomed to these stimulants, and if such reforms are to be effected, they must be slow and gradual. Those who are devoting their energies to such ends could make themselves far more useful by turning their efforts in other directions, as, for instance, toward providing pure water.

For every person who perishes from the effects of a stimulant, at least a thousand die from the consequences of drinking impure water. This precious fluid, which daily infuses new life into us, is likewise the chief vehicle through which disease and death enter our bodies. The germs of destruction it conveys are enemies all the more terrible as they perform their fatal work unperceived. They seal our doom while we live and enjoy. The majority of people are so ignorant or careless in drinking water, and the consequences of this are so disastrous, that a philanthropist can scarcely use his efforts better than by endeavoring to enlighten those who are thus injuring themselves. By systematic purification and sterilization of the drinking-water the human mass would be very considerably increased. It should be made a rigid rule — which might be enforced by law — to boil or to sterilize otherwise the drinking-water in every household and public place. The mere filtering does not afford sufficient security against infection. All ice for internal uses should be artificially prepared from water thoroughly sterilized. The importance of eliminating germs of disease from the city water is generally recognized, but little is being done to improve the existing conditions, as no satisfactory method of sterilizing great quantities of water has as yet been brought forward. By improved electrical appliances we are now enabled to produce ozone cheaply and in large amounts, and this ideal disinfectant seems to offer a happy solution of the important question.

Gambling, business rush, and excitement, particularly on the exchanges, are causes of much mass-reduction, all the more so because the individuals concerned represent units of higher value. Incapacity of observing the first symptoms of an illness, and careless neglect of the same, are important factors of mortality. In noting carefully every new sign of approaching danger, and making conscientiously every possible effort to avert it, we are not only following wise laws of hygiene in the interest of our well-being and the success of our labors, but we are also complying with a higher moral duty. Every one should consider his body as a priceless gift from one whom he loves above all, as a marvelous work of art, of indescribable beauty and mastery beyond human conception, and so delicate and frail that a word, a breath, a look, nay, a thought, may injure it. Uncleanliness, which breeds disease and death, is not only a self-destructive but a highly immoral habit. In keeping our bodies free from infection, healthful, and pure, we are expressing our reverence for the high principle with which they are endowed. He who follows the precepts of hygiene in this spirit is proving himself, so far, truly religious. Laxity of morals is a terrible evil, which poisons both mind and body, and which is responsible for a great reduction of the human mass in some countries. Many of the present customs and tendencies are productive of similar hurtful results. For example, the society life, modern education and pursuits of women, tending to draw them away from their household duties and make men out of them, must needs detract from the elevating ideal they represent, diminish the artistic creative power, and cause sterility and a general weakening of the race. A thousand other evils might be mentioned, but all put together, in their bearing upon the problem under discussion, they would not equal a single one, the want of food, brought on by poverty, destitution, and famine. Millions of individuals die yearly for want of food, thus keeping down the mass. Even in our enlightened communities, and notwithstanding the many charitable efforts, this is still, in all probability, the chief evil. I do not mean here absolute want of food, but want of healthful nutriment.

How to provide good and plentiful food is, therefore, a most important question of the day. On general principles the raising of cattle as a means of providing food is objectionable, because, in the sense interpreted above, it must undoubtedly tend to the addition of mass of a “smaller velocity”. It is certainly preferable to raise vegetables, and I think, therefore, that vegetarianism is a commendable departure from the established barbarous habit. That we can subsist on plant food and perform our work even to advantage is not a theory, but a well-demonstrated fact. Many races living almost exclusively on vegetables are of superior physique and strength. There is no doubt that some plant food, such as oatmeal, is more economical than meat, and superior to it in regard to both mechanical and mental performance. Such food, moreover, taxes our digestive organs decidedly less, and, in making us more contented and sociable, produces an amount of good difficult to estimate. In view of these facts every effort should be made to stop the wanton and cruel slaughter of animals, which must be destructive to our morals. To free ourselves from animal instincts and appetites, which keep us down, we should begin at the very root from which they spring: we should effect a radical reform in the character of the food.

There seems to be no *philosophical* necessity for food. We can conceive of organized beings living without nourishment, and deriving all the energy they need for the performance of their life-functions from the ambient medium. In a crystal we have the clear evidence of the existence of a formative life-principle, and though we cannot understand the life of a crystal, it is none the less a living being. There may be, besides crystals, other such individualized, material systems of beings, perhaps of gaseous constitution, or composed of substance still more tenuous. In view of this possibility, — nay, probability, — we cannot apodictically deny the existence of organized beings on a planet merely because the conditions on the same are unsuitable for the existence of life as we conceive it. We cannot even, with positive assurance, assert that some of them might not be present here, in this our world, in the very midst of us, for their constitution and life-manifestation may be such that we are unable to perceive them.

The production of artificial food as a means for causing an increase of the human mass naturally suggests itself, but a direct attempt of this kind to provide nourishment does not appear to me rational, at least not for the present. Whether we could thrive on such food is very doubtful. We are the result of ages of continuous adaptation, and we cannot radically change without unforeseen and, in all probability, disastrous consequences. So uncertain an experiment should not be tried. By far the best way, it seems to me, to meet the ravages of the evil, would be to find ways of increasing the productivity of the soil. With this object the preservation of forests is of an importance which cannot be overestimated, and in this connection, also, the utilization of water-power for purposes of electrical transmission, dispensing in many ways with the necessity of burning wood, and tending thereby to forest preservation, is to be strongly advocated. But there are limits in the improvement to be effected in this and similar ways.

To increase materially the productivity of the soil, it must be more effectively fertilized by artificial means. The question of food-production resolves itself, then, into the question how best to fertilize the soil. What it is that made the soil is still a mystery. To explain its origin is probably equivalent to explaining the origin of life itself. The rocks, disintegrated by moisture and heat and wind and weather, were in themselves not capable of maintaining life. Some unexplained condition arose, and some new principle came into effect, and the first layer capable of sustaining low organisms, like mosses, was formed. These, by their life and death, added more of the life-sustaining quality to the soil, and higher organisms could then subsist, and so on and on, until at last highly developed plant and animal life could flourish. But though the theories are, even now, not in agreement as to how fertilization is effected, it is a fact, only too well ascertained, that the soil cannot indefinitely sustain life, and some way must be found to supply it with the substances which have been abstracted from it by the plants. The chief and most valuable among these substances are compounds of nitrogen, and the cheap production of these is, therefore, the key for the solution of the all-important food problem. Our atmosphere contains an inexhaustible amount of nitrogen, and could we but oxidize it and produce these compounds, an incalculable benefit for mankind would follow.

Long ago this idea took a powerful hold on the imagination of scientific men, but an efficient means for accomplishing this result could not be devised. The problem was rendered extremely difficult by the extraordinary inertness of the nitrogen, which refuses to combine even with oxygen. But here electricity comes to our aid: the dormant affinities of the element are awakened by an electric current of the proper quality. As a lump of coal which has been in contact with oxygen for centuries without burning will combine with it when once ignited, so nitrogen, excited by electricity, will burn. I did not succeed, however, in producing electrical discharges exciting very effectively the atmospheric nitrogen until a comparatively recent date, although I showed, in May, 1891, in a scientific lecture, a novel form of discharge or electrical flame named “St. Elmo’s hotfire”, which, besides being capable of generating ozone in abundance, also possessed, as I pointed out on that occasion, distinctly the quality of exciting chemical affinities. This discharge or flame was then only three or four inches long, its chemical action was likewise very feeble, and consequently the process of oxidation of the nitrogen was wasteful. How to intensify this action was the question. Evidently electric currents of a peculiar kind had to be produced in order to render the process of nitrogen combustion more efficient.

The first advance was made in ascertaining that the chemical activity of the discharge was very considerably increased by using currents of extremely high frequency or rate of vibration. This was an important improvement, but practical considerations soon set a definite limit to the progress in this direction. Next, the effects of the electrical pressure of the current impulses, of their wave-form and other characteristic features, were investigated. Then the influence of the atmospheric pressure and temperature and of the presence of water and other bodies was studied, and thus the best conditions for causing the most intense chemical action of the discharge and securing the highest efficiency of the process were gradually ascertained. Naturally, the improvements were not quick in coming; still, little by little, I advanced. The flame grew larger and larger, and its oxidizing action more and more intense. From an insignificant brush-discharge a few inches long it developed into a marvelous electrical phenomenon, a roaring blaze, devouring the nitrogen of the atmosphere and measuring sixty or seventy feet across. Thus slowly, almost imperceptibly, possibility became accomplishment. All is not yet done, by any means, but to what a degree my efforts have been rewarded an idea may be gained from an inspection of Fig. 1, which, with its title, is self-explanatory. The flame-like discharge visible is produced by the intense electrical oscillations which pass through the coil shown, and violently agitate the electrified molecules of the air. By this means a strong affinity is created between the two normally indifferent constituents of the atmosphere, and they combine readily, even if no further provision is made for intensifying the chemical action of the discharge. In the manufacture of nitrogen compounds by this method, of course, every possible means bearing upon the intensity of this action and the efficiency of the process will be taken advantage of, and, besides, special arrangements will be provided for the fixation of the compounds formed, as they are generally unstable, the nitrogen becoming again inert after a little lapse of time. Steam is a simple and effective means for fixing permanently the compounds. The result illustrated makes it practicable to oxidize the atmospheric nitrogen in unlimited quantities, merely by the use of cheap mechanical power and simple electrical apparatus. In this manner many compounds of nitrogen may be manufactured all over the world, at a small cost, and in any desired amount, and by means of these compounds the soil can be fertilized and its productiveness indefinitely increased. An abundance of cheap and healthful food, not artificial, but such as we are accustomed to, may thus be obtained. This new and inexhaustible source of food-supply will be of incalculable benefit to mankind, for it will enormously contribute to the increase of the human mass, and thus add immensely to human energy. Soon, I hope, the world will see the beginning of an industry which, in time to come, will, I believe, be in importance next to that of iron.

THE SECOND PROBLEM: HOW TO REDUCE THE FORCE RETARDING THE HUMAN MASS — THE ART OF TELAUTOMATICS

As before stated, the force which retards the onward movement of man is partly frictional and partly negative. To illustrate this distinction I may name, for example, ignorance, stupidity, and imbecility as some of the purely frictional forces, or resistances devoid of any directive tendency. On the other hand, visionariness, insanity, self-destructive tendency, religious fanaticism, and the like, are all forces of a negative character, acting in definite directions. To reduce or entirely to overcome these dissimilar retarding forces, radically different methods must be employed. One knows, for instance, what a fanatic may do, and one can take preventive measures, can enlighten, convince, and possibly direct him, turn his vice into virtue; but one does not know, and never can know, what a brute or an imbecile may do, and one must deal with him as with a mass, inert, without mind, let loose by the mad elements. A negative force always implies some quality, not infrequently a high one, though badly directed, which it is possible to turn to good advantage; but a directionless, frictional force involves unavoidable loss. Evidently, then, the first and general answer to the above question is: turn all negative force in the right direction and reduce all frictional force.

There can be no doubt that, of all the frictional resistances, the one that most retards human movement is ignorance. Not without reason said that man of wisdom, Buddha: "Ignorance is the greatest evil in the world". The friction which results from ignorance, and which is greatly increased owing to the numerous languages and nationalities, can be reduced only by the spread of knowledge and the unification of the heterogeneous elements of humanity. No effort could be better spent. But however ignorance may have retarded the onward movement of man in times past, it is certain that, nowadays, negative forces have become of greater importance. Among these there is one of far greater moment than any other. It is called organized warfare. When we consider the millions of individuals, often the ablest in mind and body, the flower of humanity, who are compelled to a life of inactivity and unproductiveness, the immense sums of money daily required for the maintenance of armies and war apparatus, representing ever so much of human energy, all the effort uselessly spent in the production of arms and implements of destruction, the loss of life and the fostering of a barbarous spirit, we are appalled at the inestimable loss to mankind which the existence of these deplorable conditions must involve. What can we do to combat best this great evil?

Law and order absolutely require the maintenance of organized force. No community can exist and prosper without rigid discipline. Every country must be able to defend itself, should the necessity arise. The conditions of to-day are not the result of yesterday, and a radical change cannot be effected to-morrow. If the nations would at once disarm, it is more than likely that a state of things worse than war itself would follow. Universal peace is a beautiful dream, but not at once realizable. We have seen recently that even the noble effort of the man invested with the greatest worldly power has been virtually without effect. And no wonder, for the establishment of universal peace is, for the time being, a physical impossibility. War is a negative force, and cannot be turned in a positive direction without passing through the intermediate phases. It is the problem of making a wheel, rotating one way, turn in the opposite direction without slowing it down, stopping it, and speeding it up again the other way.

It has been argued that the perfection of guns of great destructive power will stop warfare. So I myself thought for a long time, but now I believe this to be a profound mistake. Such developments will greatly modify, but not arrest it. On the contrary, I think that every new arm that is invented, every new departure that is made in this direction, merely invites new talent and skill, engages new effort, offers a new incentive, and so only gives a fresh impetus to further development. Think of the discovery of gunpowder. Can we conceive of any more radical departure than was effected by this innovation? Let us imagine ourselves living in that period: would we not have thought then that warfare was at an end, when the armor of the knight became an object of ridicule, when bodily strength and skill, meaning so much before, became of comparatively little value? Yet gunpowder did not stop warfare; quite the opposite — it acted as a most powerful incentive. Nor do I believe that warfare can ever be arrested by any scientific or ideal development, so long as similar conditions to those now prevailing exist, because war has itself become a science, and because war involves some of the most sacred sentiments of which man is capable. In fact, it is doubtful whether men who would not be ready to fight for a high principle would be good for anything at all. It is not the mind which makes man, nor is it the body; it is mind and body. Our virtues and our failings are inseparable, like force and matter. When they separate, man is no more.

Another argument, which carries considerable force, is frequently made, namely, that war must soon become impossible because the means of defense are outstripping the means of attack. This is only in accordance with a fundamental law which may be expressed by the statement that it is easier to destroy than to build. This law defines human capacities and human conditions. Were these such that it would be easier to build than to destroy, man would go on unresisted, creating and accumulating without limit. Such conditions are not of this earth. A being which could do this would not be a man; it might be a god. Defense will always have the advantage over attack, but this alone, it seems to me, can never stop war. By the use of new principles of defense we can render harbors impregnable against attack, but we cannot by such means prevent two war-ships meeting in battle on the high sea. And then, if we follow this idea to its ultimate development, we are led to the conclusion that it would be better for mankind if attack and defense were just oppositely related: for if every country, even the smallest, could surround itself with a wall absolutely impenetrable, and could defy the rest of the world, a state of things would surely be brought on which would be extremely unfavorable to human progress. It is by abolishing all the barriers which separate nations and countries that civilization is best furthered.

Again, it is contended by some that the advent of the flying-machine must bring on universal peace. This, too, I believe to be an entirely erroneous view. The flying-machine is certainly coming, and very soon, but the conditions will remain the same as before. In fact, I see no reason why a ruling power, like Great Britain, might not govern the air as well as the sea. Without wishing to put myself on record as a prophet, I do not hesitate to say that the next years will see the establishment of an “air-power”, and its center may not be far from New York. But, for all that, men will fight on merrily.

The ideal development of the war principle would ultimately lead to the transformation of the whole energy of war into purely potential, explosive energy, like that of an electrical condenser. In this form the war-energy could be maintained without effort; it would need to be much smaller in amount, while incomparably more effective.

As regards the security of a country against foreign invasion, it is interesting to note that it depends only on the relative, and not on the absolute, number of the individuals or magnitude of the forces, and that, if every country should reduce the war-force in the same ratio, the security would remain unaltered. An international agreement with the object of reducing to a minimum the war-force which, in view of the present still imperfect education of the masses, is absolutely indispensable, would, therefore, seem to be the first rational step to take toward diminishing the force retarding human movement.

Fortunately, the existing conditions cannot continue indefinitely, for a new element is beginning to assert itself. A change for the better is imminent, and I shall now endeavor to show what, according to my ideas, will be the first advance toward the establishment of peaceful relations between nations, and by what means it will eventually be accomplished.

Let us go back to the early beginning, when the law of the stronger was the only law. The light of reason was not yet kindled, and the weak was entirely at the mercy of the strong. The weak individual then began to learn how to defend himself. He made use of a club, stone, spear, sling, or bow and arrow, and in the course of time, instead of physical strength, intelligence became the chief deciding factor in the battle. The wild character was gradually softened by the awakening of noble sentiments, and so, imperceptibly, after ages of continued progress, we have come from the brutal fight of the unreasoning animal to what we call the “civilized warfare” of to-day, in which the combatants shake hands, talk in a friendly way, and smoke cigars in the entr-actes, ready to engage again in deadly conflict at a signal. Let pessimists say what they like, here is an absolute evidence of great and gratifying advance.

But now, what is the next phase in this evolution? Not peace as yet, by any means. The next change which should naturally follow from modern developments

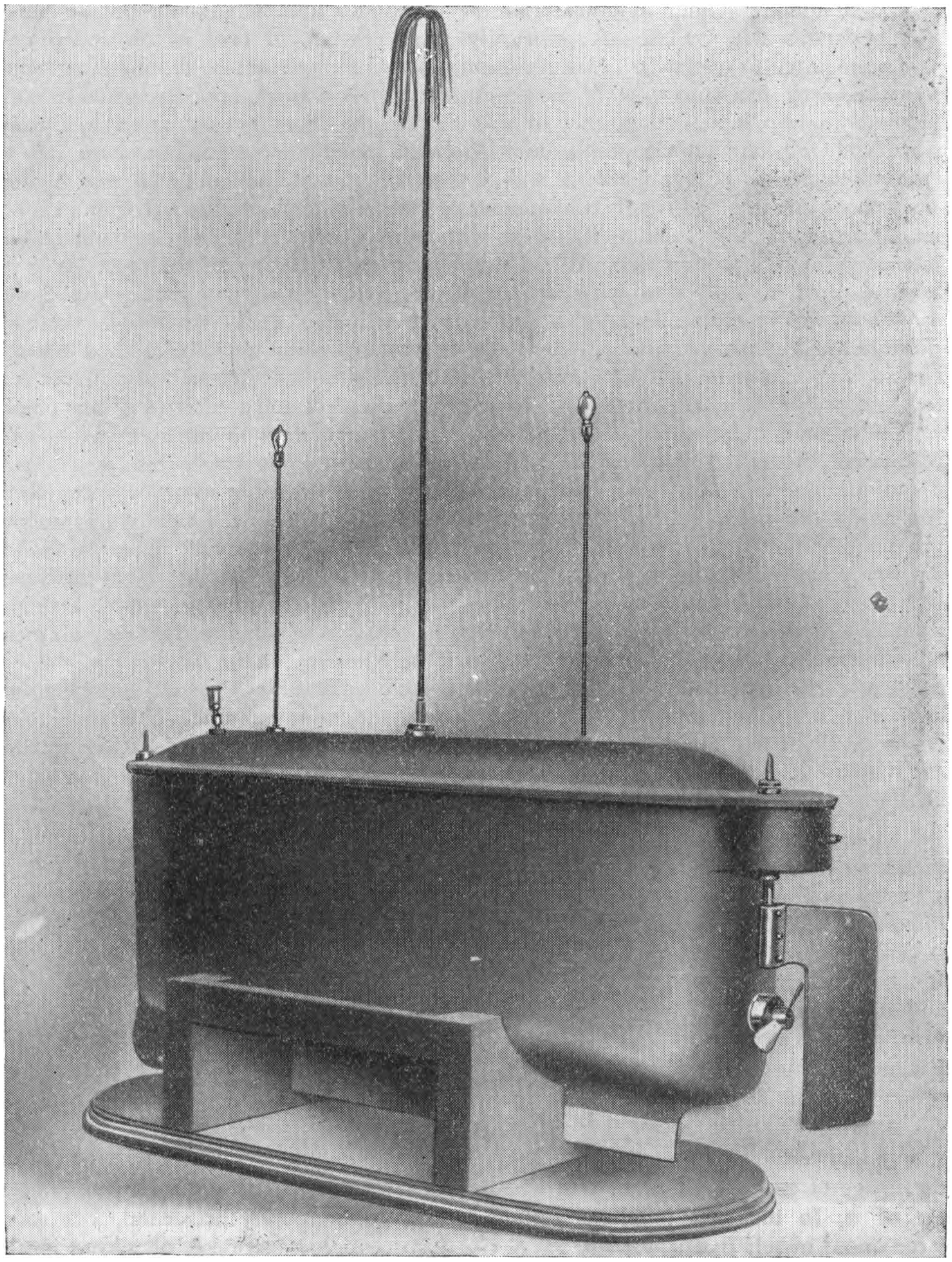


Fig. 2. THE FIRST PRACTICAL TELAUTOMATON.

A machine having all its bodily or translatory movements and the operations of the interior mechanism controlled from a distance without wires. The crewless boat shown in the photograph contains its own motive power, propelling- and steering-machinery, and numerous other accessories, all of which are controlled by transmitting from a distance, without wires, electrical oscillations to a circuit carried by the boat and adjusted to respond only to these oscillations.

should be the continuous diminution of the number of individuals engaged in battle. The apparatus will be one of specifically great power, but only a few individuals will be required to operate it. This evolution will bring more and more into prominence a machine or mechanism with the fewest individuals as an element of warfare, and the absolutely unavoidable consequence of this will be the abandonment of large, clumsy, slowly moving, and unmanageable units. Greatest possible speed and maximum rate of energy-delivery by the war apparatus will be the main object. The loss of life will become smaller and smaller, and finally, the number of the individuals continuously diminishing, merely machines will meet in a contest without bloodshed, the nations being simply interested, ambitious spectators. When this happy condition is realized, peace will be assured. But, no matter to what degree of perfection rapid-fire guns, high-power cannon, explosive projectiles, torpedo-boats, or other implements of war may be brought, no matter how destructive they may be made, that condition can never be reached through any such development. All such implements require men for their operation; men are indispensable parts of the machinery. Their object is to kill and to destroy. Their power resides in their capacity for doing evil. So long as men meet in battle, there will be bloodshed. Bloodshed will ever keep up barbarous passion. To break this fierce spirit, a radical departure must be made, an entirely new principle must be introduced, something that never existed before in warfare — a principle which will forcibly, unavoidably, turn the battle into a mere spectacle, a play, a contest without loss of blood. To bring on this result men must be dispensed with: machine must fight machine. But how accomplish that which seems impossible? The answer is simple enough: produce a machine capable of acting as though it were part of a human being — no mere mechanical contrivance, comprising levers, screws, wheels, clutches, and nothing more, but a machine embodying a higher principle, which will enable it to perform its duties as though it had intelligence, experience, reason, judgment, a mind! This conclusion is the result of my thoughts and observations which have extended through virtually my whole life, and I shall now briefly describe how I came to accomplish that which at first seemed an unrealizable dream.

A long time ago, when I was a boy, I was afflicted with a singular trouble, which seems to have been due to an extraordinary excitability of the retina. It was the appearance of images which, by their persistence, marred the vision of real objects and interfered with thought. When a word was said to me, the image of the object which it designated would appear vividly before my eyes, and many times it was impossible for me to tell whether the object I saw was real or not. This caused me great discomfort and anxiety, and I tried hard to free myself of the spell. But for a long time I tried in vain, and it was not, as I still clearly recollect, until I was about twelve years old that I succeeded for the first time, by an effort of the will, in banishing an image which presented itself. My happiness will never be as complete as it was then, but, unfortunately (as I thought at that time), the old trouble returned, and with it my anxiety. Here it was that the observations to which I refer began. I noted, namely, that whenever the image of an object appeared before my eyes I had seen something which reminded me of it. In the first instances I thought this to be purely accidental, but soon I convinced myself that it was not so. A visual impression, consciously or unconsciously received, invariably preceded the appearance of the image. Gradually the desire arose in me to find out, every time, what caused the images to appear, and the satisfaction of this desire soon became a necessity. The next observation I made was that, just as these images followed as a result of something I had seen, so also the thoughts which I conceived were suggested in like manner. Again, I experienced the same desire to locate the image which caused the thought, and this search for the original visual impression soon grew to be a second nature. My mind became automatic, as it were, and

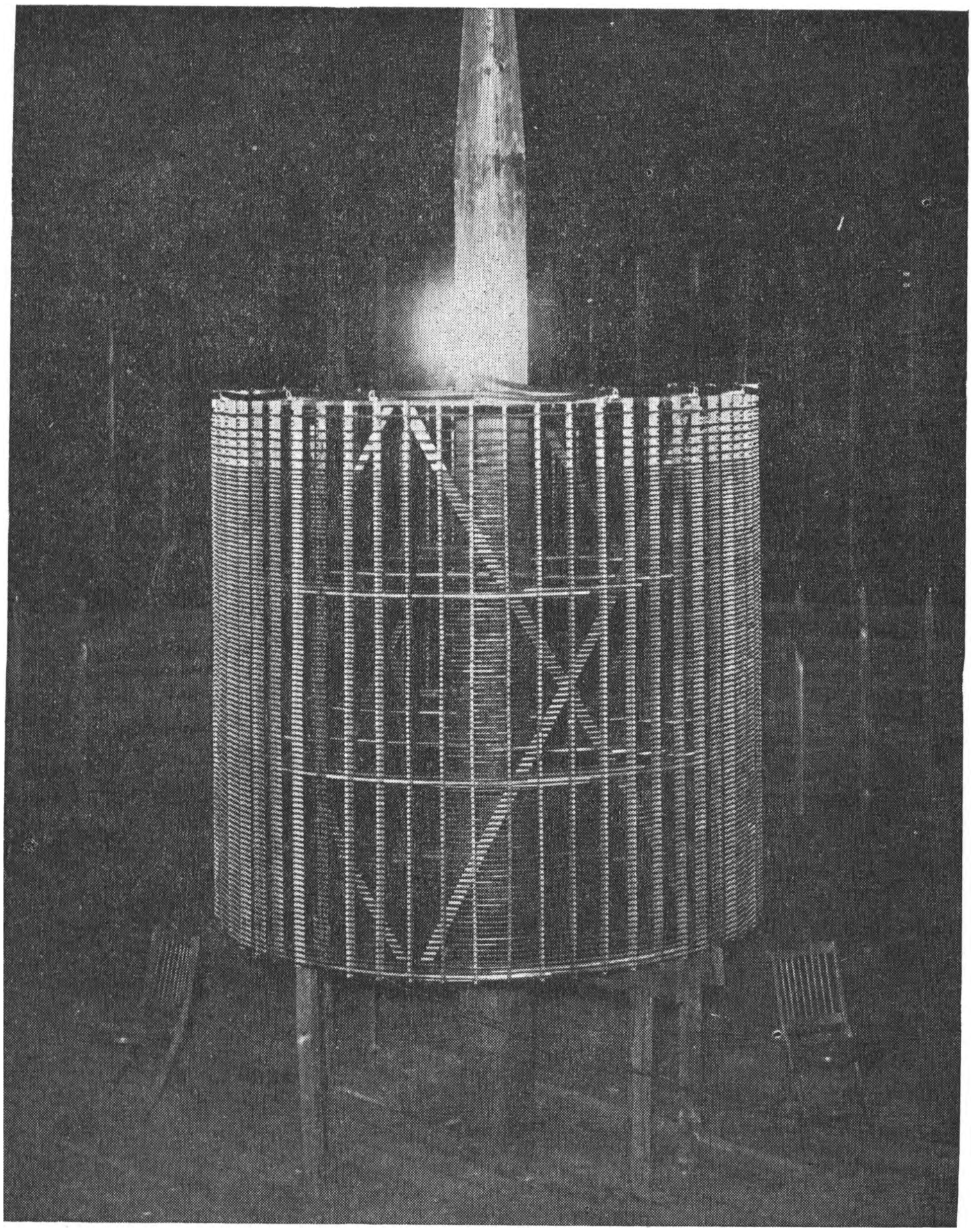


Fig. 3. EXPERIMENT TO ILLUSTRATE THE SUPPLYING OF ELECTRICAL ENERGY THROUGH A SINGLE WIRE WITHOUT RETURN.

An ordinary incandescent lamp connected with one or both of its terminals to the wire forming the upper free end of the coil shown in the photograph, is lighted by electrical vibrations conveyed to it through the coil from an electrical oscillator, which is worked only to one fifth of one per cent of its full capacity.

in the course of years of continued, almost unconscious performance, I acquired the ability of locating every time and, as a rule, instantly the visual impression which started the thought. Nor is this all. It was not long before I was aware that also all my movements were prompted in the same way, and so, searching, observing, and verifying continuously, year after year, I have, by every thought and every act of mine, demonstrated, and do so daily, to my absolute satisfaction, that I am an automaton endowed with power of movement, which merely responds to external stimuli beating upon my sense organs, and thinks and acts and moves accordingly. I remember only one or two cases in all my life in which I was unable to locate the first impression which prompted a movement or a thought, or even a dream.

With these experiences it was only natural that, long ago, I conceived the idea of constructing an automaton which would mechanically represent me, and which would respond, as I do myself, but, of course, in a much more primitive manner, to external influences. Such an automaton evidently had to have motive power, organs for locomotion, directive organs, and one or more sensitive organs so adapted as to be excited by external stimuli. This machine would, I reasoned, perform its movements in the manner of a living being, for it would have all the chief mechanical characteristics or elements of the same. There was still the capacity for growth, propagation, and, above all, the mind which would be wanting to make the model complete. But growth was not necessary in this case, since a machine could be manufactured full-grown, so to speak. As to the capacity for propagation, it could likewise be left out of consideration, for in the mechanical model it merely signified a process of manufacture. Whether the automaton be of flesh and bone, or of wood and steel, it mattered little, provided it could perform all the duties required of it like an intelligent being. To do so, it had to have an element corresponding to the mind, which would effect the control of all its movements and operations, and cause it to act, in any unforeseen case that might present itself, with knowledge, reason, judgment, and experience. But this element I could easily embody in it by conveying to it my own intelligence, my own understanding. So this invention was evolved, and so a new art came into existence, for which the name "telautomatics" has been suggested, which means the art of controlling the movements and operations of distant automatons.

This principle evidently was applicable to any kind of machine that moves on land or in the water or in the air. In applying it practically for the first time, I selected a boat (see Fig. 2). A storage battery placed within it furnished the motive power. The propeller, driven by a motor, represented the locomotive organs. The rudder, controlled by another motor likewise driven by the battery, took the place of the directive organs. As to the sensitive organ, obviously the first thought was to utilize a device responsive to rays of light, like a selenium cell, to represent the human eye. But upon closer inquiry I found that, owing to experimental and other difficulties, no thoroughly satisfactory control of the automaton could be effected by light, radiant heat, Hertzian radiations, or by rays in general, that is, disturbances which pass in straight lines through space. One of the reasons was that any obstacle coming between the operator and the distant automaton would place it beyond his control. Another reason was that the sensitive device representing the eye would have to be in a definite position with respect to the distant controlling apparatus, and this necessity would impose great limitations in the control. Still another and very important reason was that, in using rays, it would be difficult, if not impossible, to give to the automaton individual features or characteristics distinguishing it from other machines of this kind. Evidently the automaton should respond only to an individual call, as a person responds to a name. Such considerations led me to conclude that the sensitive device of the machine should correspond to the ear rather than to the eye of a human being, for in this case its actions could be controlled irrespective of intervening obstacles, regardless of its position relative to the distant controlling apparatus, and, last, but not least, it would remain deaf and unresponsive, like a faithful servant, to all calls but that of its master. These requirements made it imperative to use, in the control of the automaton, instead of light — or other rays, waves or disturbances which propagate in all directions through space, like sound, or which follow a path of least resistance, however curved. I attained the result aimed at by means of an electric circuit placed within the boat, and adjusted, or "tuned", exactly to electrical vibrations of the proper kind transmitted to it from a distant "electrical oscillator". This circuit, in responding, however feebly, to the transmitted vibrations, affected magnets and other contrivances, through the medium of which were controlled the movements of the propeller and rudder, and also the operations of numerous other appliances.

By the simple means described the knowledge, experience, judgment — the mind, so to speak — of the distant operator were embodied in that machine, which was thus enabled to move and to perform all its operations with reason and intelligence. It behaved just like a blindfolded person obeying directions received through the ear.

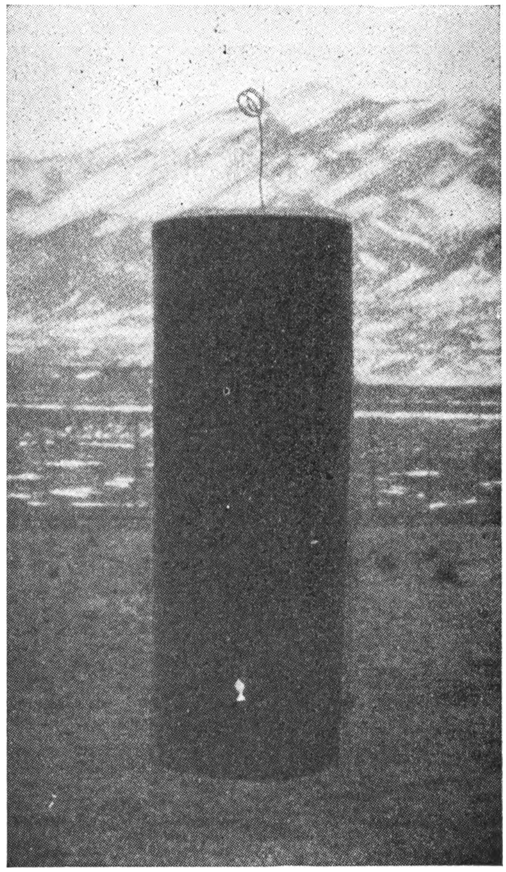


Fig. 4. EXPERIMENT TO ILLUSTRATE THE TRANSMISSION OF ELECTRICAL ENERGY THROUGH THE EARTH WITHOUT WIRE. The coil shown in the photograph has its lower end or terminal connected to the ground, and is exactly attuned to the vibrations of a distant electrical oscillator. The lamp lighted is in an independent wire loop, energized by induction from the coil excited by the electrical vibrations transmitted to it through the ground from the oscillator, which is worked only to five per cent. of its full capacity.

The automatons so far constructed had "borrowed minds", so to speak, as each merely formed part of the distant operator who conveyed to it his intelligent orders; but this art is only in the beginning. I purpose to show that, however impossible it may now seem, an automaton may be contrived which will have its "own mind", and by this I mean that it will be able, independent of any operator, left entirely to itself, to perform, in response to external influences affecting its sensitive organs, a great variety of acts and operations as if it had intelligence. It will be able to follow a course laid out or to obey orders given far in advance; it will be capable of distinguishing between what it ought and what it ought not to do, and of making experiences or, otherwise stated, of recording impressions which will definitely affect its subsequent actions. In fact, I have already conceived such a plan.

Although I evolved this invention many years ago and explained it to my visitors very frequently in my laboratory demonstrations, it was not until much later, long after I had perfected it, that it became known, when, naturally enough, it gave rise to much discussion and to sensational reports. But the true significance of this new art was not grasped by the majority, nor was the great force of the underlying principle recognized. As nearly as I could judge from the numerous comments which then

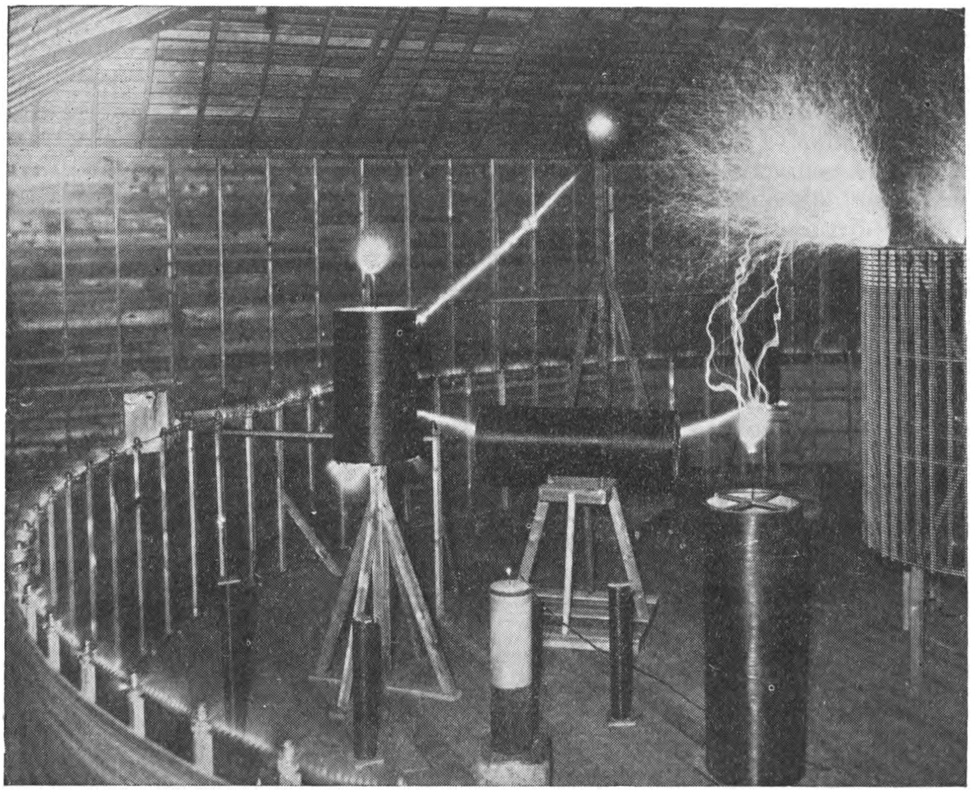


Fig. 5. PHOTOGRAPHIC VIEW OF COILS RESPONDING TO ELECTRICAL OSCILLATIONS. The picture shows a number of coils, differently attuned and responding to the vibrations transmitted to them through the earth from an electrical oscillator. The large coil on the right, discharging strongly, is tuned to the fundamental vibration, which is fifty thousand per second; the two larger vertical coils to twice that number; the smaller white wire coil to four times that number, and the remaining small coils to higher tones. The vibrations produced by the oscillator were so intense that they affected perceptibly a small coil tuned to the twenty-sixth higher tone.

appeared, the results I had obtained were considered as entirely impossible. Even the few who were disposed to admit the practicability of the invention saw in it merely an automobile torpedo, which was to be used for the purpose of blowing up battle-ships, with doubtful success. The general impression was that I contemplated simply the steering of such a vessel by means of Hertzian or other rays. There are torpedoes steered electrically by wires, and there are means of communicating without wires, and the above was, of course, an obvious inference. Had I accomplished nothing more than this, I should have made a small advance indeed. But the art I have evolved does not contemplate merely the change of direction of a moving vessel; it affords a means of absolutely controlling, in every respect, all the innumerable translatory movements, as well as the operations of all the internal organs, no matter how many, of an individualized automaton. Criticisms to the effect that the control of the automaton could be interfered with were made by people who do not even dream of the wonderful results which can be accomplished by the use of electrical vibrations. The world moves slowly, and new truths are difficult to see. Certainly, by the use of this: principle, an arm for attack as well as defense may be provided, of a destructiveness all the greater as the principle is applicable to submarine and aerial vessels. There is virtually no

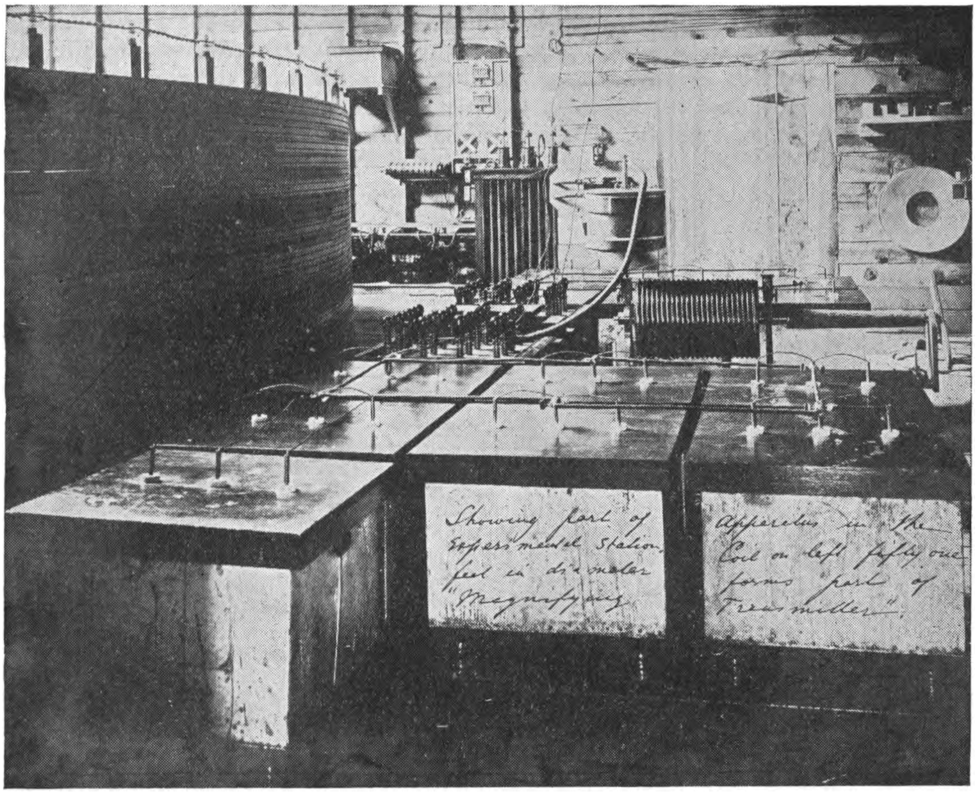


Fig. 6. PHOTOGRAPHIC VIEW OF THE ESSENTIAL PARTS OF THE ELECTRICAL OSCILLATOR USED IN THE EXPERIMENTS DESCRIBED.

restriction as to the amount of explosive it can carry, or as to the distance at which it can strike, and failure is almost impossible. But the force of this new principle does not wholly reside in its destructiveness. Its advent introduces into warfare an element which never existed before — a fighting-machine without men as a means of attack and defense. The continuous development in this direction must ultimately make war a mere contest of machines without men and without loss of life — a condition which would have been impossible without this new departure, and which, in my opinion, must be reached as preliminary to permanent peace. The future will either bear out or disprove these views. My ideas on this subject have been put forth with deep conviction, but in a humble spirit.

The establishment of permanent peaceful relations between nations would most effectively reduce the force retarding the human mass, and would be the best solution of this great human problem. But will the dream of universal peace ever be realized? Let us hope that it will. When all darkness shall be dissipated by the light of science, when all nations shall be merged into one, and patriotism shall be identical with religion, when there shall be one language, one country, one end, then the dream will have become reality.

THE THIRD PROBLEM: HOW TO INCREASE THE FORCE ACCELERATING THE HUMAN MASS — THE HARNESSING OF THE SUNS ENERGY

Of the three possible solutions of the main problem of increasing human energy, this is by far the most important to consider, not only because of its intrinsic significance, but also because of its intimate bearing on all the many elements and conditions which determine the movement of humanity. In order to proceed systematically, it would be necessary for me to dwell on all those considerations which have guided me from the outset in my efforts to arrive at a solution, and which have led me, step by step, to the results I shall now describe. As a preliminary study of the problem an analytical

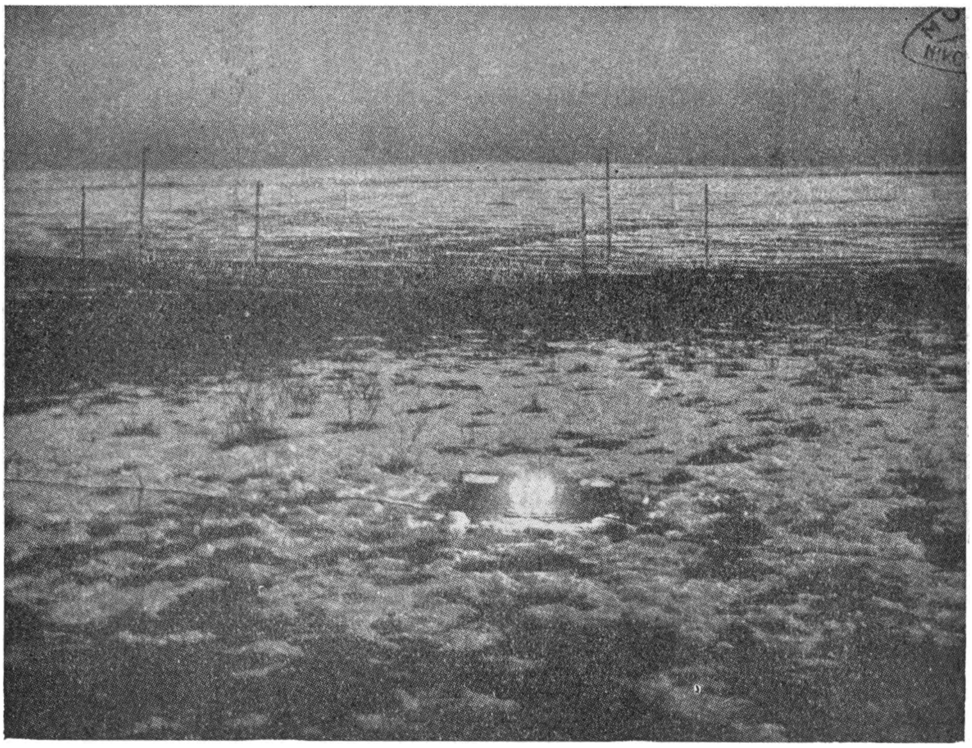
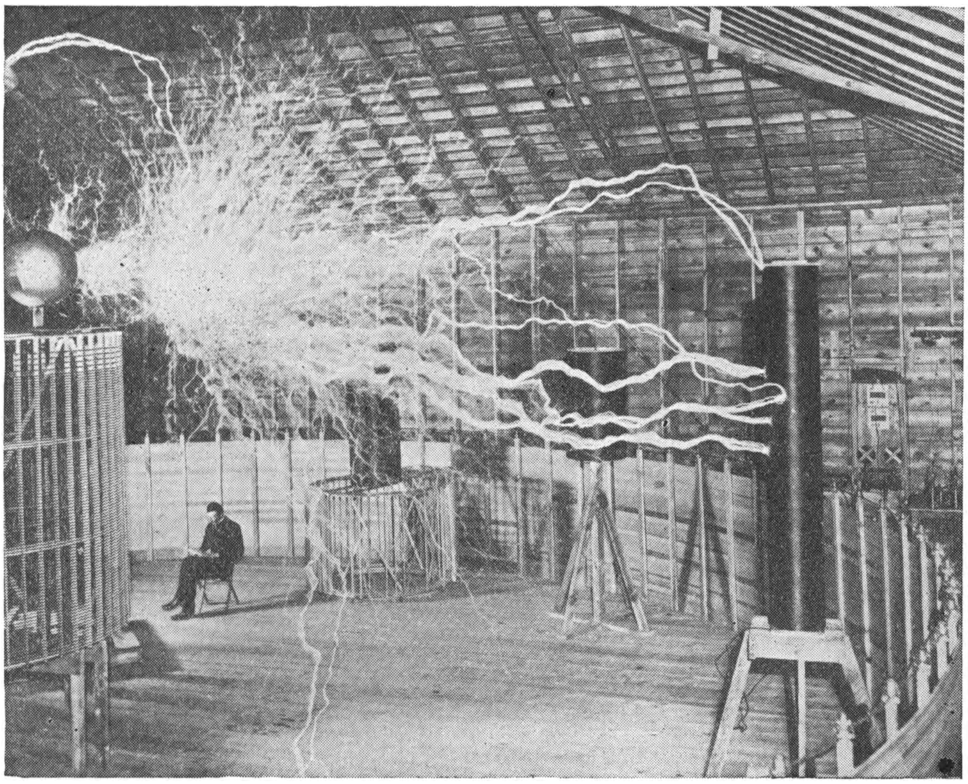


Fig. 7. EXPERIMENT TO ILLUSTRATE AN INDUCTIVE EFFECT OF AN ELECTRICAL OSCILLATOR OF GREAT POWER.

The photograph shows three ordinary incandescent lamps lighted to full candle-power by currents induced in a local loop consisting of a single wire forming a square of fifty feet each side, which includes the lamps, and which is at a distance of one hundred feet from the primary circuit energized by the oscillator. The loop likewise includes an electrical condenser, and is exactly attuned to the vibrations of the oscillator, which is worked at less than five per cent. of its total capacity.

investigation, such as I have made, of the chief forces which determine the onward movement, would be of advantage, particularly in conveying an idea of that hypothetical "velocity" which, as explained in the beginning, is a measure of human energy; but to deal with this specifically here, as I would desire, would lead me far beyond the scope of the present subject. Suffice it to state that the resultant of all these forces is always in the direction of reason, which, therefore, determines, at any time, the direction of human movement. This is to say that every effort which is scientifically applied, rational, useful, or practical, must be in the direction in which the mass is moving. The practical, rational man, the observer, the man of business, he who reasons, calculates, or determines in advance, carefully applies his effort so that when coming into effect it will be in the direction of the movement, making it thus most efficient, and in this knowledge and ability lies the secret of his success. Every new fact discovered, every new experience or new element added to our knowledge and entering into the



Note to Fig. 8. — The coil, partly shown in the photograph, creates an alternative movement of electricity from the earth into a large reservoir and back at the rate of one hundred thousand alternations per second. The adjustments are such that the reservoir is filled full and bursts at each alternation just at the moment when the electrical pressure reaches the maximum. The discharge escapes with a deafening noise, striking an unconnected coil twenty-two feet away, and creating such a comotion of electricity in the earth that sparks an inch long can be drawn from a water-main at a distance of three hundred feet from the laboratory.

domain of reason, affects the same and, therefore, changes the direction of the movement, which, however, must always take place along the resultant of all those efforts which, at that time, we designate as reasonable, that is, self-preserving, useful, profitable, or practical. These efforts concern our daily life, our necessities and comforts, our work and business, and it is these which drive man onward.

But looking at all this busy world about us, on all this complex mass as it daily throbs and moves, what is it but an immense clockwork driven by a spring? In the morning, when we rise, we cannot fail to note that all the objects about us are manufactured by machinery: the water we use is lifted by steam-power; the trains bring our breakfast from distant localities; the elevators in our dwelling and in our office building, the cars that carry us there, are all driven by power; in all our daily errands, and in our very life-pursuit, we depend upon it; all the objects we see tel us of it; and when we return to our machine-made dwelling at night, lest we should forget it, all the material comforts of our home, our cheering stove and lamp, remind us how much we depend on power. And when there is an accidental stoppage of the machinery, when the city is snow-bound, or the life-sustaining movement otherwise temporarily arrested, we are affrighted to realize how impossible it would be for us to live the life we live without motive power. Motive power means work. To increase the force accelerating human movement means, therefore, to perform more work.

So we find that the three possible solutions of the great problem of increasing human energy are answered by the three words: *food, peace, work.* Many a year I have thought and pondered, lost myself in speculations and theories, considering man as a mass moved by a force, viewing his inexplicable movement in the light of a mechanical one, and applying the simple principles of mechanics to the analysis of the same until I arrived at these solutions, only to realize that they were taught to me in my early childhood. These three words sound the key-notes of the Christian religion. Their scientific meaning and purpose are now clear to me: food to increase the mass, peace to diminish the retarding force, and work to increase the force accelerating human movement. These are the only three solutions which are possible of that great problem, and all of them have one object, one end, namely, to increase human energy. When we recognize this, we cannot help wondering how profoundly wise and scientific and how immensely practical the Christian religion is, and in what a marked contrast it stands in this respect to other religions. It is unmistakably the result of practical experiment and scientific observation which have extended through ages, while other religions seem to be the outcome of merely abstract reasoning. Work, untiring effort, useful and accumulative, with periods of rest and recuperation aiming at higher efficiency, is its chief and ever-recurring command. Thus we are inspired both by Christianity and Science to do our utmost toward increasing the performance of mankind. This, most important of human problems I shall now specifically consider.

THE SOURCE OF HUMAN ENERGY — THE THREE WAYS OF DRAWING ENERGY FROM THE SUN

First let us ask: Whence comes all the motive power? What is the spring that drives all? We see the ocean rise and fall, the rivers flow, the wind, rain, hail, and snow beat on our windows, the trains and steamers come and go; we hear the rattling noise of carriages, the voices from the street; we feel, smell, and taste; and we think of all this. And all this movement from the surging of the mighty ocean to that subtle movement concerned in our thought, has but one common cause. All this energy emanates from one single center, one single source — the sun. The sun is the spring that drives all. The sun maintains all human life and supplies all human energy. Another answer we have now found to the above great question: To increase the force accelerating human movement means to turn to the uses of man more of the sun's energy. We honor and revere those great men of bygone times whose names are linked with immortal achievements, who have proved themselves benefactors of humanity — the religious reformer with his wise maxims of life, the philosopher with his deep

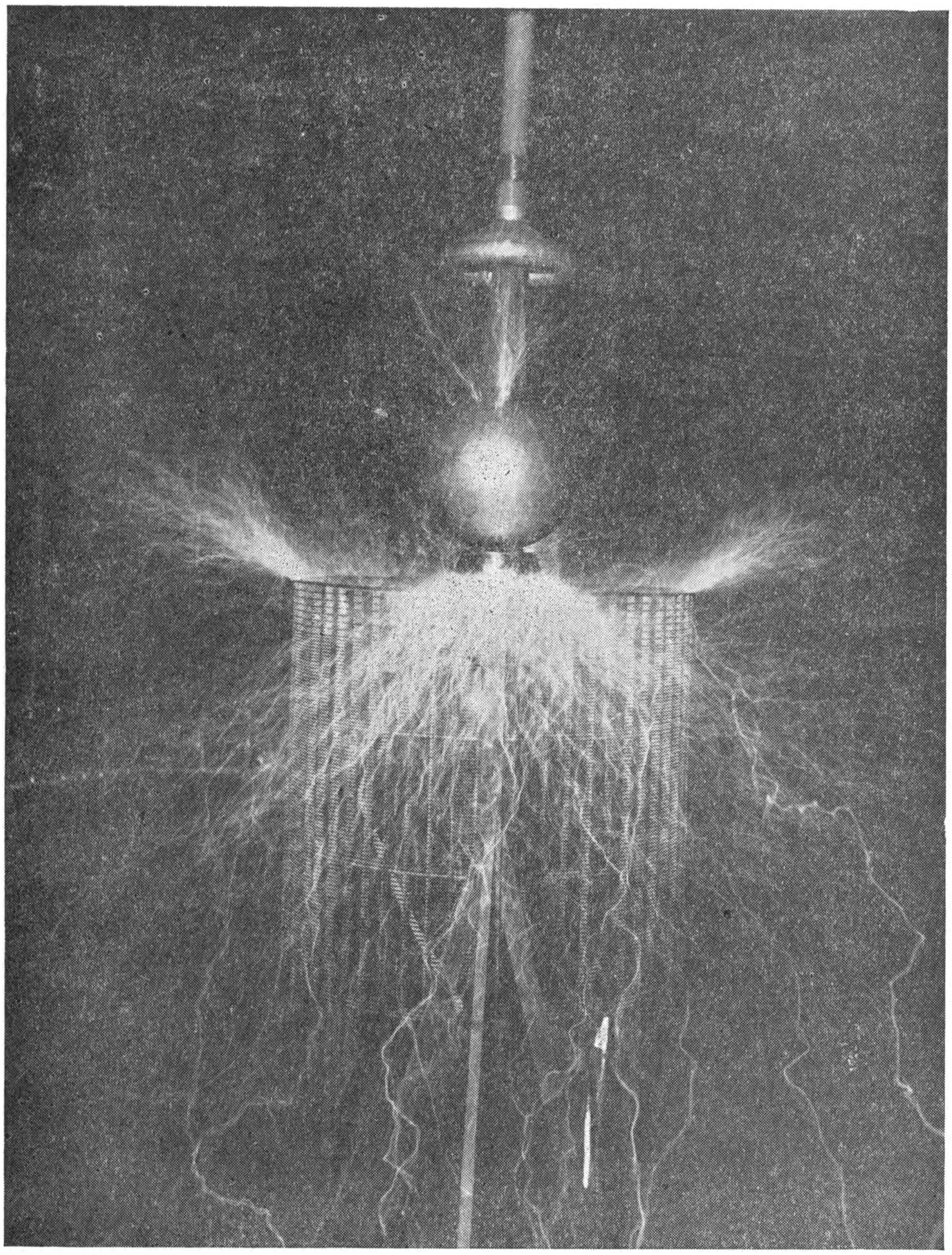


Fig. 9. EXPERIMENT TO ILLUSTRATE THE CAPACITY OF THE OSCILLATOR FOR CREATING A GREAT ELECTRICAL MOVEMENT.

The ball shown in the photograph, covered with a polished metallic coating of twenty square feet of surface, represents a large reservoir of electricity, and the inverted tin pan underneath, with a sharp rim, a big opening through which the electricity can escape before filling the reservoir. The quantity of electricity set in movement is so great that, although most of it escapes through the rim of the pan or opening provided, the ball or reservoir is nevertheless alternately emptied and filled to overflowing (as is evident from the discharge escaping on the top of the ball) one hundred and fifty thousand times per second.

truths, the mathematician with his formulae, the physicist with his laws, the discoverer with his principles and secrets wrested from nature, the artist with his forms of the beautiful; but who honors him, the greatest of all, — who can tell the name of him, — who first turned to use the sun's energy to save the effort of a weak fellow-creature? That was man's first act of scientific philanthropy, and its consequences have been incalculable.

From the very beginning three ways of drawing energy from the sun were open to man. The savage, when he warmed his frozen limbs at a fire kindled in some way, availed himself of the energy of the sun stored in the burning material. When he carried a bundle of branches to his cave and burned them there, he made use of the sun's stored energy transported from one to another locality. When he set sail to his canoe, he utilized the energy of the sun supplied to the atmosphere or ambient medium. There can be no doubt that the first is the oldest way. A fire, found accidentally, taught the savage to appreciate its beneficial heat. He then very likely conceived the idea of the carrying the glowing embers to his abode. Finally he learned to use the force of a swift current of water or air. It is characteristic of modern development that progress has been effected in the same order. The utilization of the energy stored in wood or coal, or, generally speaking, fuel, led to the steam-engine. Next a great stride in advance was made in energy-transportation by the use of electricity, which permitted the transfer of energy from one locality to another without transporting the material. But as to the utilization of the energy of the ambient medium, no radical step forward has as yet been made known.

The ultimate results of development in these three directions are: first, the burning of coal by a cold process in a battery; second, the efficient utilization of the energy of the ambient medium; and, third, the transmission without wires of electrical energy to any distance. In whatever way these results may be arrived at, their practical application will necessarily involve an extensive use of iron, and this invaluable metal will undoubtedly be an essential element in the further development along these three lines. If we succeed in burning coal by a cold process and thus obtaining electrical energy in an efficient and inexpensive manner, we shall require in many practical uses of this energy electric motors — that is, iron. If we are successful in deriving energy from the ambient medium, we shall need, both in the obtainment and utilization of the energy, machinery — again, iron. If we realize the transmission of electrical energy without wires on an industrial scale, we shall be compelled to use extensively electric generators — once more, iron. Whatever we may do, iron will probably be the chief means of accomplishment in the near future, possibly more so than in the past. How long its reign will last is difficult to tell, for even now aluminium is looming up as a threatening competitor. But for the time being, next to providing new resources of energy, it is of the greatest importance to make improvements in the manufacture and utilization of iron. Great advances are possible in these latter directions, which, if brought about, would enormously increase the useful performance of mankind.

GREAT POSSIBILITIES OFFERED BY IRON FOR INCREASING HUMAN PERFORMANCE — ENORMOUS WASTE IN IRON MANUFACTURE

Iron is by far the most important factor in modern progress. It contributes more than any other industrial product to the force accelerating human movement. So general is the use of this metal, and so intimately is it connected with all that concerns our life, that it has become as indispensable to us as the very air we breathe. Its name is synonymous with usefulness. But, however great the influence of iron may be on the present human development, it does not add to the force urging man onward nearly as much as it might. First of all, its manufacture as now carried on is connected with

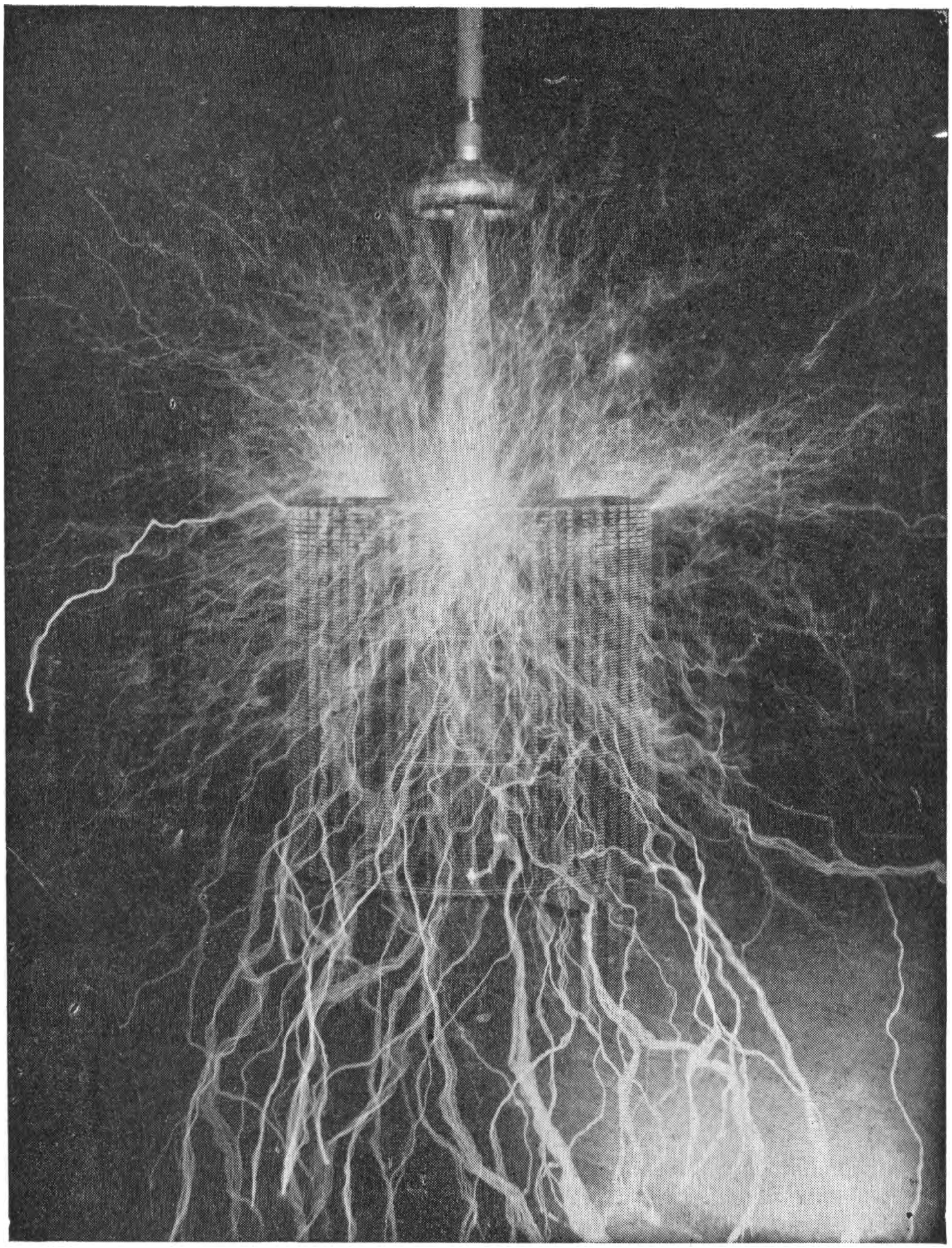


Fig. 10. PHOTOGRAPHIC VIEW OF AN EXPERIMENT TO ILLUSTRATE AN EFFECT OF AN ELECTRICAL OSCILLATOR DELIVERING ENERGY AT A RATE OF SEVENTY-FIVE THOUSAND HORSE-POWER.

The discharge, creating a strong draft owing to the heating of the air, is carried upward through the open roof of the building. The greatest width across is nearly seventy feet. The pressure is over twelve million volts, and the current alternates one hundred and thirty thousand times per second.

an appalling waste of fuel — that is, waste of energy. Then, again, only a part of all the iron produced is applied for useful purposes. A good part of it goes to create frictional resistances, while still another large part is the means of developing negative forces greatly retarding human movement. Thus the negative force of war is almost wholly represented in iron. It is impossible to estimate with any degree of accuracy the magnitude of this greatest of all retarding forces, but it is certainly very considerable. If the present positive impelling force due to all useful applications of iron be represented by ten, for instance, I should not think it exaggeration to estimate the negative force of war, with due consideration of all its retarding influences and results, at, say, six. On the basis of this estimate the effective impelling force of iron in the positive direction would be measured by the difference of these two numbers, which is four. But if, through the establishment of universal peace, the manufacture of war machinery should cease, and all struggle for supremacy between nations should be turned into healthful, ever active and productive commercial competition, then the positive impelling force due to iron would be measured by the sum of those two numbers, which is sixteen — that is, this force would have four times its present value. This example is, of course, merely intended to give an idea of the immense increase in the useful performance of mankind which would result from a radical reform of the iron industries supplying the implements of warfare.

A similar inestimable advantage in the saving of energy available to man would be secured by obviating the great waste of coal which is inseparably connected with the present methods of manufacturing iron. In some countries, as in Great Britain, the hurtful effects of this squandering of fuel are beginning to be felt. The price of coal is constantly rising, and the poor are made to suffer more and more. Though we are still far from the dreaded "exhaustion of the coal-fields", philanthropy commands us to invent novel methods of manufacturing iron, which will not involve such barbarous waste of this valuable material from which we derive at present most of our energy. It is our duty to coming generations to leave this store of energy intact for them, or at least not to touch it until we shall have perfected processes for burning coal more efficiently. Those who are to come after us will need fuel more than we do. We should be able to manufacture the iron we require by using the sun's energy, without wasting any coal at all. As an effort to this end the idea of smelting iron ores by electric currents obtained from the energy of falling water has naturally suggested itself to many. I have myself spent much time in endeavoring to evolve such a practical process, which would enable iron to be manufactured at small cost. After a prolonged investigation of the subject, finding that it was unprofitable to use the currents generated directly for smelting the ore, I devised a method which is far more economical.

ECONOMICAL PRODUCTION OF IRON BY A NEW PROCESS

The industrial project, as I worked it out six years ago, contemplated the employment of the electric currents derived from the energy of a waterfall, not directly for smelting the ore, but for decomposing water, as a preliminary step. To lessen the cost of the plant, I proposed to generate the currents in exceptionally cheap and simple dynamos, which I designed for this sole purpose. The hydrogen liberated in the electrolytic decomposition was to be burned or recombined with oxygen, not with that from which it was separated, but with that of the atmosphere. Thus very nearly the total electrical energy used up in the decomposition of the water would be recovered in the form of heat resulting from the recombination of the hydrogen. This heat was to be applied to the smelting of the ore. The oxygen gained as a by-product in the decomposition of the water I intended to use for certain other industrial purposes, which would probably yield good financial returns, inasmuch as this is the cheapest way of obtaining this gas in large quantities. In any event, it could be employed to burn all kinds of refuse, cheap hydrocarbon, or coal of the most inferior quality which could not be burned in air or be otherwise utilized to advantage, and thus again a considerable amount of heat would be made available for the smelting of the ore. To increase the economy of the process I contemplated, furthermore, using an arrangement such that the hot metal and the products of combustion, coming out of the furnace, would give up their heat upon the cold ore going into the furnace, so that comparatively little of the heat-energy would be lost in the smelting. I calculated that probably forty thousand pounds of iron could be produced per horse-power per annum by this method. Liberal allowances were made for those losses which are unavoidable, the above quantity being about half of that theoretically obtainable. Relying on this estimate and on practical data with reference to a certain kind of sand ore existing in abundance in the region of the Great Lakes, including cost of transportation and labor, I found that in some localities iron could be manufactured in this manner cheaper than by any of the adopted methods. This result would be attained all the more surely if the oxygen obtained from the water, instead of being used for smelting the ore, as assumed, should be more profitably employed. Any new demand for this gas would secure a higher revenue from the plant, thus cheapening the iron. This project was advanced merely in the interest of industry. Some day, I hope, a beautiful industrial butterfly will come out of the dusty and shriveled chrysalis.

The production of iron from sand ores by a process of magnetic separation is highly commendable in principle, since it involves no waste of coal; but the usefulness of this method is largely reduced by the necessity of melting the iron afterward. As to the crushing of iron ore, I would consider it rational only if done by water-power, or by energy otherwise obtained without consumption of fuel. An electrolytic cold process, which would make it possible to extract iron cheaply, and also to mold it into the required forms without any fuel consumption, would, in my opinion, be a very great advance in iron manufacture. In common with some other metals, iron has so far resisted electrolytic treatment, but there can be no doubt that such a cold process will ultimately replace in metallurgy the present crude method of casting, and thus obviate the enormous waste of fuel necessitated by the repeated heating of metal in the foundries.

Up to a few decades ago the usefulness of iron was based almost wholly on its remarkable mechanical properties, but since the advent of the commercial dynamo and electric motor its value to mankind has been greatly increased by its unique magnetic qualities. As regards the latter, iron has been greatly improved of late. The signal progress began about thirteen years ago, when I discovered that in using soft Bessemer steel instead of wrought iron, as then customary, in an alternating motor, the performance of the machine was doubled. I brought this fact to the attention of Mr. Albert Schmid, to whose untiring efforts and ability is largely due the supremacy of American electrical machinery, and who was then superintendent of an industrial corporation engaged in this field. Following my suggestion, he constructed transformers of steel, and they showed the same marked improvement. The investigation was then systematically continued under Mr. Schmid's guidance, the impurities being gradually eliminated from the "steel" (which was only such in name, for in reality it was pure soft iron), and soon a product resulted which admitted of little further improvement.

THE COMING AGE OF ALUMINIUM — DOOM OF THE COPPER INDUSTRY — THE GREAT CIVILIZING POTENCY OF THE NEW METAL

With the advances made in iron of late years we have arrived virtually at the limits of improvement. We cannot hope to increase very materially its tensile strength, elasticity, hardness, or malleability, nor can we expect to make it much better as regards its magnetic qualities. More recently a notable gain was secured by the mixture of a small percentage of nickel with the iron, but there is not much room for further advance in this direction. New discoveries may be expected, but they cannot greatly add to the valuable properties of the metal, though they may considerably reduce the cost of manufacture. The immediate future of iron is assured by its cheapness and its unrivaled mechanical and magnetic qualities. These are such that no other product can compete with it now. But there can be no doubt that, at a time not very distant, iron, in many of its now uncontested domains, will have to pass the scepter to another: the coming age will be the age of aluminium. It is only seventy years since this wonderful metal was discovered by Woehler, and the aluminium industry, scarcely forty years old, commands already the attention of the entire world. Such rapid growth has not been recorded in the history of civilization before. Not long ago aluminium was sold at the fanciful price of thirty or forty dollars per pound; to-day it can be had in any desired amount for as many cents. What is more, the time is not far off when this price, too, will be considered fanciful, for great improvements are possible in the methods of its manufacture. Most of the metal is now produced in the electric furnace by a process combining fusion and electrolysis, which offers a number of advantageous features, but involves naturally a great waste of the electrical energy of the current. My estimates show that the price of aluminium could be considerably reduced by adopting in its manufacture a method similar to that proposed by me for the production of iron. A pound of aluminium requires for fusion only about seventy per cent, of the heat needed for melting a pound of iron, and inasmuch as its weight is only about one third of that of the latter, a volume of aluminium four times that of iron could be obtained from a given amount of heat-energy. But a cold electrolytic process of manufacture is the ideal solution, and on this I have placed my hope.

The absolutely unavoidable consequence of the advance of the aluminium industry will be the annihilation of the copper industry. They cannot exist and prosper together, and the latter is doomed beyond any hope of recovery. Even now it is cheaper to convey an electric current through aluminium wires than through copper wires; aluminium castings cost less, and in many domestic and other uses copper has no chance of successfully competing. A further material reduction of the price of aluminium cannot but be fatal to copper. But the progress of the former will not go on unchecked, for, as it ever happens in such cases, the larger industry will absorb the smaller one: the giant copper interests will control the pygmy aluminium interests, and the slow-pacing copper will reduce the lively gait of aluminium. This will only delay, not avoid, the impending catastrophe.

Aluminium, however, will not stop at downing copper. Before many years have passed it will be engaged in a fierce struggle with iron, and in the latter it will find an adversary not easy to conquer. The issue of the contest will largely depend on whether iron shall be indispensable in electric machinery. This the future alone can decide. The magnetism as exhibited in iron is an isolated phenomenon in nature. What it is that makes this metal behave so radically different from all other materials in this respect has not yet been ascertained, though many theories have been suggested. As regards magnetism, the molecules of the various bodies behave like hollow beams partly filled with a heavy fluid and balanced in the middle in the manner of a see-saw. Evidently some disturbing influence exists in nature which causes each molecule, like such a beam, to tilt either one or the other way. If the molecules are tilted one way, the body is magnetic; if they are tilted the other way, the body is non-magnetic; but both positions are stable, as they would be in the case of the hollow beam, owing to the rushing of the fluid to the lower end. Now, the wonderful thing is that the molecules of all known bodies went one way, while those of iron went the other way. This metal, it would seem, has an origin entirely different from that of the rest of the globe. It is highly improbable that we shall discover some other and cheaper material which will equal or surpass iron in magnetic qualities.

Unless we should make a radical departure in the character of the electric currents employed, iron will be indispensable. Yet the advantages it offers are only apparent. So long as we use feeble magnetic forces it is by far superior to any other material; but if we find ways of producing great magnetic forces, then better results will be obtainable without it. In fact, I have already produced electric transformers in which no iron is employed, and which are capable of performing ten times as much work per pound of weight as those with iron. This result is attained by using electric currents of a very high rate of vibration, produced in novel ways, instead of the ordinary currents now employed in the industries. I have also succeeded in operating electric motors without iron by such rapidly vibrating currents, but the results, so far, have been inferior to those obtained with ordinary motors constructed of iron, although theoretically the former should be capable of performing incomparably more work per unit of weight than the latter. But the seemingly insuperable difficulties which are now in the way may be overcome in the end, and then iron will be done away with, and all electric machinery will be manufactured of aluminium, in all probability, at prices ridiculously low. This would be a severe, if not a fatal, blow to iron. In many other branches of industry, as ship-building, or wherever lightness of structure is required, the progress of the new metal will be much quicker. For such uses it is eminently suitable, and is sure to supersede iron sooner or later. It is highly probable that in the course of time we shall be able to give it many of those qualities which make iron so valuable.

While it is impossible to tell when this industrial revolution will be consummated, there can be no doubt that the future belongs to aluminium, and that in times to come it will be the chief means of increasing human performance. It has in this respect capacities greater by far than those of any other metal. I should estimate its civilizing potency at fully one hundred times that of iron. This estimate, though it may astonish, is not at all exaggerated. First of all, we must remember that there is thirty times as much aluminium as iron in bulk, available for the uses of man. This in itself offers great possibilities. Then, again, the new metal is much more easily workable, which adds to its value. In many of its properties it partakes of the character of a precious metal, which gives it additional worth. Its electric conductivity, which, for a given weight, is greater than that of any other metal, would be alone sufficient to make it one of the most important factors in future human progress. Its extreme lightness makes it far more easy to transport the objects manufactured. By virtue of this property it will revolutionize naval construction, and in facilitating transport and travel it will add enormously to the useful performance of mankind. But its greatest civilizing potency will be, I believe, in aerial travel, which is sure to be brought about by means of it. Telegraphic instruments will slowly enlighten the barbarian. Electric motors and lamps will do it more quickly, but quicker than anything else the flying-machine will do it. By rendering travel ideally easy it will be the best means for unifying the heterogeneous elements of humanity. As the first step toward this realization we should produce a lighter storage-battery or get more energy from coal.

EFFORTS TOWARD OBTAINING MORE ENERGY FROM COAL — THE ELECTRIC TRANSMISSION — THE GAS-ENGINE — THE COLD-COAL BATTERY

I remember that at one time I considered the production of electricity by burning coal in a battery as the greatest achievement toward advancing civilization, and I am surprised to find how much the continuous study of these subjects has modified my views. It now seems to me that to burn coal, however efficiently, in a battery would be a mere makeshift, a phase in the evolution toward something much more perfect. After all, in generating electricity in this manner, we should be destroying material, and this would be a barbarous process. We ought to be able to obtain the energy we need without consumption of material. But I am far from underrating the value of such an efficient method of burning fuel. At the present time most motive power comes from coal, and, either directly or by its products, it adds vastly to human energy. Unfortunately, in all the processes now adopted, the larger portion of the energy of the coal is uselessly dissipated. The best steam-engines utilize only a small part of the total energy. Even in gas-engines, in which, particularly of late, better results are obtainable, there is still a barbarous waste going on. In our electric-lighting systems we scarcely utilize one third of one per cent., and in lighting by gas a much smaller fraction of the total energy of the coal. Considering the various uses of coal throughout the world, we certainly do not utilize more than two per cent, of its energy theoretically available. The man who should stop this senseless waste would be a great benefactor of humanity, though the solution he would offer could not be a permanent one, since it would ultimately lead to the exhaustion of the store of material. Efforts toward obtaining more energy from coal are now being made chiefly in two directions — by generating electricity and by producing gas for motive-power purposes. In both of these lines notable success has already been achieved.

The advent of the alternating-current system of electric power-transmission marks an epoch in the economy of energy available to man from coal. Evidently all electrical energy obtained from a waterfall, saving so much fuel, is a net gain to mankind, which is all the more effective as it is secured with little expenditure of human effort, and as this most perfect of all known methods of deriving energy from the sun contributes in many ways to the advancement of civilization. But electricity enables us also to get from coal much more energy than was practicable in the old ways. Instead of transporting the coal to distant places of consumption, we burn it near the mine, develop electricity in the dynamos, and transmit the current to remote localities, thus effecting a considerable saving. Instead of driving the machinery in a factory in the old wasteful way by belts and shafting, we generate electricity by steam-power and operate electric motors. In this manner it is not uncommon to obtain two or three times as much effective motive power from the fuel, besides securing many other important advantages. It is in this field as much as in the transmission of energy to great distances that the alternating system, with its ideally simple machinery, is bringing about an industrial revolution. But in many lines this progress has not yet been felt. For example, steamers and trains are still being propelled by the direct application of steam-power to shafts or axles. A much greater percentage of the heat-energy of the fuel could be transformed in motive energy by using, in place of the adopted marine engines and locomotives, dynamos driven by specially designed high-pressure steam- or gas-engines and by utilizing the electricity generated for the propulsion. A gain of fifty to one hundred per cent. in the effective energy derived from the coal could be secured in this manner. It is difficult to understand why a fact so plain and obvious is not receiving more attention from engineers. In ocean steamers such an improvement would be particularly desirable, as it would do away with noise and increase materially the speed and the carrying capacity of the liners.

Still more energy is now being obtained from coal by the latest improved gas-engine, the economy of which is, on the average, probably twice that of the best steam-engine. The introduction of the gas-engine is very much facilitated by the importance of the gas industry. With the increasing use of the electric light more and more of the gas is utilized for heating and motive-power purposes. In many instances gas is manufactured close to the coal-mine and conveyed to distant places of consumption, a considerable saving both in the cost of transportation and in utilization of the energy of the fuel being thus effected. In the present state of the mechanical and electrical arts the most rational way of deriving energy from coal is evidently to manufacture gas close to the coal store, and to utilize it, either on the spot or elsewhere, to generate electricity for industrial uses in dynamos driven by gas-engines. The commercial success of such a plant is largely dependent upon the production of gas-engines of great nominal horse-power, which, judging from the keen activity in this field, will soon be forthcoming. Instead of consuming coal directly, as usual, gas should be manufactured from it and burned to economize energy.

But all such improvements cannot be more than passing phases in the evolution toward something far more perfect, for ultimately we must succeed in obtaining electricity from coal in a more direct way, involving no great loss of its heat-energy. Whether coal can be oxidized by a cold process is still a question. Its combination with oxygen always evolves heat, and whether the energy of the combination of the carbon with another element can be turned directly into electrical energy has not yet been determined. Under certain conditions nitric acid will burn the carbon, generating an electric current, but the solution does not remain cold. Other means of oxidizing coal have been proposed, but they have offered no promise of leading to an efficient process. My own lack of success has been complete, though perhaps not quite so complete as that of some who have "perfected" the cold-coal battery. This problem is essentially one for the chemist to solve. It is not for the physicist, who determines all his results in advance, so that, when the experiment is tried, it cannot fail. Chemistry, though a positive science, does not yet admit of a solution by such positive methods as those which are available in the treatment of many physical problems. The result, if possible, will be arrived at through patient trying rather than through deduction or calculation. The time will soon come, however, when the chemist will be able to follow a course clearly mapped out beforehand, and when the process of his arriving at a desired result will be purely constructive. The cold-coal battery would give a great impetus to electrical development; it would lead very shortly to a practical flying-machine, and would enormously enhance the introduction of the automobile. But these and many other problems will be better solved, and in a more scientific manner, by a light-storage battery.

ENERGY FROM THE MEDIUM — THE WINDMILL AND THE SOLAR ENGINE — MOTIVE POWER FROM TERRESTRIAL HEAT — ELECTRICITY FROM NATURAL SOURCES

Besides fuel, there is abundant material from which we might eventually derive power. An immense amount of energy is locked up in limestone, for instance, and machines can be driven by liberating the carbonic acid through sulphuric acid or otherwise. I once constructed such an engine, and it operated satisfactorily.

But, whatever our resources of primary energy may be in the future, we must, to be rational, obtain it without consumption of any material. Long ago I came to this conclusion, and to arrive at this result only two ways, as before indicated, appeared possible — either to turn to use the energy of the sun stored in the ambient medium, or to transmit, through the medium, the sun's energy to distant places from some locality where it was obtainable without consumption of material. At that time I at once rejected the latter method as entirely impracticable, and turned to examine the possibilities of the former.

It is difficult to believe, but it is, nevertheless, a fact, that since time immemorial man has had at his disposal a fairly good machine which has enabled him to utilize the energy of the ambient medium. This machine is the windmill. Contrary to popular belief, the power obtainable from wind is very considerable. Many a deluded inventor has spent years of his life in endeavoring to “harness the tides”, and some have even proposed to compress air by tide- or wave-power for supplying energy, never understanding the signs of the old windmill on the hill, as it sorrowfully waved its arms about and bade them stop. The fact is that a wave- or tide-motor would have, as a rule, but a small chance of competing commercially with the windmill, which is by far the better machine, allowing a much greater amount of energy to be obtained in a simpler way. Wind-power has been, in old times, of inestimable value to man, if for nothing else but for enabling him to cross the seas, and it is even now a very important factor in travel and transportation. But there are great limitations in this ideally simple method of utilizing the sun’s energy. The machines are large for a given output, and the power is intermittent, thus necessitating the storage of energy and increasing the cost of the plant.

A far better way, however, to obtain power would be to avail ourselves of the sun’s rays, which beat the earth incessantly and supply energy at a maximum rate of over four million horse-power per square mile. Although the average energy received per square mile in any locality during the year is only a small fraction of that amount, yet an inexhaustible source of power would be opened up by the discovery of some efficient method of utilizing the energy of the rays. The only rational way known to me at the time when I began the study of this subject was to employ some kind of heat- or thermodynamic engine, driven by a volatile fluid evaporated in a boiler by the heat of the rays. But closer investigation of this method, and calculation, showed that, notwithstanding the apparently vast amount of energy received from the sun’s rays, only a small fraction of that energy could be actually utilized in this manner. Furthermore, the energy supplied through the sun’s radiations is periodical, and the same limitations as in the use of the windmill I found to exist here also. After a long study of this mode of obtaining motive power from the sun, taking into account the necessarily large bulk of the boiler, the low efficiency of the heat-engine, the additional cost of storing the energy, and other drawbacks, I came to the conclusion that the “solar engine”, a few instances excepted, could not be industrially exploited with success.

Another way of getting motive power from the medium without consuming any material would be to utilize the heat contained in the earth, the water, or the air for driving an engine. It is a well-known fact that the interior portions of the globe are very hot, the temperature rising, as observations show, with the approach to the center at the rate of approximately 1° C. for every hundred feet of depth. The difficulties of sinking shafts and placing boilers at depths of, say, twelve thousand feet, corresponding to an increase in temperature of about 120° C, are not insuperable, and we could certainly avail ourselves in this way of the internal heat of the globe. In fact, it would not be necessary to go to any depth at all in order to derive energy from the stored terrestrial heat. The superficial layers of the earth and the air strata close to the same are at a temperature sufficiently high to evaporate some extremely volatile substances, which we might use in our boilers instead of water. There is no doubt that a vessel might be propelled on the ocean by an engine driven by such a volatile fluid, no other energy being used but the heat abstracted from the water. But the amount of power which could be obtained in this manner would be, without further provision, very small.

Electricity produced by natural causes is another source of energy which might be rendered available. Lightning discharges involve great amounts of electrical energy, which we could utilize by transforming and storing it. Some years ago I made known a method of electrical transformation which renders the first part of this task easy, but the storing of the energy of lightning discharges will be difficult to accomplish.

It is well known, furthermore, that electric currents circulate constantly through the earth, and that there exists between the earth and any air stratum a difference of electrical pressure, which varies in proportion to the height.

In recent experiments I have discovered two novel facts of importance in this connection. One of these facts is that an electric current is generated in a wire extending from the ground to a great height by the axial, and probably also by the translatory, movement of the earth. No appreciable current, however, will flow continuously in the wire unless the electricity is allowed to leak out into the air. Its escape is greatly facilitated by providing at the elevated end of the wire a conducting terminal of great surface, with many sharp edges or points. We are thus enabled to get a continuous supply of electrical energy by merely supporting a wire at a height, but, unfortunately, the amount of electricity which can be so obtained is small.

The second fact which I have ascertained is that the upper air strata are permanently charged with electricity opposite to that of the earth. So, at least, I have interpreted my observations, from which it appears that the earth, with its adjacent insulating and outer conducting envelop, constitutes a highly charged electrical condenser containing, in all probability, a great amount of electrical energy which might be turned to the uses of man, if it were possible to reach with a wire to great altitudes.

It is possible, and even probable, that there will be, in time, other resources of energy opened up, of which we have no knowledge now. We may even find ways of applying forces such as magnetism or gravity for driving machinery without using any other means. Such realizations, though highly improbable, are not impossible. An example will best convey an idea of what we can hope to attain and what we can never attain. Imagine a disk of some homogeneous material turned perfectly true and arranged to turn in frictionless bearings on a horizontal shaft above the ground. This disk, being under the above conditions perfectly balanced, would rest in any position. Now, it is possible that we may learn how to make such a disk rotate continuously and perform work by the force of gravity without any further effort on our part; but it is perfectly impossible for the disk to turn and to do work without any force from the outside. If it could do so, it would be what is designated scientifically as a “perpetuum mobile”, a machine creating its own motive power. To make the disk rotate by the force of gravity we have only to invent a screen against this force. By such a screen we could prevent this force from acting on one half of the disk, and the rotation of the latter would follow. At least, we cannot deny such a possibility until we know exactly the nature of the force of gravity. Suppose that this force were due to a movement comparable to that of a stream of air passing from above toward the center of the earth. The effect of such a stream upon both halves of the disk would be equal, and the latter would not rotate ordinarily; but if one half should be guarded by a plate arresting the movement, then it would turn.

A DEPARTURE FROM KNOWN METHODS — POSSIBILITY OF A “SELF-ACTING” ENGINE OR MACHINE, INANIMATE, YET CAPABLE, LIKE A LIVING BEING, OF DERIVING ENERGY FROM THE MEDIUM — THE IDEAL WAY OF OBTAINING MOTIVE POWER

When I began the investigation of the subject under consideration, and when the preceding or similar ideas presented themselves to me for the first time, though I was then unacquainted with a number of the facts mentioned, a survey of the various ways of utilizing the energy of the medium convinced me, nevertheless, that to arrive at a thoroughly satisfactory practical solution a radical departure from the methods then known had to be made. The windmill, the solar engine, the engine driven by terrestrial heat, had their limitations in the amount of power obtainable. Some new way had to be discovered which would enable us to get more energy. There was enough heat-energy in the medium, but only a small part of it was available for the operation of an engine in the ways then known. Besides, the energy was obtainable only at a very slow rate. Clearly, then, the problem was to discover some new method which would make it possible both to utilize more of the heat-energy of the medium and also to draw it away from the same at a more rapid rate.

I was vainly endeavoring to form an idea of how this might be accomplished, when I read some statements from Carnot and Lord Kelvin (then Sir William Thomson) which meant virtually that it is impossible for an inanimate mechanism of self-acting machine to cool a portion of the medium below the temperature of the surrounding, and operate by the heat abstracted. These statements interested me intensely. Evidently a living being could do this very thing, and since the experiences of my early life which I have related had convinced me that a living being is only an automaton, or, otherwise stated, a "self-acting engine", I came to the conclusion that it was possible to construct a machine which would do the same. As the first step toward this realization I conceived the following mechanism. Imagine a thermopile consisting of a number of bars of metal extending from the earth to the outer space beyond the atmosphere. The heat from below, conducted upward along these metal bars, would cool the earth or the sea or the air, according to the location of the lower parts of the bars, and the result, as is well known, would be an electric current circulating in these bars. The two terminals of the thermopile could now be joined through an electric motor, and, theoretically, this motor would run on and on, until the media below would be cooled down to the temperature of the outer space. This would be an inanimate engine which, to all evidence, would be cooling a portion of the medium below the temperature of the surrounding, and operating by the beat abstracted.

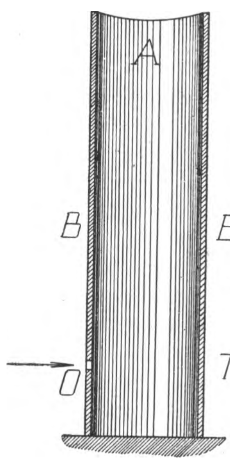


Diagram b. OBTAINING ENERGY FROM THE AMBIENT MEDIUM.

A, medium with little energy; *B, B,* ambient medium with much energy; *O,* path of the energy.

But was it not possible to realize a similar condition without necessarily going to a height? Conceive, for the sake of illustration, aft inclosure *T,* as illustrated in diagram *b,* such that energy could not be transferred across it except through a channel or path *O,* and that, by some means or other, in this inclosure a medium were maintained which would have little energy, and that on the outer side of the same there would be the ordinary ambient medium with much energy. Under these assumptions the energy would flow through the path *O,* as indicated by the arrow, and might then be converted on its passage into some other form of energy. The question was, Could such a condition be attained? Could we produce artificially such a "sink" for the energy of the ambient medium to flow in? Suppose that an extremely low temperature could be maintained by some process in a given space; the surrounding medium would then be compelled to give off heat, which could be converted into mechanical or other form of energy, and utilized. By realizing such a plan, we should be enabled to get at any point of the globe a continuous supply of energy, day and night. More than this, reasoning in the abstract, it would seem possible to cause a quick circulation of the medium, and thus draw the energy at a very rapid rate.

Here, then, was an idea which, if realizable, afforded a happy solution of the problem of getting energy from the medium. But was it realizable? I convinced myself that it was so in a number of ways, of which one is the following. As regards heat, we are at a high level, which may be represented by the surface of a mountain lake considerably above the sea, the level of which may mark the absolute zero of temperature existing in the interstellar space. Heat, like water, flows from high to low level, and, consequently, just as we can let the water of the lake run down to the sea, so we are able to let heat from the earth's surface travel up into the cold region above. Heat, like water, can perform work in flowing down, and if we had any doubt as to whether we could derive energy from the medium by means of a thermopile, as before described, it would be dispelled by this analogue. But can we produce cold in a given portion of the space and cause the heat to flow in continually? To create such a "sink", or "cold hole", as we might say, in the medium, would be equivalent to producing in the lake a space either empty or filled with something much lighter than water. This we could do by placing in the lake a tank, and pumping all the water out of the latter. We know, then, that the water, if allowed to flow back into the tank, would, theoretically, be able to perform exactly the same amount of work which was used in pumping it out, but not a bit more. Consequently nothing could be gained in this double operation of first raising the water and then letting it fall down. This would mean that it is impossible to create such a sink in the medium. But let us reflect a moment. Heat, though following certain general laws of mechanics, like a fluid, is not such; it is energy which may be converted into other forms of energy as it passes from a high to a low level. To make our mechanical analogy complete and true, we must, therefore, assume that the water, in its passage into the tank, is converted into something else, which may be taken out of it without using any, or by using very little, power. For example, if heat be represented in this analogue by the water of the lake, the oxygen and hydrogen composing the water may illustrate other forms of energy into which the heat is transformed in passing from hot to cold. If the process of heat-transformation were absolutely perfect, no heat at all would arrive at the low level, since all of it would be converted into other forms of energy. Corresponding to this ideal case, all the water flowing into the tank would be decomposed into oxygen and hydrogen before reaching the bottom, and the result would be that water would continually flow in, and yet the tank would remain entirely empty, the gases formed escaping. We would thus produce, by expending initially a certain amount of work to create a sink for the heat or, respectively, the water to flow in, a condition enabling us to get any amount of energy without further effort. This would be an ideal way of obtaining motive power. We do not know of any such absolutely perfect process of heat-conversion, and consequently some heat will generally reach the low level, which means to say, in our mechanical analogue, that some water will arrive at the bottom of the tank, and a gradual and slow filling of the latter will take place, necessitating continuous pumping out. But evidently there will be less to pump out than flows, in, or, in other words, less energy will be needed to maintain the initial condition than is developed by the fall, and this is to say that some energy will be gained from the medium. What is not converted in flowing down can just be raised up with its own energy, and what is converted is clear gain. Thus the virtue of the principle I have discovered resides wholly in the conversion of the energy on the downward flow.

FIRST EFFORTS TO PRODUCE THE SELF-ACTING ENGINE — THE MECHANICAL OSCILLATOR — WORK OF DEWAR AND LINDE — LIQUID AIR

Having recognized this truth, I began to devise means for carrying out my idea, and, after long thought, I finally conceived a combination of apparatus which should make possible the obtaining of power from the medium by a process of continuous cooling of atmospheric air. This apparatus, by continually transforming heat into mechanical work, tended to become colder and colder, and if it only were practicable to reach a very low temperature in this manner, then a sink for the heat could be produced, and energy could be derived from the medium. This seemed to be contrary to the statements of Carnot and Lord Kelvin before referred to, but I concluded from the theory of the process that such a result could be attained. This conclusion I reached, I think, in the latter part of 1883, when I was in Paris, and it was at a time when my mind was being more and more dominated by an invention which I had evolved during the preceding year, and which has since become known under the name of the "rotating magnetic field". During the few years which followed I elaborated further the plan I had imagined, and studied the working conditions, but made little headway. The commercial introduction in this country of the invention before referred to required most of my energies until 1889, when I again took up the idea of the self-acting machine. A closer investigation of the principles involved, and calculation, now showed that the result I aimed at could not be reached in a practical manner by ordinary machinery, as I had in the beginning expected. This led me, as a next step, to the study of a type of engine generally designated as "turbine", which at first seemed to offer better chances for a realization of the idea. Soon I found, however, that the turbine, too, was unsuitable. But my conclusions showed that if an engine of a peculiar kind could be brought to a high degree of perfection, the plan I had conceived was realizable, and I resolved to proceed with the development of such an engine, the primary object of which was to secure the greatest economy of transformation of heat into mechanical energy. A characteristic feature of the engine was that the work-performing piston was not connected with anything else, but was perfectly free to vibrate at an enormous rate. The mechanical difficulties encountered in the construction of this engine were greater than I had anticipated, and I made slow progress. This work was continued until early in 1892, when I went to London, where I saw Professor Dewar's admirable experiments with liquefied gases. Others had liquefied gases before, and notably Ozlewski and Pictet had performed creditable early experiments in this line, but there was such a vigor about the work of Dewar that even the old appeared new. His experiments showed, though in a way different from that I had imagined, that it was possible to reach a very low temperature by transforming heat into mechanical work, and I returned, deeply impressed with what I had seen, and more than ever convinced that my plan was practicable. The work temporarily interrupted was taken up anew, and soon I had in a fair state of perfection the engine which I have named "the mechanical oscillator". In this machine I succeeded in doing away with all packings, valves, and lubrication, and in producing so rapid a vibration of the piston that shafts of tough steel, fastened to the same and vibrated longitudinally, were torn asunder. By combining this engine with a dynamo of special design I produced a highly efficient electrical generator, invaluable in measurements and determinations of physical quantities on account of the unvarying rate of oscillation obtainable by its means. I exhibited several types of this machine, named "mechanical and electrical oscillator", before the Electrical Congress at the World's Fair in Chicago during the summer of 1893, in a lecture which, on account of other pressing work, I was unable to prepare for publication. On that occasion I exposed the principles of the mechanical oscillator, but the original purpose of this machine is explained here for the first time.

In the process, as I had primarily conceived it, for the utilization of the energy of the ambient medium, there were five essential elements in combination, and each of these had to be newly designed and perfected, as no such machines existed. The mechanical oscillator was the first element of this combination, and having perfected this, I turned to the next, which was an air-compressor of a design in certain respects resembling that of the mechanical oscillator. Similar difficulties in the construction were again encountered, but the work was pushed vigorously, and at the close of 1894

I had completed these two elements of the combination, and thus produced an apparatus for compressing air, virtually to any desired pressure, incomparably simpler, smaller, and more efficient than the ordinary. I was just beginning work on the third element, which together with the first two would give a refrigerating machine of exceptional efficiency and simplicity, when a misfortune befell me in the burning of my laboratory, which crippled my labors and delayed me. Shortly afterwards Dr. Carl Linde announced the liquefaction of air by a self-cooling process, demonstrating that it was practicable to proceed with the cooling until liquefaction of the air took place. This was the only experimental proof which I was still wanting that energy was obtainable from the medium in the manner contemplated by me.

The liquefaction of air by a self-cooling process was not, as popularly believed, an accidental discovery, but a scientific result which could not have been delayed much longer, and which, in all probability, could not have escaped Dewar. This fascinating advance, I believe, is largely due to the powerful work of this great Scotchman. Nevertheless, Linde's is an immortal achievement. The manufacture of liquid air has been carried on for four years in Germany, on a scale much larger than in any other country, and this strange product has been applied for a variety of purposes. Much was expected of it in the beginning, but so far it has been an industrial ignis fatuus. By the use of such machinery as I am perfecting, its cost will probably be greatly lessened, but even then its commercial success will be questionable. When used as a refrigerant it is uneconomical, as its temperature is unnecessarily low. It is as expensive to maintain a body at a very low temperature as it is to keep it very hot; it takes coal to keep air cold. In oxygen manufacture it cannot yet compete with the electrolytic method. For use as an explosive it is unsuitable, because its low temperature again condemns it to a small efficiency, and for motive-power purposes its cost is still by far too high. It is of interest to note, however, that in driving an engine by liquid air a certain amount of energy may be gained from the engine, or, stated otherwise, from the ambient medium which keeps the engine warm, each two hundred pounds of ironcasting of the latter contributing energy at the rate of about one effective horse-power during one hour. But this gain of the consumer is offset by an equal loss of the producer.

Much of this task on which I have labored so long remains to be done. A number of mechanical details are still to be perfected and some difficulties of a different nature to be mastered, and I cannot hope to produce a self-acting machine deriving energy from the ambient medium for a long time yet, even if all my expectations should materialize. Many circumstances have occurred which have retarded my work of late, but for several reasons the delay was beneficial.

One of these reasons was that I had ample time to consider what the ultimate possibilities of this development might be. I worked for a long time fully convinced that the practical realization of this method of obtaining energy from the sun would be of incalculable industrial value, but the continued study of the subject revealed the fact that while it will be commercially profitable if my expectations are well founded, it will not be so to an extraordinary degree.

DISCOVERY OF UNEXPECTED PROPERTIES OF THE ATMOSPHERE — STRANGE EXPERIMENTS — TRANSMISSION OF ELECTRICAL ENERGY THROUGH ONE WIRE WITHOUT RETURN — TRANSMISSION THROUGH THE EARTH WITHOUT ANY WIRE

Another of these reasons was that I was led to recognize the transmission of electrical energy to any distance through the media as by far the best solution of the great problem of harnessing the sun's energy for the uses of man. For a long time I was convinced that such a transmission on an industrial scale could never be realized, but a discovery which I made changed my view. I observed that under certain conditions the atmosphere, which is normally a high insulator, assumes conducting properties, and so becomes capable of conveying any amount of electrical energy. But the difficulties in the way of a practical utilization of this discovery for the purpose of transmitting electrical energy without wires were seemingly insuperable. Electrical pressures of many millions of volts had to be produced and handled; generating apparatus of a novel kind, capable of withstanding the immense electrical stresses, had to be invented and perfected, and a complete safety against the dangers of the high-tension currents had to be attained in the system before its practical introduction could be even thought of. All this could not be done in a few weeks or months, or even years. The work required patience and constant application, but the improvements came, though slowly. Other valuable results were, however, arrived at in the course of this long-continued work, of which I shall endeavor to give a brief account, enumerating the chief advances as they were successively effected.

The discovery of the conducting properties of the air, though unexpected, was only a natural result of experiments in a special field which I had carried on for some years before. It was, I believe, during 1889 that certain possibilities offered by extremely rapid electrical oscillations determined me to design a number of special machines adapted for their investigation. Owing to the peculiar requirements, the construction of these machines was very difficult, and consumed much time and effort; but my work on them was generously rewarded, for I reached by their means several novel and important results. One of the earliest observations I made with these new machines was that electrical oscillations of an extremely high rate act in an extraordinary manner upon the human organism. Thus, for instance, I demonstrated that powerful electrical discharges of several hundred thousand volts, which at that time were considered absolutely deadly, could be passed through the body without inconvenience or hurtful consequences. These oscillations produced other specific physiological effects, which, upon my announcement, were eagerly taken up by skilled physicians and further investigated. This new field has proved itself fruitful beyond expectation, in the few years which have passed since, it has been developed to such an extent that it now forms a legitimate and important department of medical science. Many results, thought impossible at that time, are now readily obtainable with these oscillations, and many experiments undreamed of then can now be readily performed by their means. I still remember with pleasure how, nine years ago, I passed the discharge of a powerful induction-coil through my body to demonstrate before a scientific society the comparative harmlessness of very rapidly vibrating electric currents, and I can still recall the astonishment of my audience. I would now undertake, with much less apprehension than I had in that experiment, to transmit through my body with such currents the entire electrical energy of the dynamos now working at Niagara — forty or fifty thousand horse-power. I have produced electrical oscillations which were of such intensity that when circulating through my arms and chest they have melted wires which joined my hands, and still I felt no inconvenience. I have energized with such oscillations a loop of heavy copper wire so powerfully that masses of metal, and even objects of an electrical resistance specifically greater than that of human tissue, brought close to or placed within the loop, were heated to a high temperature and melted, often with the violence of an explosion, and yet into this very space in which this terribly destructive turmoil was going on I have repeatedly thrust my head without feeling anything or experiencing injurious after-effects.

Another observation was that by means of such oscillations light could be produced in a novel and more economical manner, which promised to lead to an ideal system of electric illumination by vacuum-tubes, dispensing with the necessity of renewal of lamps or incandescent filaments, and possibly also with the use of wires in the interior of buildings. The efficiency of this light increases in proportion to the rate of the oscillations, and its commercial success is, therefore, dependent on the economical production of electrical vibrations of transcending rates. In this direction I have met with gratifying success of late, and the practical introduction of this new system of illumination is not far off.

The investigations led to many other valuable observations and results, one of the more important of which was the demonstration of the practicability of supplying electrical energy through one wire without return. At first I was able to transmit in this novel manner only very small amounts of electrical energy, but in this line also my efforts have been rewarded with similar success.

The photograph shown in Fig. 3 illustrates, as its title explains, an actual transmission of this kind effected with apparatus used in other experiments here described. To what a degree the appliances have been perfected since my first demonstrations early in 1891 before a scientific society, when my apparatus was barely capable of lighting one lamp (which result was considered wonderful), will appear when I state that I have now no difficulty in lighting in this manner four or five hundred lamps, and could light many more. In fact, there is no limit to the amount of energy which may in this way be supplied to operate any kind of electrical device.

After demonstrating the practicability of this method of transmission, the thought naturally occurred to me to use the earth as a conductor, thus dispensing with all wires. Whatever electricity may be, it is a fact that it behaves like an incompressible fluid, and the earth may be looked upon as an immense reservoir of electricity, which, I thought, could be disturbed effectively by a properly designed electrical machine. Accordingly, my next efforts were directed toward perfecting a special apparatus which would be highly effective in creating a disturbance of electricity in the earth. The progress in this new direction was necessarily very slow and the work discouraging, until I finally succeeded in perfecting a novel kind of transformer or induction-coil, particularly suited for this special purpose. That it is practicable, in this manner, not only to transmit minute amounts of electrical energy for operating delicate electrical devices, as I contemplated at first, but also electrical energy in appreciable quantities, will appear from an inspection of Fig. 4, which illustrates an actual experiment of this kind performed with the same apparatus. The result obtained was all the more remarkable as the top end of the coil was not connected to a wire or plate for magnifying the effect.

"WIRELESS" TELEGRAPHY — THE SECRET OF TUNING — ERRORS IN THE HERTZIAN INVESTIGATIONS — A RECEIVER OF WONDERFUL SENSITIVENESS

As the first valuable result of my experiments in this latter line a system of telegraphy without wires resulted, which I described in two scientific lectures in February and March, 1893. It is mechanically illustrated in diagram *c*, the upper part of which shows the electrical arrangement as I described it then, while the lower part illustrates its mechanical analogue. The system is extremely simple in principle. Imagine two tuning-forks F, F_1, one at the sending and the other at the receiving-station respectively, each having attached to its lower prong a minute piston *p,* fitting in a cylinder. Both the cylinders communicate with a large reservoir *R,* with elastic walls, which is supposed to be closed and filled with a light and incompressible fluid. By striking repeatedly one of the prongs of the tuning-fork *F,* the small piston *p* below would be vibrated, and its vibrations, transmitted through the fluid, would reach the distant fork F_1, which is "tuned" to the fork *F*, or stated otherwise, of exactly the same note as the latter. The fork F_1 would now be set vibrating, and its vibration would be intensified by the continued action of the distant fork F until its upper prong, swinging far out, would make an electrical connection with a stationary contact *c*", starting in this manner some electrical or other appliances which may be used for recording the signals. In this simple way messages could be exchanged between the two stations, a similar contact *c*' being provided for this purpose, close to the upper prong of the fork F, so that the apparatus at each station could be employed in turn as receiver and transmitter.

The electrical system illustrated in the upper figure of diagram *c* is exactly the same in principle, the two wires or circuits *ESP* and $E_1S_1P_1$, which extend vertically to a height, representing the two tuning-forks with the pistons attached to them. These circuits

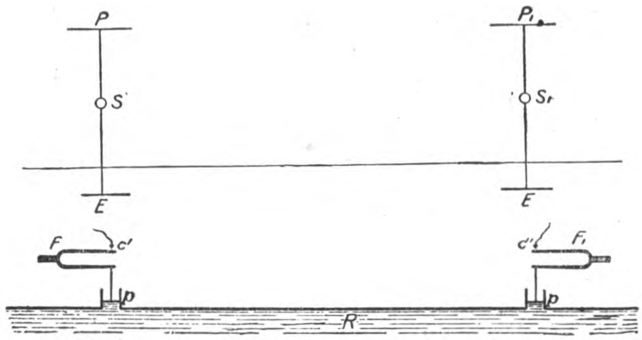


Diagram c. "WIRELESS" TELEGRAPHY MECHANICALLY ILLUSTRATED.

are connected with the ground by plates E, E_1, and to two elevated metal sheets P, P_1, which store electricity and thus magnify considerably the effect. The closed reservoir *R,* with elastic walls, is in this case replaced by the earth, and the fluid by electricity. Both of these circuits are "tuned" and operate just like the two tuning-forks. Instead of striking the fork F at the sending-station, electrical oscillations are produced in the vertical sending- or transmitting-wire *ESP,* as by the action of a source *S,* included in this wire, which spread through the ground and reach the distant vertical receiving-wire $E_1S_1P_1$, exciting corresponding electrical oscillations in the same. In the latter wire or circuit is included a sensitive device or receiver S_1, which is thus set in action and made to operate a relay or other appliance. Each station is, of course, provided both with a source of electrical oscillations S and a sensitive receiver S_1, and a simple provision is made for using each of the two wires alternately to send and to receive the messages.

The exact attunement of the two circuits secures great advantages, and, in fact, it is essential in the practical use of the system. In this respect many popular errors exist, and, as a rule, in the technical reports on this subject circuits and appliances are described as affording these advantages when from their very nature it is evident that this is impossible. In order to attain the best results it is essential that the length of each wire or circuit, from the ground connection to the top, should be equal to one quarter of the wave-length of the electrical vibration in the wire, or else equal to that length multiplied by an odd number. Without the observation of this rule it is virtually impossible to prevent the interference and insure the privacy of messages. Therein lies the secret of tuning. To obtain the most satisfactory results it is, however, necessary to resort to electrical vibrations of low pitch. The Hertzian spark apparatus, used generally by experimenters, which produces oscillations of a very high rate, permits no effective tuning, and slight disturbances are sufficient to render an exchange of messages impracticable. But scientifically designed, efficient appliances allow nearly perfect adjustment. An experiment performed with the improved apparatus repeatedly referred to, and intended to convey an idea of this feature, is illustrated in Fig. 5, which is sufficiently explained by its note.

Since I described these simple principles of telegraphy without wires I have had frequent occasion to note that the identical features and elements have been used, in the evident belief that the signals are being transmitted to considerable distances by "Hertzian" radiations. This is only one of many misapprehensions to which the investigations of the lamented physicist have given rise. About thirty-three years ago Maxwell, following up a suggestive experiment made by Faraday in 1845, evolved an ideally simple theory which intimately connected light, radiant heat, and electrical phenomena, interpreting them as being all due to vibrations of a hypothetical fluid of inconceivable tenuity, called the ether. No experimental verification was arrived at until Hertz, at the suggestion of Helmholtz, undertook a series of experiments to this effect. Hertz proceeded with extraordinary ingenuity and insight, but devoted little energy to the perfection of his old-fashioned apparatus. The consequence was that he failed to observe the important function which the air played in his experiments, and which I subsequently discovered. Repeating his experiments and reaching different results, I ventured to point out this oversight. The strength of the proofs brought forward by Hertz in support of Maxwell's theory resided in the correct estimate of the rates of vibration of the circuits he used. But I ascertained that he could not have obtained the rates he thought he was getting. The vibrations with identical apparatus he employed are, as a rule, much slower, this being due to the presence of air, which produces a dampening effect upon a rapidly vibrating electric circuit of high pressure, as a fluid does upon a vibrating tuning-fork. I have, however, discovered since that time other causes of error, and I have long ago ceased to look upon his results as being an experimental verification of the poetical conceptions of Maxwell. The work of the great German physicist has acted as an immense stimulus to contemporary electrical research, but it has likewise, in a measure, by its fascination, paralyzed the scientific mind, and thus hampered independent inquiry. Every new phenomenon which was discovered was made to fit the theory, and so very often the truth has been unconsciously distorted.

When I advanced this system of telegraphy, my mind was dominated by the idea of effecting communication to any distance through the earth or environing medium, the practical consummation of which I considered of transcendent importance, chiefly on account of the moral effect which it could not fail to produce universally. As the first effort to this end I proposed, at that time, to employ relay-stations with tuned circuits, in the hope of making thus practicable signaling over vast distances, even with apparatus of very moderate power then at my command. I was confident, however, that with properly designed machinery signals could be transmitted to any point of the globe, no matter what the distance, without the necessity of using such intermediate stations. I gained this conviction through the discovery of a singular electrical phenomenon, which I described early in 1892, in lectures delivered before some scientific societies abroad, and which I have called a "rotating brush". This is a bundle of light which is formed, under certain conditions, in a vacuum-bulb, and which is of a sensitiveness to magnetic and electric influences bordering, so to speak, on the supernatural. This light-bundle is rapidly rotated by the earth's magnetism as many as twenty thousand times per second, the rotation in these parts being opposite to what it would be in the southern hemisphere, while in the region of the magnetic equator it should not rotate at all. In its most sensitive state, which is difficult to attain, it is responsive to electric or magnetic influences to an incredible degree. The mere stiffening of the muscles of the arm and consequent slight electrical change in the body of an observer standing at some distance from it, will perceptibly affect it. When in this highly sensitive state it is capable of indicating the slightest magnetic and electric changes taking place in the earth. The observation of this wonderful phenomenon impressed me strongly that communication at any distance could be easily effected by its means, provided that apparatus could be perfected capable of producing an electric or magnetic change of state, however small, in the terrestrial globe or environing medium.

DEVELOPMENT OF A NEW PRINCIPLE — THE ELECTRICAL OSCILLATOR — PRODUCTION OF IMMENSE ELECTRICAL MOVEMENTS — THE EARTH RESPONDS TO MAN — INTERPLANETARY COMMUNICATION NOW PROBABLE

I resolved to concentrate my efforts upon this venturesome task, though it involved great sacrifice, for the difficulties to be mastered where such that I could hope to consummate it only after years of labor. It meant delay of other work to which I would have preferred to devote myself, but I gained the conviction that my energies could not be more usefully employed; for I recognized that an efficient apparatus for the production of powerful electrical oscillations, as was needed for that specific purpose, was the key to the solution of other most important electrical and, in fact, human problems. Not only was communication, to any distance, without wires possible by its means, but, likewise, the transmission of energy in great amounts, the burning of the atmospheric nitrogen, the production of an efficient illuminant, and many other results of inestimable scientific and industrial value. Finally, however, I had the satisfaction of accomplishing the task undertaken by the use of a new principle, the virtue of which is based on the marvelous properties of the electrical condenser. One of these is that it can discharge or explode its stored energy in an inconceivably short time. Owing to this it is unequaled in explosive violence. The explosion of dynamite is only the breath of a consumptive compared with its discharge. It is the means of producing the strongest current, the highest electrical pressure, the greatest commotion in the medium. Another of its properties, equally valuable, is that its discharge may vibrate at any rate desired up to many millions per second.

I had arrived at the limit of rates obtainable in other ways when the happy idea presented itself to me to resort to the condenser. I arranged such an instrument so as to be charged and discharged alternately in rapid succession through a coil with a few turns of stout wire, forming the primary of a transformer of induction-coil. Each time the condenser was discharged the current would quiver in the primary wire and induce corresponding oscillations in the secondary. Thus a transformer or induction-coil on new principles was evolved, which I have called "the electrical oscillator", partaking of those unique qualities which characterize the condenser, and enabling results to be attained impossible by other means. Electrical effects of any desired character and of intensities undreamed of before are now easily producible by perfected apparatus of this kind, to which frequent reference has been made, and the essential parts of which are shown in Fig. 6. For certain purposes a strong inductive effect is required; for others the greatest possible suddenness; for others again, an exceptionally high rate of vibration or extreme pressure; while for certain other objects immense electrical movements are necessary. The photographs in Figs. 7, 8, 9, and 10, of experiments performed with such an oscillator, may serve to illustrate some of these features and convey an idea of the magnitude of the effects actually produced. The completeness of the titles of the figures referred to makes a further description of them unnecessary.

However extraordinary the results shown may appear, they are but trifling compared with those which are attainable by apparatus designed on these same principles. I have produced electrical discharges the actual path of which, from end to end, was probably more than one hundred feet long; but it would not be difficult to reach lengths one hundred times as great. I have produced electrical movements occurring at the rate of approximately one hundred thousand horse-power, but rates of one, five, or ten million horse-power are easily practicable. In these experiments effects were developed incomparably greater than any ever produced by human agencies, and yet these results are but an embryo of what is to be.

That communication without wires to any point of the globe is practicable with such apparatus would need no demonstration, but through a discovery which I made I obtained absolute certitude. Popularly explained, it is exactly this: When we raise the voice and hear an echo in reply, we know that the sound of the voice must have reached a distant wall, or boundary, and must have been reflected from the same. Exactly as the sound, so an electrical wave is reflected, and the same evidence which is afforded by an echo is offered by an electrical phenomenon known as a "stationary" wave — that is, a wave with fixed nodal and ventral regions. Instead of sending sound-vibrations toward a distant wall, I have sent electrical vibrations toward the remote boundaries of the earth, and instead of the wall the earth has replied. In place of an echo I have obtained a stationary electrical wave, a wave reflected from afar.

Stationary waves in the earth mean something more than mere telegraphy without wires to any distance. They will enable us to attain many important specific results impossible otherwise. For instance, by their use we may produce at will, from a sending-station, an electrical effect in any particular region of the globe; we may determine the relative position or course of a moving object, such as a vessel at sea, the distance traversed by the same, or its speed; or we may send over the earth a wave of electricity traveling at any rate we desire, from the pace of a turtle up to lightning speed.

With these developments we have every reason to anticipate that in a time not very distant most telegraphic messages across the oceans will be transmitted without cables. For short distances we need a "wireless" telephone, which requires no expert operators. The greater the spaces to be bridged, the more rational becomes communication without wires. The cable is not only an easily damaged and costly instrument, but it limits us in the speed of transmission by reason of a certain electrical property inseparable from its construction. A properly designed plant for effecting communication without wires ought to have many times the working capacity of a cable, while it will involve incomparably less expense. Not a long time will pass, I believe, before communication by cable will become obsolete, for not only will signaling by this new method be quicker and cheaper, but also much safer. By using some new means for isolating the messages which I have contrived, an almost perfect privacy can be secured.

I have observed the above effects so far only up to a limited distance of about six hundred miles, but inasmuch as there is virtually no limit to the power of the vibrations producible with such an oscillator, I feel quite confident of the success of such a plant for effecting transoceanic communication. Nor is this all. My measurements and calculations have shown that it is perfectly practicable to produce on our globe, by the use of these principles, an electrical movement of such magnitude that, without the slightest doubt, its effect will be perceptible on some of our nearer planets, as Venus and Mars. Thus from mere possibility interplanetary communication has entered the stage of probability. In fact, that we can produce a distinct effect on one of these planets in this novel manner, namely, by disturbing the electrical condition of the earth, is beyond any doubt. This way of effecting such communication is, however, essentially different from all others which have so far been proposed by scientific men. In all the previous instances only a minute fraction of the total energy reaching the planet — as much as it would be possible to concentrate in a reflector — could be utilized by the supposed observer in his instrument. But by the means I have developed he would be enabled to concentrate the larger portion of the entire energy transmitted to the planet in his instrument, and the chances of affecting the latter are thereby increased many millionfold.

Besides machinery for producing vibrations of the required power, we must have delicate means capable of revealing the effects of feeble influences exerted upon the earth. For such purposes, too, I have perfected new methods. By their use we shall likewise be able, among other things, to detect at considerable distance the presence of an iceberg or other object at sea. By their use, also, I have discovered some terrestrial phenomena still unexplained. That we can send a message to a planet is certain, that we can get an answer is probable; man is not the only being in the Infinite gifted with a mind.

TRANSMISSION OF ELECTRICAL ENERGY TO ANY DISTANCE WITHOUT WIRES — NOW PRACTICABLE — THE BEST MEANS OF INCREASING THE FORCE ACCELERATING THE HUMAN MASS

The most valuable observation made in the course of these investigations was the extraordinary behavior of the atmosphere toward electric impulses of excessive electromotive force. The experiments showed that the air at the ordinary pressure became distinctly conducting, and this opened up the wonderful prospect of transmitting large amounts of electrical energy for industrial purposes to great distances without wires, a possibility which, up to that time, was thought of only as a scientific dream. Further investigation revealed the important fact that the conductivity imparted to the air by these electrical impulses of many millions of volts increased very rapidly with the degree of rarefaction, so that air strata at very moderate altitudes, which are easily accessible, offer, to all experimental evidence, a perfect conducting path, better than a copper wire, for currents of this character.

Thus the discovery of these new properties of the atmosphere not only opened up the possibility of transmitting, without wires, energy in large amounts, but, what was still more significant, it afforded the certitude that energy could be transmitted in this manner economically. In this new system it matters little — in fact, almost nothing — whether the transmission is effected at a distance of a few miles or of a few thousand miles.

While I have not, as yet, actually effected a transmission of a considerable amount of energy, such as would be of industrial importance, to a great distance by this new method, I have operated several model plants under exactly the same conditions which will exist in a large plant of this kind, and the practicability of the system is thoroughly demonstrated. The experiments have shown conclusively that, with two terminals maintained at an elevation of not more than thirty thousand to thirty-five thousand feet above sea-level, and with an electrical pressure of fifteen to twenty million volts, the energy of thousands of horse-power can be transmitted over distances which may be hundreds and, if necessary, thousands of miles. I am hopeful, however, that I may be able to reduce very considerably the elevation of the terminals now required, and with this object I am following up an idea which promises such a realization. There is, of course, a popular prejudice against using an electrical pressure of millions of volts, which may cause sparks to fly at distances of hundreds of feet, but, paradoxical as it may seem, the system, as I have described it in a technical publication, offers greater personal safety than most of the ordinary distribution circuits now used in the cities. This is, in a measure, borne out by the fact that, although I have carried on such experiments for a number of years, no injury has been sustained either by me or any of my assistants.

But to enable a practical introduction of the system, a number of essential requirements are still to be fulfilled. It is not enough to develop appliances by means of which such a transmission can be effected. The machinery must be such as to allow the transformation and transmission of electrical energy under highly economical and practical conditions. Furthermore, an inducement must be offered to those who are engaged in the industrial exploitation of natural sources of power, as waterfalls, by guaranteeing greater returns on the capital invested than they can secure by local development of the property.

From that moment when it was observed that, contrary to the established opinion, low and easily accessible strata of the atmosphere are capable of conducting electricity, the transmission of electrical energy without wires has become a rational task of the engineer, and one surpassing all others in importance. Its practical consummation would mean that energy would be available for the uses of man at any point of the globe, not in small amounts such as might be derived from the ambient medium by suitable machinery, but in quantities virtually unlimited, from waterfalls. Export of power would then become the chief source of income for many happily situated countries, as the United States, Canada, Central and South America, Switzerland, and Sweden. Men could settle down everywhere, fertilize and irrigate the soil with little effort, and convert barren deserts into gardens, and thus the entire globe could be transformed and made a fitter abode for mankind. It is highly probable that if there are intelligent beings on Mars they have long ago realized this very idea, which would explain the changes on its surface noted by astronomers. The atmosphere on that planet, being of considerably smaller density than that of the earth, would make the task much more easy.

It is probable that we shall soon have a self-acting heat-engine capable of deriving moderate amounts of energy from the ambient medium. There is also a possibility — though a small one — that we may obtain electrical energy direct from the sun. This might be the case if the Maxwellian theory is true, according to which electrical vibrations of all rates should emanate from the sun. I am still investigating this subject. Sir William Crookes has shown in his beautiful invention known as the “radiometer” that rays may produce by impact a mechanical effect, and this may lead to some important revelation as to the utilization of the sun’s rays in novel ways. Other sources of energy may be opened up, and new methods of deriving energy from the sun discovered, but none of these or similar achievements would equal in importance the transmission of power to any distance through the medium. I can conceive of no technical advance which would tend to unite the various elements of humanity more effectively than this one. or of one which would more add to and more economize human energy. It would be the best means of increasing the force accelerating the human mass. The mere moral influence of such a radical departure would be incalculable. On the other hand, if at any point of the globe energy can be obtained in limited quantities from the ambient medium by means of a self-acting heat-engine or otherwise, the conditions will remain the same as before. Human performance will be increased, but men will remain strangers as they were.

I anticipate that many, unprepared for these results, which, through long familiarity, appear to me simple and obvious, will consider them still far from practical application. Such reserve, and even opposition, of some is as useful a quality and as necessary an element in human progress as the quick receptivity and enthusiasm of others. Thus, a mass which resists the force at first, once set in movement, adds to the energy. The scientific man does not aim at an immediate result. He does not expect that his advanced ideas will be readily taken up. His work is like that of the planter — for the future. His duty is to lay foundation for those who are to come, and point the way. He lives and labors and hopes with the poet who says:

Schaff’, das Tagwerk meiner Hände,
Hohes Glück, dass ich’s vollende!
Lass, o lass mich nicht ermatten!

Nein, es sind nicht leere Träume:
Jetzt nur Stangen, diese Bäume
Geben eins noch Frucht und Schatten.[1]

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[1] *Daily work — my hands' employment,*
To complete is pure enjoyment!
Let, oh, let me never falter!
No! there is no empty dreaming:
Lo! these trees, but bare poles seeming,
Yet will yield both fruit and shelter!
Goethe's "*Hope,*"
(Translated by William Gibson)

3

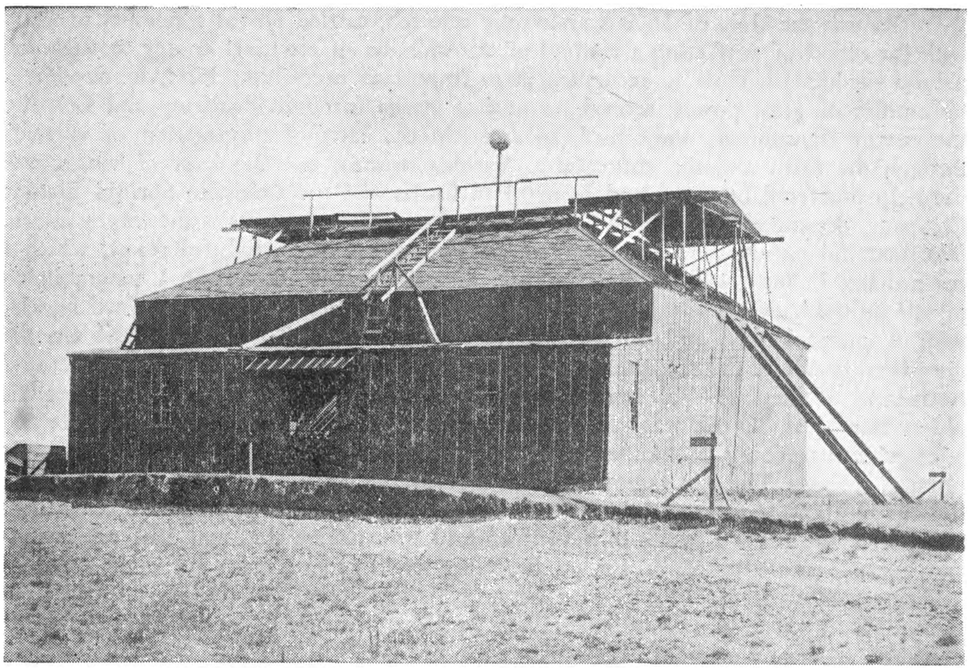
THE TRANSMISSION OF ELECTRIC ENERGY WITHOUT WIRES*

Towards the close of 1898 a systematic research, carried on for a number of years with the object of perfecting a method of transmission of electrical energy through the natural medium, led me to recognize three important necessities; First, to develop a transmitter of great power; second, to perfect means for individualizing and isolating the energy transmitted; and, third, to ascertain the laws of propagation of currents through the earth and the atmosphere. Various reasons, not the least of which was the help proffered by my friend Leonard E. Curtis and the Colorado Springs Electric Company, determined me to select for my experimental investigations the large plateau, two thousand meters above sea-level, in the vicinity of that delightful resort, which I reached late in May, 1899. I had not been there but a few days when I congratulated myself on the happy choice and I began the task, for which I had long trained myself, with a grateful sense and full of inspiring hope. The perfect purity of the air, the unequaled beauty of the sky, the imposing sight of a high mountain range, the quiet and restfulness of the place — all around contributed to make the conditions for scientific observation ideal. To this was added the exhilarating influence of a glorious climate and a singular sharpening of the senses. In those regions the organs undergo perceptible physical changes. The eyes assume an extraordinary limpidity, improving vision; the ears dry out and become more susceptible to sound. Objects can be clearly distinguished there at distances such that I prefer to have them told by someone else, and I have heard — this I can venture to vouch for — the claps of thunder seven and eight hundred kilometers away. I might have done better still, had it not been tedious to wait for the sounds to arrive, in definite intervals, as heralded precisely by an electrical indicating apparatus — nearly an hour before.

In the middle of June, while preparations for other work were going on, I arranged one of my receiving transformers with the view of determining in a novel manner, experimentally, the electric potential of the globe and studying its periodic and casual fluctuations. This formed part of a plan carefully mapped out in advance. A highly sensitive, selfrestorative device, controlling a recording instrument, was included in the secondary circuit, while the primary was connected to the ground and an elevated terminal of adjustable capacity. The variations of potential gave rise to electric surgings in the primary; these generated secondary currents, which in turn affected the sensitive device and recorder in proportion to their intensity. The earth was found to be, literally, alive with electrical vibrations, and soon I was deeply absorbed in this interesting investigation. No better opportunities for such observations as I intended to make could be found anywhere. Colorado is a country famous for the natural displays of electric force. In that dry and rarefied atmosphere the sun's rays beat the objects with fierce intensity. I raised steam, to a dangerous pressure, in barrels filled with concentrated

* The Electrical World and Engineer, March 5, 1904.

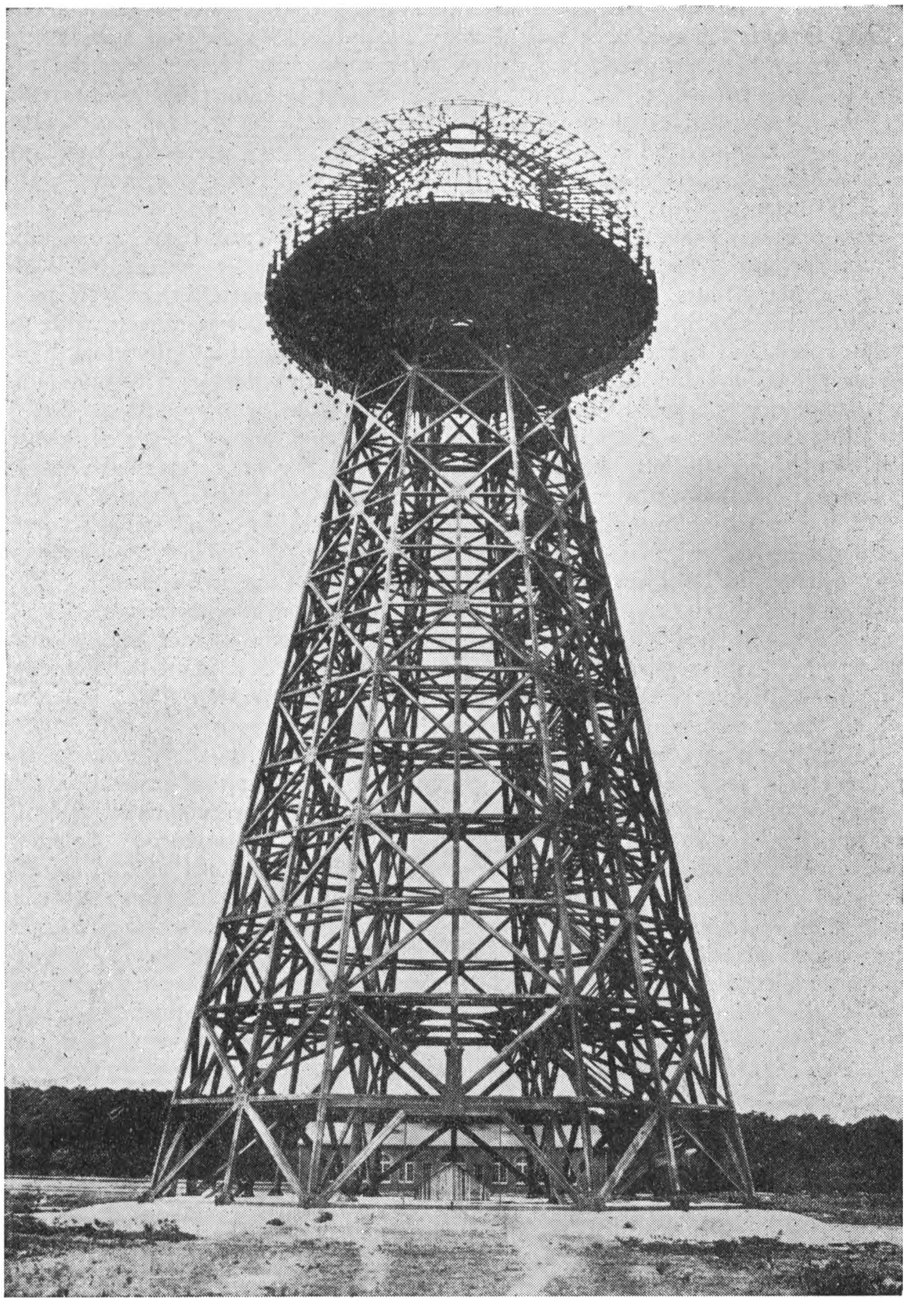
salt solution, and the tin-foil coatings of some of my elevated terminals shriveled up in the fiery blaze. An experimental high-tension transformer, carelessly exposed to the rays of the setting sun, had most of its insulating compound melted out and was rendered useless. Aided by the dryness and rarefaction of the air, the water evaporates as in a boiler, and static electricity is developed in abundance. Lightning discharges are, accordingly, very frequent and sometimes of inconceivable violence. On one occasion approximately twelve thousand discharges occurred in two hours, and all in a radius of certainly less than fifty kilometers from the laboratory. Many of them resembled gigantic trees of fire with the trunks up or down. I never saw fire balls, but as a compensation for my disappointment I succeeded later in determining the mode of their formation and producing them artificially.



Experimental Laboratory, Colorado Springs.

In the latter part of the same month I noticed several times that my instruments were affected stronger by discharges taking place at great distances than by those near by. This puzzled me very much. What was the cause? A number of observations proved that it could not be due to the differences in the intensity of the individual discharges, and I readily ascertained that the phenomenon was not the result of a varying relation between the periods of my receiving circuits and those of the terrestrial disturbances. One night, as I was walking home with an assistant, meditating over these experiences, I was suddenly staggered by a thought. Years ago, when I wrote a chapter of my lecture before the Franklin Institute and the National Electric Light Association, it had presented itself to me, but I had dismissed it as absurd and impossible. I banished it again. Nevertheless, my instinct was aroused and somehow I felt that I was nearing a great revelation.

It was on the third of July — the date I shall never forget — when I obtained the first decisive experimental evidence of a truth of overwhelming importance for the



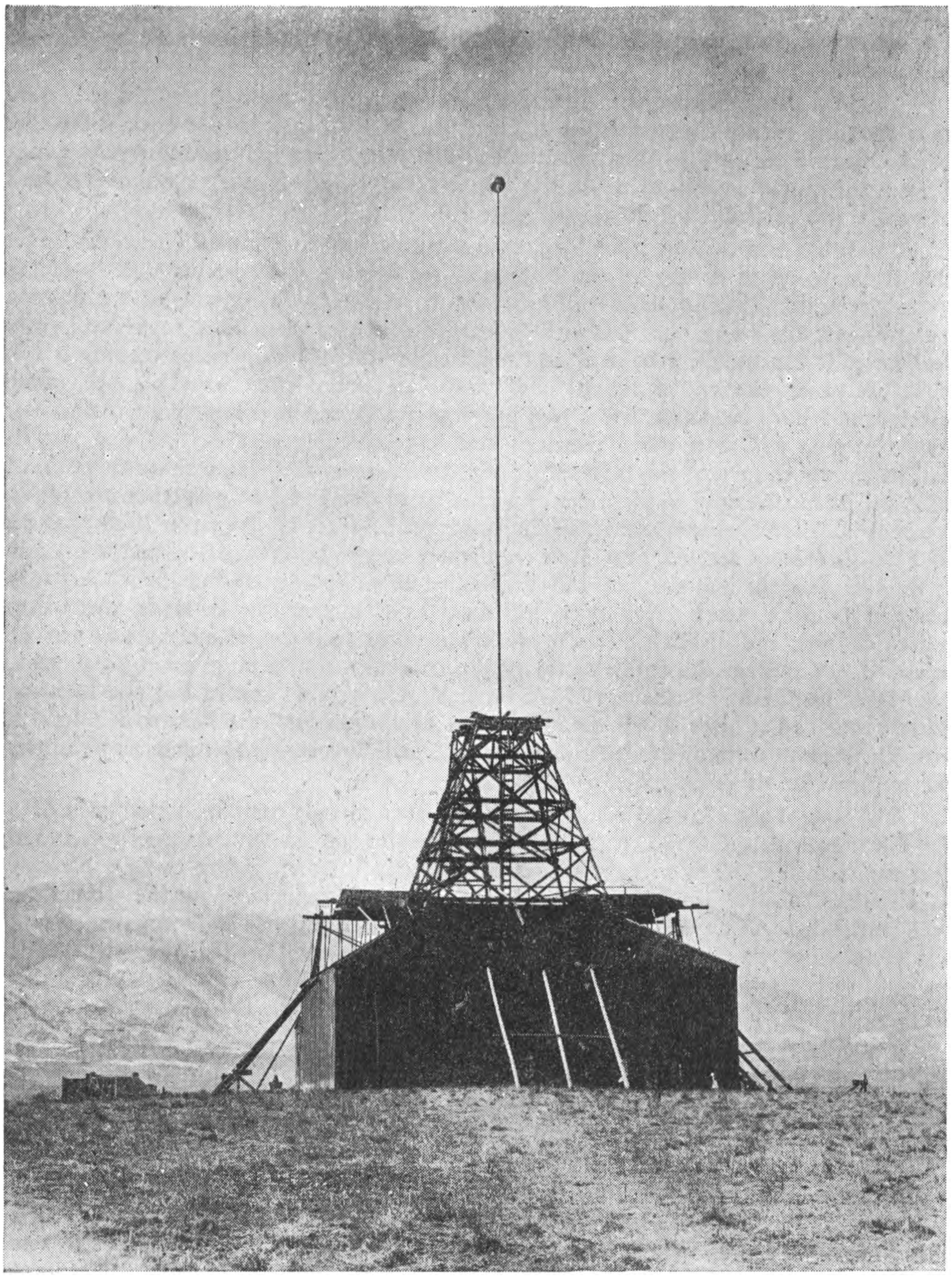
Central Power Plant and Transmitting Tower for “World Telegraphy”,
Long Island, N. Y.

advancement of humanity. A dense mass of strongly charged clouds gathered in the west and towards the evening a violent storm broke loose which, after spending much of its fury in the mountains, was driven away with great velocity over the plains. Heavy and long persisting arcs formed almost in regular time intervals. My observations were now greatly facilitated and rendered more accurate by the experiences already gained. I was able to handle my instruments quickly and I was prepared. The recording apparatus being properly adjusted, its indications became fainter and fainter with the increasing distance of the storm, until they ceased altogether. I was watching in eager expectation. Surely enough, in a little while the indications again began, grew stronger and stronger and, after passing through a maximum, gradually decreased and ceased once more. Many times, in regularly recurring intervals, the same actions were repeated until the storm which, as evident from simple computations, was moving with nearly constant speed, had retreated to a distance of about three hundred kilometers. Nor did these strange actions stop then, but continued to manifest themselves with undiminished force. Subsequently, similar observations were also made by my assistant, Mr. Fritz Lowenstein, and shortly afterward several admirable opportunities presented themselves which brought out, still more forcibly, and unmistakably, the true nature of the wonderful phenomenon. No doubt whatever remained: I was observing stationary waves.

As the source of disturbances moved away the receiving circuit came successively upon their nodes and loops. Impossible as it seemed, this planet, despite its vast extent, behaved like a conductor of limited dimensions. The tremendous significance of this fact in the transmission of energy by my system had already become quite clear to me. Not only was it practicable to send telegraphic messages to any distance without wires, as I recognized long ago, but also to impress upon the entire globe the faint modulations of the human voice, far more still, to transmit power, in unlimited amounts, to any terrestrial distance and almost without any loss.

With these stupendous possibilities in sight, with the experimental evidence before me that their realization was henceforth merely a question of expert knowledge, patience and skill, I attacked vigorously the development of my magnifying transmitter, now, however, not so much with the original intention of producing one of great power, as with the object of learning how to construct the best one. This is, essentially, a circuit of very high self-induction and small resistance which in its arrangement, mode of excitation and action, may be said to be the diametrical opposite of a transmitting circuit typical of telegraphy by Hertzian or electromagnetic radiations. It is difficult to form an adequate idea of the marvelous power of this unique appliance, by the aid of which the globe will be transformed. The electromagnetic radiations being reduced to an insignificant quantity, and proper conditions of resonance maintained, the circuit acts like an immense pendulum, storing indefinitely the energy of the primary exciting impulses and impressions upon the earth and its conducting atmosphere uniform harmonic oscillations of intensities which, as actual tests have shown, may be pushed so far as to surpass those attained in the natural displays of static electricity.

Simultaneously with these endeavors, the means of individualization and isolation were gradually improved. Great importance was attached to this, for it was found that simple tuning was not sufficient to meet the vigorous practical requirements. The fundamental idea of employing a number of distinctive elements, co-operatively associated, for the purpose of isolating energy transmitted, I trace directly to my perusal of Spencer's clear and suggestive exposition of the human nerve mechanism. The influence of this principle on the transmission of intelligence, and electrical energy in general, cannot as yet be estimated, for the art is still in the embryonic stage; but many thousands of simultaneous telegraphic and telephonic messages, through one single conducting channel, natural or artificial, and without serious mutual interference, are certainly practicable, while millions are possible. On the other hand, any desired degree of individualization may be secured by the use of a great number of co-operative



Experimental Laboratory, Colorado Springs.

elements and arbitrary variation of their distinctive features and order of succession. For obvious reasons, the principle will also be valuable in the extension of the distance of transmission.

Progress though of necessity slow was steady and sure, for the objects aimed at were in a direction of my constant study and exercise. It is, therefore, not astonishing that before the end of 1899 I completed the task undertaken and reached the results which I have announced in my article in the *Century Magazine* of June, 1900, every word of which was carefully weighed.

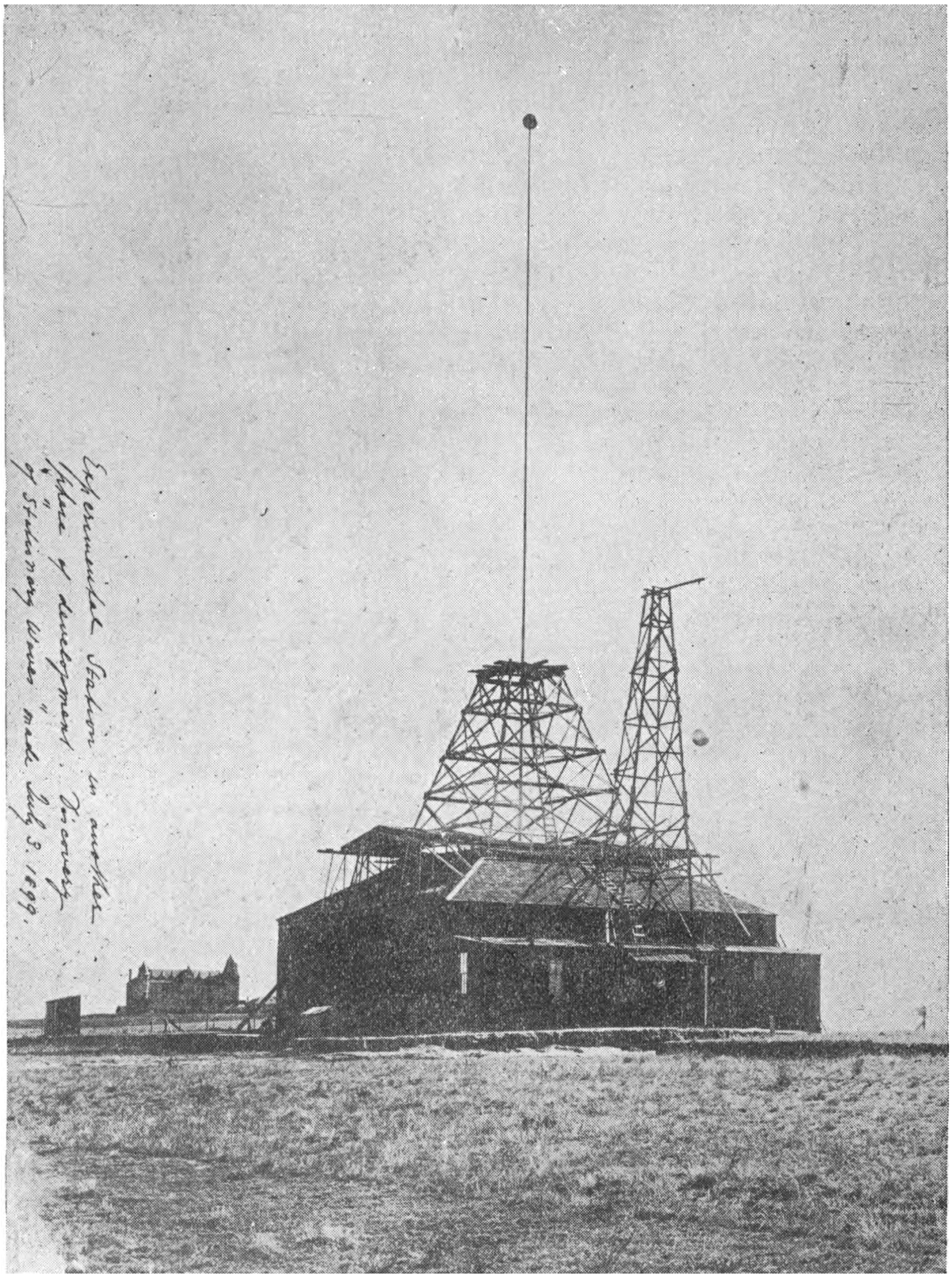
Much has already been done towards making my system commercially available, in the transmission of energy in small amounts for specific purposes, as well as on an industrial scale. The results attained by me have made my scheme of intelligence transmission, for which the name of "World Telegraphy" has been suggested, easily realizable. It constitutes, I believe, in its principle of operation, means employed and capacities of application, a radical and fruitful departure from what has been done heretofore. I have no doubt that it will prove very efficient in enlightening the masses, particularly in still uncivilized countries and less accessible regions, and that it will add materially to general safety, comfort and convenience, and maintenance of peaceful relations. It involves the employment of a number of plants, all of which are capable of transmitting individualized signals to the uttermost confines of the earth. Each of them will be preferably located near some important center of civilization and the news it receives through any channel will be flashed to all points of the globe. A cheap and simple device, which might be carried in one's pocket, may then be set up somewhere on sea or land, and it will record the world's news or such special messages as may be intended for it. Thus the entire earth will be converted into a huge brain, as it were, capable of response in every one of its parts. Since a single plant of but one hundred horse-power can operate hundreds of millions of instruments, the system will have a virtually infinite working capacity, and it must needs immensely facilitate and cheapen the transmission of intelligence.

The first of these central plants would have been already completed had it not been for unforeseen delays which, fortunately, have nothing to do with its purely technical features. But this loss of time, while vexatious, may, after all, prove to be a blessing in disguise. The best design of which I knew has been adopted, and the transmitter will emit a wave complex of a total maximum activity of ten million horse-power, one per cent. of which is amply sufficient to "girdle the globe". This enormous rate of energy delivery, approximately twice that of the combined falls of Niagara, is obtainable only by the use of certain artifices, which I shall make known in due course.

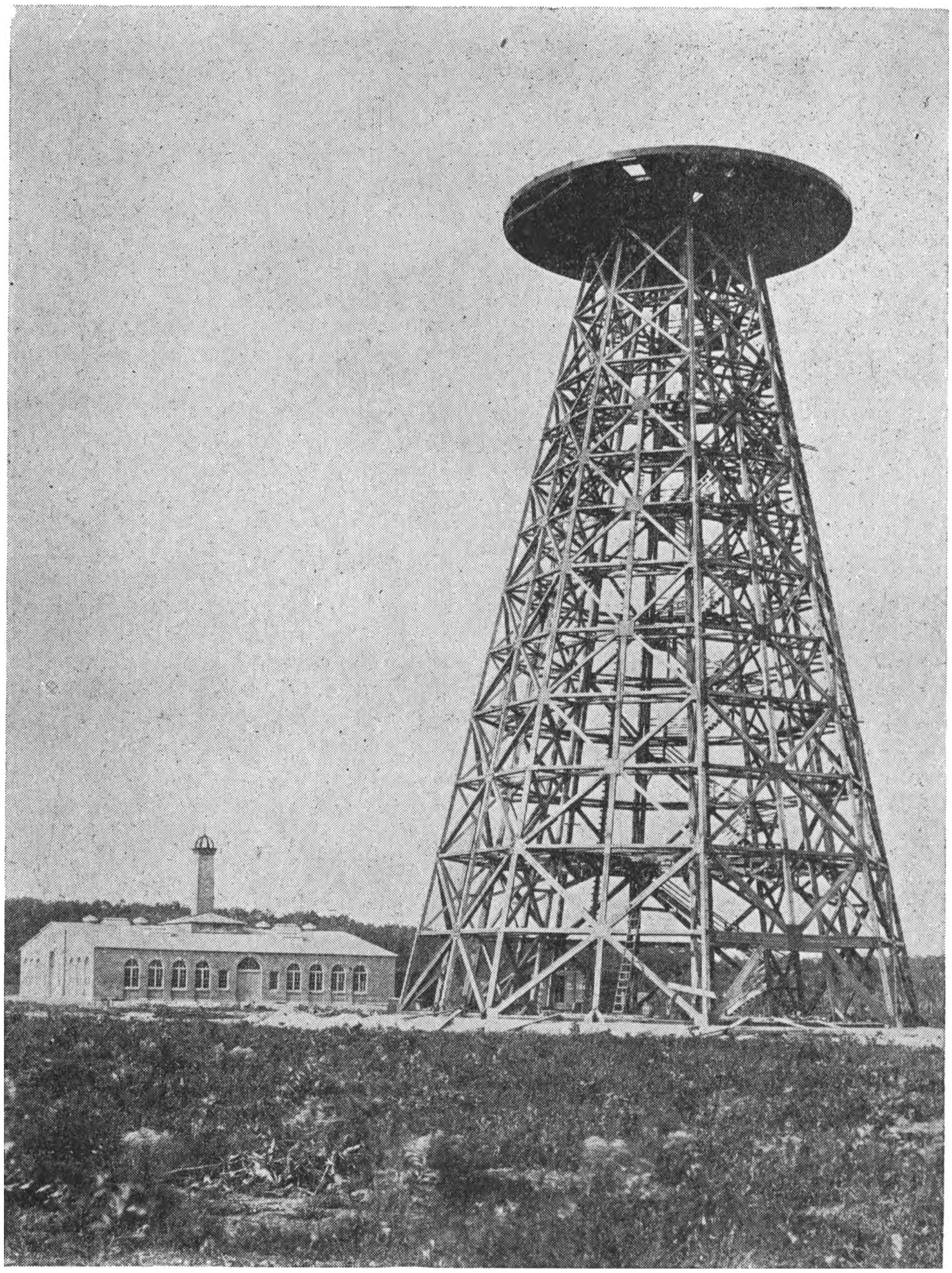
For a large part of the work which I have done so far I am indebted to the noble generosity of Mr. J. Pierpont Morgan, which was all the more welcome and stimulating, as it was extended at a time when those, who have since promised most, were the greatest of doubters. I have also to thank my friend, Stanford White, for much unselfish and valuable assistance. This work is now far advanced, and though the results may be tardy, they are sure to come.

Meanwhile, the transmission of energy on an industrial scale is not being neglected. The Canadian Niagara Power Company have offered me a splendid inducement, and next to achieving success for the sake of the art, it will give me the greatest satisfaction to make their concession financially profitable to them. In this first power plant, which I have been designing for a long time, I propose to distribute ten thousand horse-power under a tension of one hundred million volts, which I am now able to produce and handle with safety.

This energy will be collected all over the globe preferably in small amounts, ranging from a fraction of one to a few horse-power. One of its chief uses will be the illumination of isolated homes. It takes very little power to light a dwelling with



Experimental Laboratory, Colorado, erected Summer of 1899.



Central Power Plant, Transmitting Tower, and Laboratory for "World Telegraphy",
Warderclyffe, Long Island.

vacuum tubes operated by high-frequency currents and in each instance a terminal a little above the roof will be sufficient. Another valuable application will be the driving of clocks and other such apparatus. These clocks will be exceedingly simple, will require absolutely no attention and will indicate rigorously correct time. The idea of impressing upon the earth American time is fascinating and very likely to become popular. There are innumerable devices of all kinds which are either now employed or can be supplied, and by operating them in this manner I may be able to offer a great convenience to the whole world with a plant of no more than ten thousand horse-power. The introduction of this system will give opportunities for invention and manufacture such as have never presented themselves before.

Knowing the far-reaching importance of this first attempt and its effect upon future development, I shall proceed slowly and carefully. Experience has taught me not to assign a term to enterprises the consummation of which is not wholly dependent on my own abilities and exertions. But I am hopeful that these great realizations are not far off, and I know that when this first work is completed they will follow with mathematical certitude.

When the great truth accidentally revealed and experimentally confirmed is fully recognized, that this planet, with all its appalling immensity, is to electric currents virtually no more than a small metal ball and that by this fact many possibilities, each baffling imagination and of incalculable consequence, are rendered absolutely sure of accomplishment; when the first plant is inaugurated and it is shown that a telegraphic message, almost as secret and non-interferable as a thought, can be transmitted to any terrestrial distance, the sound of the human voice, with all its intonations and inflections, faithfully and instantly reproduced at any other point of the globe, the energy of a waterfall made available for supplying light, heat or motive power, anywhere — on sea, or land, or high in the air — humanity will be like an ant heap stirred up with a stick: See the excitement coming!

4

SCIENCE AND DISCOVERY ARE THE GREAT FORCES WHICH WILL LEAD TO THE CONSUMMATION OF THE WAR*

Whatever future ages may have in store for the human race, the development so far would indicate as its probable fate perpetual strife. Civilization alone is evidently insufficient for insuring permanent peace on earth. It but retards the clash to add to its intensity and magnitude, making it all the more dreadful and ruinous.

The present colossal struggle creates an impression apart, a feeling of awe, a sense of solemnity, springing from the knowledge that a terrible calamity, greater than any recorded in the annals of history, has befallen the world. Suddenly awakened from fancied security to the consciousness of insuspected and universal danger, the nations stand aghast. It is as if some vast terrestrial upheaval were taking place, as if gigantic forces were unchained, threatening the entire globe.

Never before were such immense armies engaged in battle and such frightfully destructive implements employed; never was so much dependent on a victory of arms. Already the losses incurred amount to tens of billions of dollars; more than three million men have been killed and disabled, and for each of these ten, at least, have been turned into nervous wrecks, which will impress their miseries on the succeeding generations and darken their days. All the world over countless sufferers, torn by anxiety, ask themselves how long is this appalling slaughter and sacrilegious waste to continue.

War is essentially a manifestation of energy involving the acceleration and retardation of a mass by a force. In such a case it is a universally established truth that the time necessary to impart a given velocity and momentum is proportionate to the mass. The same law also applies to the annihilation of velocity and momentum by a resisting force. Translated in popular language this means that the period or duration of an armed conflict is theoretically proportionate to the magnitude of the armies or number of combatants.

It is obviously assumed that the resources are ample and all other conditions equal. Furthermore, in making deductions from previous wars a number of factors have to be taken into consideration and all quantities estimated at their proper value on the basis of statistical and other data. Supposing that, as it appears, 12,000,000 men are engaged in the present struggle, a comparison with some of the past wars gives the following results:

Wars	Number of Combatants	Duration Y.	Duration M.	Remarks
Civil war	4,600.000	4	. .	Protracted by distance, poor communication and ineffective arms.
Present war	12,000.000	10		
Franco-German war	1,700.000	. .	13	Equipment not quite modern.
Present war	12,000.000	7	6	

* The Sun, Dec. 20, 1914. ("Nikola Tesla looks to Science to end the War")

Russo-Japanese war	2,200.000	1	6	Lengthened by distance, poor communication and nature of campaign.
Present war	12,000.000	8		
First Balkan war	1,200.000	· ·	6	In all respects up to date.
Present war	12,000.000	5		
Hypothetical average war	2,425.000	1	9	Various causes affecting duration.
Present war	12,000.000	8	6	

Much more concordant and shorter terms would be obtained in these comparative estimates if the records available were corrected as indicated and due allowances made for the facilities of transport and communication, increased power and destructiveness of arms and other factors tending to magnify the rate at which energy is delivered, and so to hasten the termination of the clash. The best inference is certainly that drawn from the Balkan war, as the most modern, according to which the term should be five years. Even though this be but a rough approximation, it is sufficient to show that, barring some extraordinary development, this war will be a long one.

Indeed, it seems on purely scientific grounds that a conflict on such a vast scale can only be ended by exhaustion. The enormous extent of the battle front, owing to numbers and attendant impossibility of striking a decisive blow, is in further support of this theory. It is also highly significant to observe in this connection how the original battle lines, determined in advance by strategy, have been gradually shifted and straightened, contact between the fighting masses being finally established on lines fixed by natural law and brute force of push in defiance of military design. The likelihood of such termination is increased by the fact that the disturbance extends over an immense area, making the supply of necessities to some of the affected regions exceptionally difficult.

Accepting, then, this theory as correct, we are justified in expecting that, conditions remaining normal, the struggle will last more or less according to the form the exhaustion may take. Lack of food, deterioration and shortage of equipment, want of metals, chemicals and ammunition, scarcity of ready capital, failing supply of trained men or sheer giving out of human energy are some of the elements to be reckoned with, any one of which may compel an early cessation of hostilities. That the war cannot be continued much longer with its present intensity can be easily shown.

The daily cost of operation is more than forty millions of dollars, and judging from the casualties recorded to date; twenty-five thousand men, on the average, are killed and disabled in battle every day. At that rate only four more months of active campaign would result in an expenditure of five billions of dollars and a loss of life of three millions of men. This is, manifestly, too great an additional burden to be borne, for even though the fighting material might be available, capital is sure to be lacking. It could be, therefore, concluded with certitude that peace would be restored before next winter, were it not for one possibility, or rather probability, that of a deadlock, which would be the very worst calamity, for, in view of the real cause of the trouble and the temper of nations involved, it could not fail to protract the war for years.

Prophesying is an ungrateful occupation, but scientific forecasting is a useful form of endeavor and would be much more such if human nature were not so prone to leave advice and lesson unheeded. Having made a careful study of the situation, an expert can predict certain happenings with perfect confidence. There are now only three possible issues of this war: first, collapse of Austria; second, conquest of England by the Germans, and, third, Germany's exhaustion and defeat.

The fall of Austria is inevitable and must occur within the next few months. She may defy German influence and sue independently for peace to save herself, but it is doubtful that she could offer anything acceptable to the Allies. Much more likely it is that the old Emperor, tired of life and recognizing the injustice of Austria's cause, will himself abdicate and recommend partition.

This may not be unwelcome to hard pressed Germany, for it will open up a way of making peace on terms which will not be humiliating and compensate her for the probable loss of Alsace-Lorraine and East Prussia.

The dual monarchy has maintained herself through decades as if by a wonder. It would have been dissolved long ago had it not been for the stubborn adherence of Hungarian magnates to a promise given to Maria Theresa and the extraordinary popularity of the reigning dynasty, largely due to compassion of the subjects of all nationalities aroused by the many strange misfortunes which have befallen the house of Hapsburg. It is well recognized that the unnatural existence of this feudal state has been a constant menace to European peace and is the chief cause, of the present upheaval. A division of Austro-Hungarian territory along racial lines will satisfy all warring nations on the European continent. This is sure to come. It is a process natural and unavoidable as the falling of an overripe apple from the tree.

Regarding the second possibility, it is still unsafe to make a prediction and further developments must be awaited before a conclusion can be drawn as to the outcome. There are many indications that Germany is preparing for an attack on England with all energy and speed, and perhaps her operations in the east and west serve the purpose of masking this move. The tension between the two countries is very great, the causes of the quarrel peculiar and a peaceful solution of the difficulty is next to impossible.

The third of the issues mentioned would mean a very long war. Germany cannot break through the steel wall in France and Belgium; her partial victories in Poland can make no impression on the Russian masses. Gradually she must settle on a defensive. She has the greatest load to carry and must give out first, according to financiers and statisticians.

But with a people so intelligent, industrious, resourceful and solidly united such forecasts are hazardous. The Germans are fully capable of "making two blades of grass grow where one grew before" and it is precisely because of this and their perfect military organization that the danger of a long conflict exists. Such a prospect is enough to cause the gravest apprehensions and the uppermost thought in the minds of seers is how to prevent such paralysis of progress and horrible carnage and waste. Can it be done?

There is a grim determination of all directly concerned to fight the issues to the bitter end on the ground that a premature peace, leaving the vital questions unsettled, would only mean the continuance of the existing pernicious regime and repetition of the evil. A new and irresistible argument must be brought forward to stop the conflict. The case is desperate, but there is a hope. This hope lies in science, discovery and invention.

Modern machinery wrought by science is responsible for this calamity; science will also undo the Frankenstein monster it has created. Centuries ago an ingenious contrivance of Archimedes is said to have decided a battle and terminated a great war. Be it a myth or a fact, this story affords an inspiring lesson. What is needed at this psychological moment is some such revelation. A new force, a new agent, a demonstration by any means, old or novel, but of a kind to surprise and suddenly illuminate, to bring the belligerents to their senses and furnish irrefutable proof of the folly and uselessness of carrying on the brutal fight.

This idea, to which I have myself devoted years of work, has now taken hold of scientific men and experts all the world over. Thousands of inventors, fired on by this unique opportunity, are bent upon developing some process or apparatus for accomplishing the purpose, and there is feverish activity in France, Russia, and especially in Germany, among electricians, chemists and engineers. What the genius of nations will bring forth none can tell, but it is not too much to say that the results will be of such character as materially to affect the outcome and duration of the struggle.

It is on this account that importance attaches to vague reports of mysterious experiments with Zeppelins, explosive rays and magic bombs, for though such news items cannot be accepted as true, they reveal just so many startling possibilities. In the production and application of novel means of warfare Germany should be first, no only by reason of superior facilities and excellent training of her experts, but because this has become a dire necessity, a question of life and death in her present trying position.

The uncertain and often conflicting despatches of the daily happenings received from various sources have made it difficult to form a decided opinion as to the actual state of things, but in spite of rigid censorship the main facts have gradually transpired. One of these is that the Germans were the only people ready for war.

Not even the French, who boasted of preparedness, were able to mobilize on time. The invasion of East Prussia was but a daring stroke of the Russians to draw the enemy and relieve the pressure on France, successful but very costly to them. As to the complacent Britons, they were fast asleep. Whatever may be said against Great Britain, her utter unreadiness and the great danger to which she was exposing herself by her ultimatum to Germany would seem to be proof positive that she did not desire to enter the conflict.

Another fact, equally apparent, is that Germany, not content with a partial, even if certain, victory, had determined to defeat all the Allies in quick succession. Her plan of dictating terms of peace first in Paris, then in Petrograd, and finally in London, was not adopted as a military necessity, but as a deliberate programme based on the absolute confidence in the overwhelming power of her arms. Nor did she mean to stop at that. Her aim was much higher; she wanted nothing less than to rule all nations.

This is now frankly admitted by many of her leading men. To most of us such an undertaking is dumbfounding in its boldness and magnitude, all the more as it is intended to be carried through by force. But it would be a mistake to accuse the Germans of conceit and arrogance. They are convinced of their superiority, and it must be admitted that there is some justification for their attempt.

The question has often been raised as to whether our further development will be in the direction of the artistic and beautiful or the scientific and useful. The inevitable conclusion is that art must be sacrificed to science. This being so, the rational Germans represent the nearest approach of the humanity of the future. The Slavs, who are in the ascendency and will lead in their turn, will give a fresh impetus to creative and spiritual effort, but they too will have to concentrate on the necessary and practical. A world of bees will be the ultimate result.

Germany has been foiled in her attempt. Though still undefeated, her campaign is a failure. Many statements have been made in explanation of the sudden halt of her victorious armies, as if by a miracle, at the very gates of Paris, but the views expressed are of speculative character and do not deal with the real physical causes. These may be briefly elucidated.

The German war machine is an attempt to substitute for an assemblage of loosely linked temperamental and problematical units a compact and apathetic mass moving at command with clock precision, machinelike, impassive, indifferent to danger and death, in battle the same as on parade. Its conception rests on a deeply scientific foundation. Every human being is swayed by courage and fear, but the former predominates. This is evident, for life or existence itself is a struggle fraught with perils and pains which must be met with determination and fortitude. Fear comes from the consciousness of inimical environment and is accentuated by isolation.

When many men are placed close together the friendly surrounding and sense of connectedness are productive of a distinct psychological mass effect, calming the nerves and subduing the inborn dread and apprehension. On the other hand, frequent and severe drilling kept up for years, besides being conducive to precision and synchrony of movements, is of decided hypnotic influence, still further eliminating individual initiative and incertitude. Thus results a strong and healthy body which moves and acts as a unit, which is without human failings and shortcomings and capable of maximum performance through well directed and simultaneous application of separate efforts.

Such is the formidable engine Germany has perfected for the protection of her Kultur and conquest of the globe — an unfeeling automaton, a diabolical contrivance for scientific, pitiless, wholesale destruction the like of which was not dreamed of before. It is believed to express the highest efficiency, but is deceptive in this respect, to none more than the Germans themselves. In reality this modern war machine, considered as a transformer of energy, is barbarously wasteful.

Not only does it call for enormous expenditure of money and effort when idle, but involves a fundamental fallacy which military writers ignore, namely, the conditions determining its performance, and therefore its efficiency, are largely, if not wholly, controlled by the enemy. Indeed, it is lack of appreciation of this truth that is responsible for the Paris failure.

The first of the two chief causes of German unsuccess is found in the admirable defensive tactics of the French, who refused to make a stand for a decisive battle, thus preventing the German machine from developing its full power and compelling it to work at low efficiency. The second, even more important, was the result of undue hurry of the Germans, who drove their engine too fast, thereby increasing greatly the losses without adequate gain in useful performance. Had they taken more time, which, as subsequent developments have shown, they could have well afforded, there would have been more energy conserved and the task in all probability successfully accomplished.

The most surprising of the facts which have transpired is that there have been made in diplomatic transaction and conduct of the German campaign a number of grievous mistakes, so patent now that no representations of the press can disguise them. This is a revelation for which the world was least prepared and which shows clearly that German erudition and technical proficiency have been obtained at the expense of intuition, tact and good judgment.

What a blunder was the violation of Belgian neutrality, what an error the expectation that England would tolerate an encroachment so dangerous to her existence, that Italy would sacrifice her fleet and commerce to please the alliance! The Germans had wonderful guns, rendering fortifications useless, and yet in attacking France, instead of the shortest route, they took a circuitous path through Belgium, thus losing time and conjuring new perils and complications besides. Tens of thousands of men were driven into certain death in vain assaults in mass formation when a few shots from these guns would have been sufficient to level the forts.

Troops were withdrawn from France to less important points at the very moment when their presence meant certain victory. The Germans could have marched on Warsaw and Petrograd before the enemy was ready to put up an effective resistance, yet they delayed the invasion until the Russians brought up their millions. They could have taken Dunkirk and Calais without great effort and so avoided the terrible losses which this task, if at all realizable, must now involve. At present they are recklessly venturing far into Russian territory against overwhelming numbers and in a season when snow-storms may cut the communications and put the whole army at the mercy of the enemy.

What explanation can be offered for these and other singular errors of a nation to which economy is religion, which is admittedly the first in achieving successes in the most scientific manner, along lines of least resistance? Only one reason can be given and it is one which has caused the downfall of many an empire! It is overconfidence and contemptuous disregard of the adversaries.

Germany began the war with a blind faith in an offensive which knows no opposition. She has learned, after a frightful and unnecessary sacrifice of life and property, that France can be strong without Napoleon, that the rights of liberty loving nations, as the Belgian and Servian, cannot be trampled upon with impunity, that Russia is no longer the clumsy and helpless beast of the north. She has finally recognized what she should have known from the first, that England is her most dangerous enemy. She might maintain herself against the armies of the Continent, but with Great Britain shutting her off from the sea and strangling her by degrees the task is rendered impossible.

Victory over the Allies in the west, if at all obtainable, would weaken her to the point of danger; in the East the situation is becoming more hopeless every hour. Germany is losing ten thousand men and spending seventy-five millions of marks a day. Her life blood is ebbing fast; in the end she must lose. The only way to win is to crush England. In doing this she frees herself from the deadly grip at her throat and triumphs over all her enemies.

The Fatherland is now aflame with this thought and has started, with energy never shown before, a new campaign which if undertaken four months ago might have terminated the war before it was fairly under way. Germany enters this mortal combat not with the cold deliberation of a military power but with the passionate resolve of a nation animated by that one desire. She depends for success not only on her generals but on her physicists, engineers, inventors, chemists and artisans and on her volunteers who will offer themselves as martyrs for her cause.

She may make raids and demonstrations to trap the enemy, but she does not have the remotest intention to engage the British fleet in open battle. What she proposes to do is to destroy it by hellish means and artifices without losing a single ship of her own. Unless England wakes up immediately to this grave danger and prepares to meet science with science, skill with skill and sacrifice with sacrifice, the next few months may be critical for her reign as mistress of the seas. That the rules set down at The Hague are ineffective in preventing the use of infernal devices has been already shown. International agreements are of two kinds and may be classified under two captions, which are: “United we stand, divided we fall” and “Circumstances alter cases”. The provisions of The Hague are of the latter kind.

Those who would brush aside the above suggestion as highly improbable if not preposterous should bear in mind that a great nation leading in technical achievement is making a fight for its existence and that invention has already provided means by which such destruction can be accomplished, while others are foreshadowed in scientific investigations of recent years. The question that will interest everybody is what methods and contrivances is Germany likely to employ in her cunning undertaking and how can her efforts be met and frustrated?

In her attack upon England four ways are open to Germany: First, forceful invasion in disregard of the British fleet; second, engagement with the fleet in open battle; third, gradual destruction and weakening of the fleet by devices other than guns, and fourth, aerial attacks on land and sea.

History is full of daring conquests. It may be that we are to witness the most remarkable of all. The British Isles have been invaded before, but it was in times of primitive arms. The means of defence have been brought to great perfection, it is true, but this is largely offset by correspondingly increased powers of offensive. The feat is difficult but not impossible.

Strategy, however, can play no important part in its consummation. It is a case of Hannibal crossing the Alps, a problem of overcoming natural barriers. England has a small coast line on which landing can be effected and many places are likely to be well guarded and fortified. If the Germans contemplate invasion it will come like a lightning stroke. They will attempt it in broad daylight and in their favored manner of hacking through the obstacles regardless of loss. Their frantic efforts to get control of the coast would seem to indicate that such is their intention.

Many experts are of the opinion that so long as there is a superior British fleet in existence an undertaking of this nature is wholly out of the question, but this is a mistake. It is certainly possible for the Germans to establish an operating zone in the Channel, protected on the sides by impenetrable mine fields and submarines. What is more, the possession of Calais, while it would be of great advantage to them, is not absolutely necessary to their purpose.

Whatever the plan, it will be a piece of engineering worked out in all details with German thoroughness. That is the reason why no credence can be placed in the flimsy proposals which have been described in some papers. No feasible scheme has as yet been disclosed, but I think that I am guessing correctly when I say that the Germans contemplate the use of specially designed floating fortresses, which will be in sections and transportable by rail.

They will be made virtually invulnerable to torpedo and gun attack and will be equipped with guns of great range and destructive power constructed with this very object in view. Under the protection of these fortresses, which will sweep the coast clear, landing of troops and artillery is to be effected while bodies of infantry are transported through the air, this latter operation being performed under cover of darkness. With guns of inferior calibre, and more or less unprepared, it will be hard for the Britons to frustrate the attempt.

There is some foundation to the belief that the Germans may venture a naval engagement on a large scale. They have a smaller number of vessels, but they are mostly of quite modern type and without doubt every unit is in perfect order. All reports agree that their guns are superior to those of the British, both in range and durability. The Germans are masters in the manufacture and treatment of heat resisting materials and many technical branches in other countries are entirely dependent on their product. When we add to this advantage the possibilities offered by mines, torpedoes, submarines, Zeppelins and other means of destruction, skilful manoeuvre and surprise the numerical inequality of the fleet assumes secondary importance.

The marvelous exploit of a small German submarine which sank four British cruisers and escaped undamaged is in itself sufficient to justify the conclusion that the impending duel between the two countries will not be decided by guns and armor alone, considered heretofore supreme on the ocean. And yet the full capabilities of this kind of craft remain to be shown.

Germany is apt to go other nations one better. Most inventions originating elsewhere are improved by the Germans. Not only this, but they work for effect, knowing that to surprise is to strike, to strike is to win. It is highly probable that they have developed new things in submarines and may have solved the particular problem confronting them now, which is to destroy battleships in protected harbors.

This might be done by miniature vessels of simplified construction which would be virtually nothing but torpedoes and manned with one or two volunteer operators. The displacement would not need to be more than five tons, so that two or three, if not more, could be lowered from a Zeppelin in convenient localities at night. Such devices controlled by resolute men would be a new terror of the sea hard to guard against.

In general it will be very difficult for the British to combat effectively the submarine peril. An airship or aeroplane can be fought with a similar machine, but under water this method is impracticable and special craft will have to be perfected. Battleships might discourage submarine attacks by small shells filled with explosives of very high velocity so as to produce shocks of great intensity. Minute mines may also be employed, so constructed as to float at a certain depth and to explode on contact. They would do no harm to a large surface vessel but would reveal the presence of and injure a submarine, the delicate apparatus of which is easily deranged.

Next to guns the Zeppelin form of airship is the most valuable war asset of the Germans; at least they think so. Many difficulties had to be overcome in its development. A process of manufacturing cheaply pure hydrogen was perfected, a new alloy of remarkable strength and lightness produced, suitable and highly economical engines constructed and a number of other technical problems successfully solved. While not involving great originality it was a notable advance such as could only be achieved in Germany. Much has been said, both in exaltation and depreciation, of the Zeppelin, making it necessary to separate the wheat from the chaff before expressing an opinion as to its merits.

A claim has been advanced that a new non-inflammable gas was recently discovered, by the use of which the carrying capacity of the vessel is increased two and a half times. The only foundation of this persistent report is that according to the periodic hypothesis of elements evolved by the great Russian Mendelejeff, which has proved an unerring guide in chemical research, there should be a gas of an atomic weight 04. In a way its existence is demonstrated in the solar corona — hence the name coronium — and also in the aurora borealis, in which case it is referred to as terrestrial, or geocoronium.

In order to estimate what Germany might do with her air fleet a correct guess must be made as to its magnitude. Prior to the declaration of war she had thirty-six vessels of various sizes and actual facilities for turning out from eight to ten each month. But under war pressure this rate could be greatly increased.

The machine has passed the experimental stage and it is simply a question of reproduction. In view of the situation it would not be surprising to find that a hundred or more have been manufactured by this time. Produced in such numbers the cost of each would not be more than $125,000, which means that one hundred could be had for the price of one single dreadnought.

The carrying capacity has heretofore been given on the basis of passenger weight, but for war purposes it could be considerably increased, and in the latest type it might be as much as twenty tons. Such a vessel could transport 200 men with full equipment and a fleet of 100 could land 20,000 men in one operation.

But the possibilities of damage by explosives are much more impressive, especially as it can be inflicted without risk. A Zeppelin fitted out with proper instruments may sail in perfect safety at great height, find the exact point for attack by reference to two wireless plants in absolute darkness, drop many tons of picric compound and do this again and again.

Several experts have expressed themselves in a slighting manner in regard to the destructive effects, but the fact is that the explosion of three tons of dynamite produces an earthquake perceptible at a distance of thirty miles. If ten tons of clastic explosive were dropped into the heart of a large city thousands would be killed and hundreds of millions of property annihilated. Suppose that a fleet of 100 such vessels were to pass over England at night dropping 100,000 bombs of twenty pounds. Who can judge of the damage and demoralization which would ensue?

At the outbreak of the war it was reported that the Germans had devised a shell the poisonous fumes of which were of great destructiveness. Shortly after a marvelous new explosive was said to have been produced in France named turpinite. The first intimation came from military quarters and some weight was attached to the news on this account and also because the discovery was attributed to Eugene Turpin, an ingenious and prolific inventor of chemicals.

The idea of employing poisonous or asphyxiating bombs is old. It is authoritatively stated that some were actually thrown during the second siege of Paris against the army of Versailles, but with the only result of killing the expert who was filling them. There is a natural and deeply rooted prejudice against the employment of poisonous agents in warfare, and many of those who tolerate the present methods of destroying life would shrink from such use. Yet death from many of the toxins known is less painful and disfiguring.

In the absence of demonstrated facts I will endeavor to show in a few words how the effectiveness of such means can be enormously increased. Consider first a large shell which, on striking the ground, liberates a poisonous gas of atmospheric density spreading in half a sphere, and let the effective radius be 1,000 feet. Now imagine that an equivalent charge is subdivided in one million parts, giving that many little shells which can be scattered over a large area. Then, since the gas will be of the same volume as before, the radius of action of each shell will be ten feet and their combined destructive effect will be 100 times greater than that of the large shell; in fact, much more so, for the distribution of the gas will not be uniform. It will be seen the secret lies in the employment of extremely small charges in great numbers.

The same reasoning leads to the conclusion that by using minute projectiles of tungsten dipped in curare or similar poison, paralyzing heart or locomotor function, a means for fighting battles would be provided more humane than the present and incomparably more effective. A complete revolution in methods of attack may be brought on through the use of toxins or asphyxiants heavier than air. This may be illustrated by an example.

Let us suppose that ten tons of such liquefied gas are dropped on a battlefield from an aerial vessel. On evaporating a gas blanket will be formed over the earth's surface, the effective height of which may be assumed to be ten feet. If ten cubic feet of the gas weigh one pound, then ten tons will give 200,000 cubic feet of gas, which may be more or less diluted, according to its toxic activity. Assume that it is not more poisonous than carbon monoxide, which is fatal when its percentage in the atmosphere is one-half of one per cent. That means that the gas blanket will contain 40,000,000 cubic feet, and being ten feet high it will cover 4,000,000 square feet, or, roughly, 100 acres. In a populated city, on account of structures and other objects, the deadly zone would be very much extended.

This is danger enough, but if a gas were employed of lethal power equal to that of prussic acid, aconitine or of the strongest poison known, pseudoaconitine, the destructive area would be a hundred times greater. Evidently then there is a prospect that the chemist, who is largely responsible for the war, may also find the means of compelling its speedy termination.

Telautomatics is a name suggested for the wireless control of the organs and translatory movements of self-propelled automata. Fifteen years ago I showed its first applications and the results were received with an interest such as only few inventions have elicited. My demonstrations were repeated in Germany and other countries, but on account of the fact that Hertz waves and imperfectly tuned circuits were employed a general impression was created that such distant control of apparatus was not absolutely reliable.

A further argument was advanced that if it were unfailing, volunteers could always be found ready for sacrifice and more dependable because of intelligence and judgment not possessed by an inanimate machine. This view is held by those who are now advocating the use of manned aerial torpedoes, but nothing could be more erroneous. A crewless vessel controlled by proper wireless apparatus is in every way superior as a means of attack.

Large guns are now being manufactured in Germany so expensive and shortlived that a single shot from them costs a small fortune. It would be possible to produce for less than the price of a shot a telautomatic aerial torpedo of much longer range and greater destructiveness which would hit its mark every time and dispense with the necessity of the gun altogether.

The new principle can also be applied to a submarine, and, particularly in connection with control from great elevation, it will afford the most perfect means for coast defence so far devised. But its full possibilities will only be appreciated when the use of certain electrical waves to which the earth is resonantly responsive becomes general. It will then be practicable to despatch a crewless boat or balloon to distances of hundreds of miles, guide it along any chart at will and release its potential energy at any point desired.

Great many of the present means and methods will then become obsolete. It is very likely that if this war is protracted this invention will prove of importance. Recent reports would indicate that experiments are being made in Germany with telautomatic torpedoes released from balloons.

One good effect of this disastrous disturbance will be a long period of peace. This is a natural consequence of the law that action and reaction are equal. But in the present phase of human development occasional convulsions are in the order of things. A still greater struggle will probably come, that between the united races of the Orient and Occident.

So long as there are different nationalities there will be patriotism. This feeling must be eradicated from our hearts before permanent peace can be established. Its place must be filled by love of nature and scientific ideal. Science and discovery are the great forces which will lead to that consummation.

I have just made known an invention which will show to electricians how to produce immense electrical pressures and activities. By their means many wonderful results will be achieved. The human voice and likeness will be flashed around the globe without wire, energy projected through space, the wastes of the ocean will be made safe to navigation, transport facilitated, rain precipitated at will and, perhaps, the inexhaustible store of atomic energy released.

Advances of this kind will, in times to come, remove the physical causes of war, the chief of which is the vast extent of this planet. The gradual annihilation of distance will put human beings in closer contact and harmonize their views and aspirations. The harnessing of the forces of nature will banish misery and want and provide ample means for safe and comfortable existence.

But one more accomplishment will still be lacking to make the triumph of the mind of man complete. A way must be found to interpret thought and thereby enable the accurate reduction of all forms of human effort to a common equivalent. The problem is susceptible of solution.

The consequences of such an advance are incalculable. A new epoch in human history would be inaugurated and a colossal revolution in moral, social and other respects accomplished, innumerable causes of trouble would be removed, our lives profoundly modified for the better, and a new and firm foundation laid to all that makes for peace.

5

HOW COSMIC FORCES SHAPE OUR DESTINIES*

Every living being is an engine geared to the wheelwork of the universe. Though seemingly affected only by its immediate surrounding, the sphere of external influence extends to infinite distance. There is no constellation or nebula, no sun or planet, in all the depths of limitless space, no passing wanderer of the starry heavens, that does not exercise some control over its destiny — not in the vague and delusive sense of astrology, but in the rigid and positive meaning of physical science.

More than this can be said. There is no thing endowed with life — from man, who is enslaving the elements, to the humblest creature — in all this world that does not sway it in turn. Whenever action is born from force, though it be infinitesimal, the cosmic balance is upset and universal motion results.

Herbert Spencer has interpreted life as a continuous adjustment to the environment, a definition of this inconceivably complex manifestation quite in accord with advanced scientific thought, but, perhaps, not broad enough to express our present views. With each step forward in the investigation of its laws and mysteries our conceptions of nature and its phases have been gaining in depth and breadth.

In the early stages of intellectual development man was conscious of but a small part of the macrocosm. He knew nothing of the wonders of the microscopic world, of the molecules composing it, of the atoms making up the molecules and of the dwindlingly small world of electrons within the atoms. To him life was synonymous with voluntary motion and action. A plant did not suggest to him what it does to us — that it lives and feels, fights for its existence, that it suffers and enjoys. Not only have we found this to be true, but we have ascertained that even matter called inorganic, believed to be dead, responds to irritants and gives unmistakable evidence of the presence of a living principle within.

Thus, everything that exists, organic or inorganic, animated or inert, is susceptible to stimulus from the outside. There is no gap between, no bleak of continuity, no special and distinguishing vital agent. The same law governs all matter, all the universe is alive. The momentous question of Spencer, "What is it that causes inorganic matter to run into organic forms?" has been answered. It is the sun's heat and light. Wherever they are there is life. Only in the boundless wastes of interstellar space, in the eternal darkness and cold, is animation suspended, and, possibly, at the temperature of absolute zero all matter may die.

MAN AS A MACHINE

This realistic aspect of the perceptible universe, as a clockwork wound up and running down, dispensing with the necessity of a hypermechanical vital principle, need not be in discord with our religious and artistic aspirations — those indefinable

* New York American, Febr. 7, 1915 ("Did the War cause the Italian Earthquake").

and beautiful efforts through which the human mind endeavors to free itself from material bonds. On the contrary, the better understanding of nature, the consciousness that our knowledge is true, can only be all the more elevating and inspiring.

It was Descartes, the great French philosopher, who, in the seventeenth century, laid the first foundation to the mechanistic theory of life, not a little assisted by Harvey's epochal discovery of blood circulation. He held that animals were simply automata without consciousness and recognized that man, though possessed of a higher and distinctive quality, is incapable of action other than those characteristic of a machine. He also made the first attempt to explain the physical mechanism of memory. But in this time many functions of the human body were not as yet understood, and in this respect some of his assumptions were erroneous.

Great strides have since been made in the art of anatomy, physiology and all branches of science, and the workings of the man-machine are now perfectly clear. Yet the very fewest among us are able to trace their actions to primary external causes. It is indispensable to the arguments I shall advance to keep in mind the main facts which I have myself established in years of close reasoning and observation and which may be summed up as follows:

1. The human being is a self-propelled automaton entirely under the control of external influences. Willful and predetermined though they appear, his actions are governed not from within, but from without. He is like a float tossed about by the waves of a turbulent sea.

2. There is no memory or retentive faculty based on lasting impression. What we designate as memory is but increased responsiveness to repeated stimuli.

3. It is not true, as Descartes taught, that the brain is an accumulator. There is no permanent record in the brain, there is no stored knowledge. Knowledge is something akin to an echo that needs a disturbance to be called into being.

4. All knowledge or form conception is evoked through the medium of the eye, either in response to disturbances directly received on the retina or to their fainter secondary effects and reverberations. Other sense organs can only call forth feelings which have no reality of existence and of which no conception can be formed.

5. Contrary to the most important tenet of Cartesian philosophy that the perceptions of the mind are illusionary, the eye transmits to it the true and accurate likeness of external things. This is because light propagates in straight lines and the image cast on the retina is an exact reproduction of the external form and one which, owing to the mechanism of the optic nerve, can not be distorted in the transmission to the brain. What is more, the process must be reversible, that is to say, a form brought to consciousness can, by reflex action, reproduce the original image on the retina, just as an echo can reproduce the original disturbance. If this view is borne out by experiment an immense revolution in all human relations and departments of activity will be the consequence.

NATURAL FORCES INFLUENCE US

Accepting all this as true let us consider some of the forces and influences which act on such a wonderfully complex automatic engine with organs inconceivably sensitive and delicate, as it is carried by the spinning terrestrial globe in its lightning flight through space. For the sake of simplicity we may assume that the earth's axis is perpendicular to the ecliptic and that the human automaton is at the equator. Let his weight be one hundred and sixty pounds, then, at the rotational velocity of about 1,520 feet per second with which he is whirled around, the mechanical energy stored in his body will be nearly 5,780,000 foot pounds, which is about the energy of a hundred-pound cannon ball.

This momentum is constant as well as the upward centrifugal push, amounting to about fifty-five hundredth of a pound, and both will probably be without marked influence on his life functions. The sun, having a mass 332,000 times that of the earth, but being 23,000 times farther, will attract the automaton with a force of about one-tenth of one pound, alternately increasing and diminishing his normal weight by that amount.

Though not conscious of these periodic changes, he is surely affected by them.

The earth in its rotation around the sun carries him with the prodigious speed of nineteen miles per second and the mechanical energy imparted to him is over 25,160,000,000 foot pounds. The largest gun ever made in Germany hurls a projectile weighing one ton with a muzzle velocity of 3,700 feet per second, the energy being 429,000,000 foot pounds. Hence the momentum of the automaton's body is nearly sixty times greater. It would be sufficient to develop 762,400 horse-power for one minute, and if the motion were suddenly arrested the body would be instantly exploded with a force sufficient to carry a projectile weighing over sixty tons to a distance of twenty-eight miles.

This enormous energy is, however, not constant, but varies with the position of the automaton in relation to the sun. The circumference of the earth has a speed of 1,520 feet per second, which is either added to or subtracted from the translatory velocity of nineteen miles through space. Owing to this the energy will vary from twelve to twelve hours by an amount approximately equal to 1,533,000,000 foot pounds, which means that energy streams in some unknown way into and out of the body of the automaton at the rate of about sixty-four horse-power.

But this is not all. The whole solar system is urged towards the remote constellation of Hercules with a speed which some estimate at twenty miles per second, and owing to this there should be similar annual changes in the flux of energy, which may reach the appalling figure of over one hundred billion foot pounds. All these varying and purely mechanical effects are rendered more complex through the inclination of the orbital planes and many other permanent or casual mass actions.

This automaton is, however, subjected to other forces and influences. His body is at the electric potential of two billion volts, which fluctuates violently and incessantly. The whole earth is alive with electrical vibrations in which he takes part. The atmosphere crushes him with a pressure of from sixteen to twenty tons, according to barometric conditions. He receives the energy of the sun's rays in varying intervals at a mean rate of about forty foot pounds per second, and is subjected to periodic bombardment of the sun's particles, which pass through his body as if it were tissue paper. The air is rent with sounds which beat on his eardrums, and he is shaken by the unceasing tremors of the earth's crust. He is exposed to great temperature changes, to rain and wind.

What wonder then that in such a terrible turmoil, in which cast iron existence would seem impossible, this delicate human engine should act in an exceptional manner? If all automata were in every respect alike they would react in exactly the same way, but this is not the case. There is concordance in response to those disturbances only which are most frequently repeated, not to all. It is quite easy to provide two electrical systems which, when subjected to the same influence, will behave in just the opposite way.

So also two human beings, and what is true of individuals also holds good for their large aggregations. We all sleep periodically. This is not an indispensable physiological necessity any more than stoppage at intervals is a requirement for an engine. It is merely a condition gradually imposed upon us by the diurnal revolution of the globe, and this is one of the many evidences of the truth of the mechanistic theory. We note a rhythm, or ebb and tide, in ideas and opinions, in financial and political movements, in every department of our intellectual activity.

HOW WARS ARE STARTED

It only shows that in all this a physical system of mass inertia is involved which affords a further striking proof. If we accept the theory as a fundamental truth and, furthermore, extend the limits of our sense perceptions beyond those within which we become conscious of the external impressions, then all the states in human life, however unusual, can be plausibly explained. A few examples may be given in illustration.

The eye responds only to light vibrations through a certain rather narrow range, but the limits are not sharply defined. It is also affected by vibrations beyond, only in a lesser degree. A person may thus become aware of the presence of another in darkness, or through intervening obstacles, and people laboring under illusions ascribe this to telepathy. Such transmission of thought is absurdly impossible.

The trained observer notes without difficulty that these phenomena are due to suggestion or coincidence. The same may be said of oral impressions, to which musical and imitative people are especially susceptible. A person possessing these qualities will often respond to mechanical shocks or vibrations which are inaudible.

To mention another instance of momentary interest reference may be made to dancing, which comprises certain harmonious muscular contractions and contortions of the body in response to a rhythm. How they come to be in vogue just now can be satisfactorily explained by supposing the existence of some new periodic disturbances in the environment, which are transmitted through the air or the ground and may be of mechanical, electrical or other character.

Exactly so it is with wars, revolutions and similar exceptional states of society.

Though it may seem so, a war can never be caused by arbitrary acts of man.

It is invariably the more or less direct result of cosmic disturbance in which the sun is chiefly concerned.

In many international conflicts of historical record which were precipitated by famine, pestilence or terrestrial catastrophes the direct dependence of the sun is unmistakable. But in most cases the underlying primary causes are numerous and hard to trace.

In the present war it would be particularly difficult to show that the apparently wilful acts of a few individuals were not causative. Be it so. The mechanistic theory, being founded on truth demonstrated in everyday experience, absolutely precludes the possibility of such a state being anything but the inevitable consequence of cosmic disturbance.

The question naturally presents itself as to whether there is some intimate relation between wars and terrestrial upheavals. The latter are of decided influence on temperament and disposition, and might at times be instrumental in accelerating the clash, but aside from this there seems to be no mutual dependence, though both may be due to the same primary cause.

What can be asserted with perfect confidence is that the earth may be thrown into convulsions through mechanical effects such as are produced in modern warfare. This statement may be startling, but it admits of a simple explanation.

Earthquakes are principally due to two causes — subterranean explosions or structural adjustments. The former are called volcanic, involve immense energy and are hard to start. The latter are named tectonic; their energy is comparatively insignificant and they can be caused by the slightest shock or tremor. The frequent slides in the Culebra are displacements of this kind.

WAR AND THE EARTHQUAKE

Theoretically, it may be said that one might think of a tectonic earthquake and cause it to occur as a result of the thought, for just preceding the release the mass may be in the most delicate balance. There is a popular error in regard to the energy of such displacements. In a case recently reported as quite extraordinary, extending as it did over a vast territory, the energy was estimated at 65,000,000,000,000 foot tons. Assuming even that the whole work was performed in one minute it would only be equivalent to that of 7,500,000 horse-power during one year, which seems much, but is little for a terrestrial upheaval. The energy of the sun's rays falling on the same area is a thousand times greater.

The explosions of mines, torpedoes, mortars and guns develop reactive forces on the ground which are measured in hundreds or even thousands of tons and make themselves felt all over the globe. Their effect, however, may be enormously magnified by resonance. The earth is a sphere of a rigidity slightly greater than that of steel and vibrates once in about one hour and forty-nine minutes.

If, as might well be possible, the concussions happen to be properly timed their combined action could start tectonic adjustments in any part of the earth, and the Italian calamity may thus have been the result of explosions in France. That man can produce such terrestrial convulsions is beyond any doubt, and the time may be near when it will be done for purposes good or apt.

6

THE WONDER WORLD TO BE CREATED BY ELECTRICITY*

Whoever wishes to get a true appreciation of the greatness of our age should study the history of electrical development. There he will find a story more wonderful than any tale from the Arabian Nights. It begins long before the Christian era, when Thales, Theophrastus and Pliny tell of the magic properties of electron — the precious substance we call amber — that came from the pure tears of the Heliades, sisters of Phaeton, the unfortunate youth who attempted to run the blazing chariot of Phoebus and nearly burned up the earth. It was but natural for the vivid imagination of the Greeks to ascribe the mysterious manifestations to a hyperphysical cause, to endow the amber with life and with a soul.

Whether this was actual belief or merely poetic interpretation is still a question. Even at this very day many of the most enlightened people think that the pearl is alive; that it grows more lustrous and beautiful in the warm contact of the human body. So, too, it is the opinion of men of science that a crystal is a living being, and this view is being extended to embrace the entire physical universe since Prof. Jagadis Chunder Bose has demonstrated, in a series of remarkable experiments, that inanimate matter responds to stimuli in exactly the same manner as plant fiber and animal tissue.

The superstitious belief of the ancients, if it existed at all, can therefore not be taken as a reliable proof of their ignorance, but just how much they knew about electricity can only be conjectured. A curious fact is that the ray or torpedo fish was used by them in electrotherapy. Some old coins show twin stars, or sparks, such as might be produced by a galvanic battery. The records, though scanty, are of a nature to fill us with conviction that a few initiated, at least, had a deeper knowledge of amber phenomena. To mention one, Moses was undoubtedly a practical and skillful electrician far in advance of his time. The Bible describes precisely and minutely arrangements constituting a machine in which electricity was generated by friction of air against silk curtains and stored in a box constructed like a condenser. It is very plausible to assume that the sons of Aaron were killed by a high-tension discharge, and that the vestal fires of the Romans were electrical. The belt drive must have been known to engineers of that epoch, and it is difficult to see how the abundant evolution of static electricity could have escaped their notice. Under favorable atmospheric conditions a belt may be transformed into a dynamic generator capable of producing many striking actions. I have lighted incandescent lamps, operated motors and performed numerous other equally interesting experiments with electricity drawn from belts and stored in tin cans.

That many facts in regard to the subtle force were known to the philosophers of old can be safely concluded. The wonder is, why 2000 years elapsed before Gilbert in 1600 published his famous work, the first scientific treatise on electricity and magnetism. To an extent this long period of unproductiveness can be explained. Learning

* Manufacturer's Record, Sept. 9, 1915.

was the privilege of a few and all information was jealously guarded. Communication was difficult and slow, and a mutual understanding between widely-separated investigators hard to reach. Then again, men of those times had no thought of the practical; they lived and fought for abstract principles, creeds, traditions and ideals. Humanity did not change much in Gilbert's time, but his clear teachings had a telling effect on the minds of the learned. Friction machines were produced in rapid succession and experiments and observations multiplied. Gradually fear and superstition gave way to scientific insight, and in 1745 the world was thrilled with the news that Kleist and Leyden had succeeded in imprisoning the uncanny agent in a phial, from which it escaped with an angry snap and destructive force. This was the birth of the condenser, perhaps the most marvelous electrical device ever invented.

Two tremendous leaps were made in the succeeding 40 years. One was when Franklin demonstrated the identity between the gentle soul of amber and the awe-inspiring bolt of Jupiter; the other when Galvany and Volta brought out the contact and chemical battery, from which the magic fluid could be drawn in unlimited quantities. The succeeding 40 years bore still greater fruit. Oersted made a significant advance in deflecting a magnetic needle by an electric current, Arago produced the electro-magnet, Seebeck the thermopile and in 1831, as the crowning achievement of all, Faraday announced that he had obtained electricity from a magnet, thus discovering the principle of that wonderful engine, the dynamo, and inaugurating a new era both in scientific research and practical application.

From that time on inventions of inestimable value have followed one another at a bewildering rate. The telegraph, telephone, phonograph and incandescent lamp, the induction motor, oscillatory transformer, Roentgen ray, radium, wireless and numerous other revolutionary advances have been made and all conditions of existence profoundly modified. In the 84 years which have since elapsed the subtle agents dwelling in the living amber and loadstone have been transformed into cyclopean forces, turning the wheels of human progress with ever-increasing speed. This, in brief, is the fairy tale of electricity from Thales to the present day. The impossible has happened, the wildest dreams have been surpassed and the astounded world is asking. What is coming next?

ELECTRICAL POSSIBILITIES IN COAL AND IRON

Many a would-be discoverer, failing in his efforts, has felt the regret to have been born at a time when everything has been already accomplished and nothing is left to be done. This erroneous impression that, as we are advancing, the possibilities of invention are being exhausted, is not uncommon. In reality it is just the opposite. Spenser has conveyed the right idea when he likened civilization to the sphere of light which a lamp throws out in darkness. The brighter the lamp and the larger the sphere the greater is its dark boundary. It is paradoxical, yet true, to say, that the more we know the more ignorant we become in the absolute sense, for it is only through enlightenment that we become conscious of our limitations. Precisely one of the most gratifying results of intellectual evolution is the continuous opening up of new and greater prospects. We are progressing at an amazing pace, but the truth is that, even in the fields most successfully exploited, the ground has only been broken. What has been so far done by electricity is nothing as compared with what the future has in store. Not only this, but there are now innumerable things done in old-fashioned ways which are much inferior in economy, convenience and many other respects to the new method. So great are the advantages of the latter that whenever an opportunity presents itself the engineer advises his client to "do it electrically".

Consider, in illustration, one of the largest industries, that of coal. From this valuable mineral we chiefly draw the sun's stored energy which is required to meet our industrial and commercial needs. According to statistical records, the output in the United States during the past year was 480,000,000 tons. In perfect engines this fuel would have been sufficient to develop 500,000,000 horse-power steadily for one year, but the squandering is so reckless that we do not get more than 5 per cent. of its heating value on the average. There is an appalling waste in mining, handling, transportation, store and use of coal, which could be very much reduced through the adoption of a comprehensive electrical plan in all these operations. The market value of the yearly product could be easily doubled and an immense sum added to the revenues of the country. What is more, inferior grades, billions of tons of which are being thrown away, might be turned to profitable use.

Similar considerations apply to natural gas and mineral oil, the annual loss of which amounts to hundreds of millions of dollars. In the very near future such waste will be looked upon as criminal and the introduction of the new methods will be forced upon the owners of such properties. Here, then, is an immense field for the use of electricity in many ways, vast industries which are bound to be revolutionized through its extensive application.

To give another example, I may refer to the manufacture of iron and steel, which is carried on in this country on a scale truly colossal. During the last year, notwithstanding unfavorable business conditions, 31,000,000 tons of steel have been produced. It would lead too far to dwell on the possibilities of electrical improvements in the manufacturing processes themselves, and I will only indicate what is likely to be accomplished in using the waste gases from the coke ovens and blast furnaces to generate electricity for industrial purposes.

Since in the production of pig-iron for every ton about one ton of coke is employed, the yearly consumption of coke may be put at 31,000,000 tons. The combustion in the blast furnaces yields, per minute, 7,000,000 cubic feet of gas of a heating value of 110 B. T. units per cubic foot. Of this total, without making special provision, 4,000,000 cubic feet may be made available for power purposes. If all the heat energy of this gas could be transformed into mechanical effort, it would develop 10,389,000 horse-power. This result is impossible, but it is perfectly practicable to obtain 2,500,000 horse-power electrical energy at the terminals of the dynamos.

In the manufacture of coke approximately 9400 cubic feet of gas are evolved per ton of coal. This gas is excellent for power purposes, having an average heating value of 600 B. T. units, but very little is now used in engines, largely because of their great cost and other imperfections. A ton of coke requires about 1.32 tons of American coal; hence the total coal consumption per annum on the above basis is nearly 41,000,000 tons, which give, per minute, 733,000 cubic feet of gas. Assuming the yield of surplus or rich gas to be 333,000 cubic feet, the balance of 400,000 cubic feet could be used in gas engines. The heat contents would be, theoretically, sufficient to develop 5,660,000 horse-power, of which 1,500,000 horse-power could be obtained in the form of electric energy.

I have devoted much thought to this industrial proposition, and find that *with new, efficient, extremely cheap and simple thermo-dynamic transformers not less than 4,000,000 horse-power could be developed in electric generators by utilizing the heat of these gases, which, if not entirely wasted, are only in part and inefficiently employed.*

With systematic improvements and refinements much better results could be secured and an annual revenue of $50,000,000 or more derived. The electrical energy could be advantageously used in the fixation of atmospheric nitrogen and production of fertilizers, for which there is an unlimited demand and the manufacture of which is restricted here on account of the high cost of power. I expect confidently the practical realization of this project in the very near future, and look to exceptionally rapid electrical development in this direction.

HYDRO-ELECTRIC DEVELOPMENT

Water-power offers great opportunities for novel electrical applications, particularly in the department of electro-chemistry. The harnessing of waterfalls is the most economical method known for drawing energy from the sun. This is due to the fact that both water and electricity are incompressible. The net efficiency of the hydro-electric process can be as high as 85 per cent. The initial outlay is generally great, but the cost of maintenance is small and the convenience offered ideal. My alternating system is invariably employed, and so far about 7,000,000 horse-power have been developed. As generally used we do not get more than six-hundredths of a horse-power per ton of coal per year. *This water energy is therefore equivalent to that obtainable from an annual supply of 120,000,000 tons of coal, which is about 25 per cent. of the total output in the United Stales.* The estimate is conservative, and in view of the immense waste of coal 50 per cent. may be a closer guess.

We get better appreciation of the tremendous value of this power in our economic development when we remember that, unlike fuel, which demands a terrible sacrifice of human energy and is consumed, it is supplied without effort and destruction of material and equals the mechanical performance of 150,000,000 men — one and one- half times the entire population of this country. These figures are imposing; nevertheless, we have only begun the exploitation of this vast national resource.

There are two chief limitations at present — one in the availability of the energy, the other in its transmission to distance. The theoretical power of the falling water is enormous. If we assume for the rain clouds an average height of 15,000 feet and annual precipitation of 33 inches, the 24 horse-power per square mile is over 4000, and for the whole area of the United States more than 12,000,000,000 horse-power. As a matter of fact, the larger portion of the potential energy is used up in air friction. This, while disappointing to the economist, is a fortunate circumstance, for otherwise the drops would reach the ground with a speed of 800 feet per second — sufficient to raise blisters on our bodies, while hail would be positively deadly. Most of the water, which is available for power purposes comes from a height of about 2000 feet and represents over one and one-half billion horse-power, but we are only able to use an average fall of, say, 100 feet, which means that if all the water- power in this country were harnessed under the existing conditions only 80,000,000 horse-power could be obtained.

THE NEXT GREAT ACHIEVEMENT — ELECTRICAL CONTROL OF ATMOSPHERIC MOISTURE

But the time is very near when we shall have the precipitation of the moisture of the atmosphere under complete control, and then it will be possible to draw unlimited quantities of water from the oceans, develop any desired amount of energy, and completely transform the globe by irrigation and intensive farming. A greater achievement of man through the medium of electricity can hardly be imagined.

The present limitations in the transmission of power to distance will be overcome in two ways — through the adoption of underground conductors insulated by power, and through the introduction of the wireless art. The first plan I have advanced years ago. The underlying principle is to convey through a tubular conductor hydrogen at a very low temperature, freeze the surrounding material and thus secure a perfect insulation by indirect use of electric energy. In this manner the power derived from falls can be transmitted to distances of hundreds of miles with the highest economy and at a small cost. This innovation is sure to greatly extend the fields of electrical application. As to the wireless method, we have now the means for economic transmission of energy in any desired amount and to distances only limited by the dimensions of this planet. In view of assertions of some misinformed experts to the effect that in the wireless system I have perfected the power of the transmitter is dissipated in all directions, I wish to be emphatic in my statement that such is not the case. The energy goes only to the place where it is needed and to no other.

When these advanced ideas are practically realized we shall get the full benefit of water-power, and it will become our chief dependence in the supply of electricity for domestic, public and other uses in the arts of peace and war.

ECONOMY IN LIGHT AND POWER — ELECTRIC PROPULSION

In the great departments of electric light and power immense opportunities are offered through the introduction of all kinds of novel devices which can be attached to the circuits at convenient hours for the purpose of equalizing the loads and increasing the revenues from the plants. I have myself knowledge of a number of new appliances of this kind. The most important among them is probably an electrical ice machine which obviates entirely the use of dangerous and otherwise objectionable chemicals. The new machine will also require absolutely no attention and will be extremely economical in operation, so that the refrigeration will be effected very cheaply and conveniently in every household.

An interesting fountain, electrically operated, has been brought out which is likely to be extensively introduced, and will afford an unusual and pleasing sight in squares, parks, hotels and residences.

Cooking devices for all domestic purposes are being provided, and there is great demand for practical designs and suggestions in this field. The same may be stated of electric signs and other attractive means of advertising which can be electrically operated. Some of the effects which it is possible to produce by electric currents are wonderful and lend themselves to exhibitions, and there is no doubt that much can be done in that direction. Theatres, public halls and private dwellings are in need of a great many devices and instruments for convenience and offer ample opportunities to an ingenious and practical inventor.

A vast and absolutely untouched field is the use of electricity for the propulsion of ships. The leading electrical company in this country has just equipped a large vessel with high-speed turbines and electric motors and has achieved a signal success. Applications of this kind will multiply at a rapid rate, for the advantages of the electrical drive are now patent to everybody. In this connection gyroscopic apparatus will probably play an important part, as its general adoption on vessels is sure to come. Very little has yet been done in the introduction of electrical drive in the various branches of industry and manufacture, and the prospects are unlimited.

A FEW OF THE WONDERS TO COME

Books have already been written on the agricultural uses of electricity, but the fact is that hardly anything has been practically done. The beneficial effects of electricity of high tension have been unmistakably established, and a revolution will be brought about through the extensive adoption of agricultural electrical apparatus.

The safeguarding of forests against fires, the destruction of microbes, insects and rodents will, in due course, be accomplished by electrical means.

In the near future we shall see a great many new uses of electricity aiming at safety, particularly of vessels at sea. *We shall have electrical instruments for preventing collisions, and we shall even be able to disperse fogs by electric force and powerful and penetrative rays.* I am hopeful that within the next few years *wireless plants will be installed for the purpose of illuminating the oceans.* The project is perfectly feasible, and if carried out will contribute more than any other provision to the safety of property and human lives at sea. The same plant could also produce stationary electrical waves and enable vessels to get at any time accurate bearings and other valuable practical data without resorting to the present means. It could also be used for time signaling and many other purposes of similar nature.

Electrotherapy is another great field in which there are unlimited possibilities for electrical applications. High-frequency currents especially have a great future. The time will come when this form of electrical energy will be available in every private residence. I consider it quite possible that through their surface actions we may do away with the customary bath, as the cleaning of the body can be instantaneously effected simply by connecting it to a source of currents or electric energy of very high potential, which results in the throwing off of dust or any small particles adhering to the skin. Such a dry bath, besides being convenient and time-saving, would also be of beneficial therapeutic influence. New electric devices for use of the deaf and blind are coming and will be a blessing to the afflicted.

In the prevention of crime electrical instruments will soon become an important factor. In court proceedings electric evidence will often be decisive. *In a time not distant it will be possible to flash any image formed in thought on a screen and render it visible at any place desired.* The perfection of this means of reading thought will create a revolution for the better in all our social relations. Unfortunately, it is true, that cunning lawbreakers will avail themselves of such advantages to further their nefarious business.

TELEGRAPHIC PHOTOGRAPHY AND OTHER ADVANCES

Great improvements are still possible in telegraphy and telephony. The use of a new receiving device which will be shortly described, and the sensitiveness of which can be increased almost without limit, will enable telephoning through aerial lines or cables however long by reducing the necessary working current to an infinitesimal value. This invention will dispense with the necessity of resorting to expensive constructions, which, however, are of circumscribed usefulness. It will also enormously extend the wireless transmission of intelligence in all its departments.

The next art to be inaugurated is that of picture transmission by ordinary telegraphic methods and existing apparatus. This idea of telegraphing or telephoning pictures is old, but practical difficulties have hampered commercial realizations. A number of improvements of great promise have been made, and there is every reason to expect that success will soon be achieved.

Another valuable novelty will be a typewriter electrically operated by the human voice. This advance will fill a long-felt want, as it will do away with the operator and save a great deal of labor and time in offices.

A new and extremely simple electric tachometer is being prepared for the market, and it is expected that it will prove useful in power plants and central stations, on boats, locomotives and automobiles.

Many municipal improvements based on the use of electricity are about to be introduced. *We have soon to have everywhere smoke annihilators, dust absorbers, ozonizers, sterilizers of water, air, food and clothing, and accident preventers on streets, elevated roads and in subways. It will become next to impossible to contract disease germs or get hurt in the city, and country folk will go to town to rest and get well.*

ELECTRIC INVENTIONS IN WAR

The present international conflict is a powerful stimulus to invention of devices and implements of warfare. An electric gun will soon be brought out. The wonder is that it was not produced long ago. Dirigibles and aeroplanes will be equipped with small electric generators of high tension, from which the deadly currents will be conveyed through tin wires to the ground. Battleships and submarines will be provided with electric and magnetic feelers so delicate that the approach of any body under water or in darkness will be detected. Torpedoes and floating mines are almost in sight which will direct themselves automatically and without fail get in fatal contact with the object to be destroyed. The art of telautomatics, or wireless control of automatic machines at a distance, will play a very important part in future wars and, possibly, in the next phases of the present one. Such contrivances which act as if endowed with intelligence will be used in innumerable ways for attack as well as defense. They may take the shape of aeroplanes, balloons, automobiles, surface or under-water boats, or any other form according to the requirement in each special case, and will be of greater range and destructiveness than the implements now employed. *I believe that the telautomatic aerial torpedo will make the large siege gun, on which so much dependence is placed at present, obsolete.*

A volume might be filled with such suggestions without exhausting the possibilities. The advance even under the conditions existing is rapid enough, but when the wireless transmission of energy for general use becomes a practical fact the human progress will assume the character of a hurricane. So all-surpassing is the importance of this marvelous art to the future existence and welfare of the human race that every enlightened person should have a clear idea of the chief factors bearing on its development.

THE POWER OF THE FUTURE

We have at our disposal three main sources of life-sustaining energy — fuel, water-power and the heat of the sun's rays. Engineers often speak of harnessing the tides, but the discouraging truth is that the tidewater over one acre of ground will, on the average, develop only one horse-power. Thousands of mechanics and inventors have spent their best efforts in trying to perfect wave motors, not realizing that the power so obtained could never compete with that derived from other sources. The force of wind offers much better chances and is valuable in special instances, but is by far inadequate. Moreover, the tides, waves and winds furnish only periodic and often uncertain power and necessitate the employment of large and expensive storage plants. Of course, there are other possibilities, but they are remote, and we must depend on the first of three resources. If we use fuel to get our power, we are living on our capital and exhausting it rapidly. This method is barbarous and wantonly wasteful, and will have to be stopped in the interest of coming generations. The heat of the sun's rays represents an immense amount of energy vastly in excess of water-power. The earth receives an equivalent of 83 foot-pounds per second for each square foot on which the rays fall perpendicularly. From simple geometrical rules applying to a spherical body it follows that the mean rate per square foot of the earth's surface is one-quarter of that, or 20¾ foot-pounds. This is to say over one million horse-power per square mile, or 250 times the water-power for the same area. But that is only true in theory; the practical facts put this in a different aspect. For instance, considering the United States, and taking into account the mean latitude, the daily variation, the diurnal changes, the seasonal variations and casual changes, this power of the sun's rays reduces to about one-tenth, or 100,000 horse-power per square mile, of which we might be able to recover in high-speed low-pressure turbines 10,000 horse-power. To do this would mean the instalment of apparatus and storage plants so large and expensive that such a project is beyond the pale of the practical. *The inevitable conclusion is that water-power is by far our most valuable resource. On this humanity must build its hopes for the future.* With its full development and a perfect system of wireless transmission of the energy to any distance man will be able to solve all the problems of material existence. Distance, which is the chief impediment to human progress, will be completely annihilated in thought, word and action. Humanity will be united, wars will be made impossible and peace will reign supreme.

7

ELECTRIC DRIVE FOR BATTLE SHIPS*

The ideal simplicity of the induction motor, its perfect reversibility and other unique qualities render it eminently suitable for ship propulsion, and ever since I brought my system of power transmission to the attention of the profession through the American Institute of Electrical Engineers I have vigorously insisted on its application for that purpose. During many years the scheme was declared to be impracticable and I was assailed in a manner as vicious as incompetent. In 1900, when an article from me advocating the electric drive appeared in the Century Magazine, Marine Engineering pronounced the plan to be the "climax of asininity", and such was the fury aroused by my proposals that the editor of another technical periodical resigned and severed his connection rather than to allow the publication of some attacks.

A similar reception was accorded to my wireless boat repeatedly described in the Herald of 1898. The patents on these inventions have since expired and they are now common property. Meanwhile insane antagonism and ignorance have been replaced by helpful interest and appreciation of their value. Recently the Navy Department has let contracts aggregating $ 100,000,000 for the construction of seven war vessels with the induction motor drive, and an equal sum is appropriated to cover the cost of four huge battle cruisers which are to be fitted out in the same way. This latter project is resisted by some shipbuilders, turbine makers, electrical manufacturers and engineers who, in fear of a fatal mistake by the government and under the sway of patriotic motives, urged upon the authorities the employment of the geared turbine.

CONTROVERSIAL CORRESPONDENCE

Numerous letters of protest have been written to C. A. Swanson, of the Senate Naval Committee, but what has so far come out of this correspondence is purely controversial and of no profit whatever to those who seek information. It is regrettable that the question should have been raised at this critical moment, when speedy preparation against threatening national perils is recognized as imperative, and in view of this no doubt should be permitted to remain in the public mind as to the superiority of the equipment recommended by the naval experts. In the following I shall endeavor to make this clear to the general reader.

The most efficient means of propulsion is a jet of water expelled astern from the body of the vessel. Though the theoretical laws governing its action were precisely expressed fifty years ago by Rankine, a singular and inexplicable prejudice against this device still prevails among engineers and writers of text books on hydraulics. But the far sighted are keenly alive to its possibilities. While our present motive resources do not admit of an advantageous use of the jet, it can be confidently predicted that it will soon

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* New York Herald, Febr. 25, 1917.

be instrumental in a more complete conquest of the deep. I firmly believe that at this writing it is being applied to the submarines devastating the oceans, for their silence alone can explain why they escape so easily detection by microphonic instruments. The sound emitted is the Achilles talon of the undersea boat. Its suppression materially increases the destructiveness of the new weapon.

THE HELICAL PROPELLER

However, under the existing conditions the best results are obtained in all kinds of surface craft with a helical propeller, which is operated in four different ways. First, straight from the shaft of the prime mover; second, by means of a gear wheel; third, through a hydraulic transformer, and, fourth, by an electric transmitter of power. As the screw in order to save energy must be revolved at a moderate rate, the first mentioned, or "direct drive", lends itself best to a reciprocating or rotary engine. The former is clumsy, the latter impossible, and competition has forced the turbine on the market. But, excessive speed being indispensable to its good performance, it had to be adapted to the propeller. This was, in a measure, accomplished by "staging" — that is, passing the steam through a number of turbines in succession — a plan obviously entailing great drawbacks, financial and otherwise. Need of reducing the bulk and cost of the machinery and insuring better working then compelled the adoption of the second arrangement — "geared turbine drive" — in which a peculiar pinioned wheel, first introduced by De Laval, transmits motion to the screw. Next, efforts to do away with certain limitations of this combination resulted in the third, or "hydraulic drive", the turbine actuating the propeller through a centrifugal pump and water motor. Finally, as the furthest step toward perfection, the last named disposition — "electric drive" — was resorted to. In this case the turbine imparts rotation to a dynamo, which in turn runs a motor carrying the screw on its shaft.

ADVANTAGES OF TYPES

Each of these forms has its supporters and champions. In principle the first would be the preferable were it not handicapped in many respects. The second type is cheap, but the gear is a serious objection. Though less economical, the third commends itself by a number of practical and valuable features. As to the last, it is not only very efficient but obtains results impossible with other forms. The law of survival of the fittest is asserting itself, and the struggle for supremacy is now on between the geared turbine and the electric drive.

Through gradual improvement of the cutting tools, scientific design, metallurgical advances and refinement of lubricants, the so-called herringbone gear has been brought to great perfection. De Laval attained an efficiency of ninety-seven per cent and MacAlpine, Melville and Westinghouse ninety-eight and one-half per cent in the transmission from the driving to the driven shaft. On the other hand, ninety-three and three-quarters per cent may be considered as the maximum with electrical apparatus. This means that with the gear the same turbine would impart five per cent more power to the propeller, which should increase the speed of the cruiser from thirty-five to a little more than thirty-five and one-half knots. As it also appears at first sight that the electric drive requires additional space, is heavier and more costly, it is only natural for those who have not made a thorough study of all its phases to decide in favor of the gear.

SOME FATAL MISTAKES

But a careful inquiry into the subject would induce them to reverse their opinion. In estimating the relative merits of these essentially different propelling means they make two fatal mistakes. The first is to take the power transmitted under abnormal conditions as a criterion; the second to draw a parallel between instalments entirely unlike, one primitive, the other elaborate, the former being incapable of fulfilling important functions of the latter. When premises are erroneous deductions therefrom must needs be faulty. Thus the opponents of the electric drive have been led to the conclusion that it is less efficient than the gear, of greater weight, more expensive and uncertain of success. How much truth there is in these contentions will be apparent from an examination of well established facts.

The electric drive is of complex influence on results in ship operation. For the sake of brevity it will be viewed only in the following principal aspects: — (1) turbine performance, (2) power transmitted to the propeller, (3) efficiency of the screw, (4) low power cruising, (5) high power action, (6) fuel consumption by auxiliaries and apparatus for ship use, (7) general economy and (8) promptness and precision of control of all effects, internal and external.

The present turbines are extremely unsuitable for ship propulsion. They offer a striking example of an antiquated invention of small value elevated to a position of extraordinary commercial utility through profound research and astonishing mechanical skill. With hundreds of thousands of thin blades easily destroyed, buckets that through corrosion and erosion soon become wasteful and small clearances between surfaces rotating at terrific rates, they are a cause of constant danger and hazard.

IRREVERSIBLE TURBINES

But their cardinal defect is that they are irreversible, which necessitates the employment of separate turbines for backing. These, besides involving great expense and considerable friction loss, impose narrow limits on the temperature of the working medium. Very high superheat, so desirable in thermo-dynamic conversion, is out of the question in such perishable structures, but from 200 to 300 degrees F. are permissible.

To that extent, then, the turbine is at an advantage when driving a dynamo. Two hundred degrees superheat will usually effect a saving of about twenty-three per cent of steam and ten per cent of fuel. This, however, is not the only gain. The turbine, freed from all the impediments of the gear drive, is capable of being safely run at a higher peripheral speed with a correspondingly increased efficiency and output. Thus, by moderate superheat and other simple and allowable expedients, it becomes practicable to develop twenty-five per cent more power from the same fuel, and this alone would make the electric drive decidedly superior to its competitor.

A MECHANICAL TOUR DE FORCE

As regards the power transmitted from the turbine to the propeller, it will seem in the light of the preceding that the gear is better by five per cent. That may be the case in exceptional tests, but it is quite different in actual service. To this is to be traced the error of those who are taking results obtained at constant load as standard of comparison. The perfection of the modern high speed gear was a veritable tour de force of the scientific machinist. It is a wonderful device, but it also has its inseparable weaknesses and shortcomings. Since the friction loss in it is sensibly constant through a wide range of performance, a relatively great amount of energy is absorbed at small load. The gear is likewise very sensitive to shocks and vibrations, which break down the capillary oil film, vital to smooth running. In consequence, there is great waste of power when the resisting force is subject to frequent and sudden fluctuations. Measurements I made with turbine gears have shown that while the efficiency with steady and normal effort was ninety-six per cent, not more than ninety per cent was realized with a rapidly varying load. This is what might be expected in practice. Any one who has listened to the tortured engines of a steamship in heavy sea could not have failed to observe how the turning effort varies as the vessel rolls, pitches and ploughs through billows and conflicting undercurrents. A similar state of things is apt to confront a war ship in action, as was evidenced in recent naval engagements, when mountains of water were raised by the exploding shells. Under such circumstances the gear is at a great disadvantage, as the electric drive is susceptible to these drawbacks in a much smaller degree. The idea that the gear transmits more of the primary power to the propeller than the combination of dynamo and motor is, therefore, largely illusionary. There is ample evidence, experimental and inferential, that rather the opposite is true.

SUPERIORITY OF ELECTRIC DRIVE

Considering the efficiency of the screw as distinct from that attained in the transmission of power, it is admittedly better with the electric drive, this conclusion being entirely based on the superior adaptability and flexibility of the system. But there are deeper causes which should be taken into account. The interposition of electromagnetic means between the turbine and propeller materially reduces the loss due to shocks, vibrations, racing and other disturbances owing to inherent elastic resilience and equalizing tendency. The saving of energy thus effected at high speed and in a heavy sea is considerable.

Economy in cruising is one of the most desirable qualities of a war vessel. This is its ordinary use, for the chance of ever being engaged in battle is remote. The bitterest opponents of the electric drive do not deny that it excels in this feature, upon which the manufacturer chiefly relies in guaranteeing a fuel consumption from 10 to 12 per cent smaller than with the gear. The latter is hopelessly condemned by inability of adjustment to varying speed and wasteful in cruising operations, while the former is readily adaptable and economical under all conditions.

Another quality of the electric drive, which may prove especially valuable in action, is its capacity of carrying great overload without danger, owing to the nature of the connection between the turbine and propeller, as explained. The gear is rigid and unyielding and any increase of effort, particularly if sudden, may cause a breakdown.

SAVING OF POWER

Referring to the auxiliaries proper and other apparatus for ship use, to which are chargeable approximately 20 per cent of the fuel consumed, a very substantial saving of power will be achieved through the introduction of the electrical method.

Quite apart from this central station supply will be operative in reducing other waste, many accessories will be dispensed with and general economy materially increased.

But from the military point of view the quickness, ease and precision of control will perhaps be the most significant of the advantages gained. Everything may be made to respond instantly to the pressure of a button. By reversing the motors the vessel may be brought from full speed to a stop within its length. It will be possible to make it go through all evolutions with extraordinary rapidity and a perfection of manoeuvre, undreamed of before, will be attained.

A curious mistake is made by the advocates of the turbine gear in estimating relative weight. It hardly needs be stated that it is unfair, if not absurd, to compare arrangements of widely different character and scope. Only such as are capable of accomplishing the same results should be considered. Now, a gear drive corresponding to the electric would consist of four main turbines with gears, four reversing turbines of the same capacity, and eight smaller driving and reversing turbines for cruising. This agglomeration of complex and not all too rugged machinery, with its network of water, air and oil pipes, valves, pumps and attachments, would by far exceed in weight the proposed electric drive, and would also require better structural protection, not to speak of other defects and shortcomings.

QUESTION OF WEIGHT

It should be observed, however, that the weights must be taken in their relation to that of the ship. One equipment may be heavier than another, but if it is more efficient and thereby reduces the weight of fuel and other cargo, it is for all purposes the lighter of the two.

The same is true of the cost. Comparative figures mean nothing. The question is whether the investment of capital is justified by what is to be accomplished. But enough has been said to show that for results in all respects equivalent, assuming them to be possible, the gear type, notwithstanding all claims to the contrary, would be more expensive.

That the electric drive is experimental and uncertain of performance is the least tenable of adverse assertions. In the first place, it has been successfully employed on a number of vessels and a great many more are being built. It also was found to be capable of an efficiency higher than that of any other form. But this is quite immaterial. The confidence that in the present instance all expectations will be realized is not based on a few demonstrations, but on years of experience with power plants ever since my system was commercially inaugurated. Tens of millions of horse power of induction motors are now in use the world over and no failure is recorded.

NEW CRUISERS' REQUIREMENTS

The new cruisers will require 180,000 horse power each, which, if necessary can be developed by four units of 45,000 horse power. Turbines of that capacity have been constructed and are in operation today. Dynamos of corresponding output have been installed at several places and are supplying light and power to large cities and districts. Induction motors of 15,000 horse power are being turned out by the manufacturers and can be produced in any size that may be desired, for of all kinds of motors this is the simplest and most dependable. Long since the whole system has been worked out and perfected to the least detail. The project is colossal, but it can be readily carried out by any of the few concerns who are possessed of the proper facilities. Not even a new tool has to be made. There is nothing whatever untried or hazardous about the electric drive.

Much stress is laid on reports, still to be verified, that it was rejected by England and Germany. But this is of no consequence. It has been rejected here more than once. Besides, there was war in the air of Europe and the time for radical innovations unpropitious. Moreover, the Diesel engine was looming up with large possibilities and

Dr. Föttinger's hydraulic drive was being tried. The beginning must be made somewhere and it would be deplorable indeed if the United States, where the invention was first announced and introduced on a gigantic scale, were the last to recognize it. Such mistakes have happened only too often. The foreign navies are not in the habit of keeping the press informed of their doings and it is safe to predict that if progress in this country is much retarded there will be a repetition of previous disappointments.

It is unnecessary to dwell on other objections which are of minor importance and of no bearing on the principle. Without going into tedious technical discussion, it may be stated that the electric drive, if judiciously designed, will save not less than twenty-five per cent of fuel and, with due regard to this and certain specific and invaluable advantages, will be lighter, cheaper and in every respect more dependable than the gear. In fact, I believe that a scheme can be devised permitting the placing of all vital parts below the water line. In view of this, it is to be hoped that the Secretary of the Navy will not pay attention to the protests of rivals, however patriotic, but will cause the good work to be pushed to completion with all the power at his command.

These statements are to be understood as reflecting the present state of the art. The advent of a reversible turbine will profoundly affect the situation in favor of the gear. Such a machine has been perfected and was described in the Herald of October 15, 1911. It is the lightest prime mover ever produced and can be operated without trouble at red heat, thereby obtaining a very high economy in the transformation of heat energy. I anticipate its speedy and extensive application to ship propulsion. But although an ideally simple and very inexpensive drive will be thus provided, there will still be weighty reasons for adopting the electric method on war ships. In order to dissipate all doubt created in the mind by diversified engineering opinion, I will make known but one of them, which in itself is sufficiently consequential and convincing to dispense with further arguments.

DISARMAMENT IMPOSSIBLE

It is idle to dream of disarmament and universal peace in the face of the terrible events which are now unfolding. They prove conclusively that no country will be allowed to control all others by any means. Before all peoples can feel secure of their national existence and worldwide harmony established certain obstacles will have to be removed, the chief of which are German militarism, British domination of the seas, the rising tide of Russian millions, the yellow peril and the money power of America. These adjustments will be slow and pennible in conformity with natural laws. International friction and armed conflict will net be banished from the earth for a long period to come. The drag on human progress would not be so great if war energy could be maintained in purely potential form. This can and will be done through the universal introduction of wireless power. Then all destructive energy will be obtained without effort merely by controlling the life sustaining forces of peace.

The maintenance of war ships and other military implements involves an appalling waste. A vessel costing twenty millions of dollars is rendered virtually worthless in the short span of ten years, deteriorating at the mean rate of two million dollars a year, interest not considered. Hardly more than one out of fifty serves its real purpose. To lessen this ruinous loss and exploit certain inventions I elaborated a scheme some years ago. It was recognized as rational bur financially and in other ways difficult of realization. Now, when national economy and preparedness have become burning questions, it assumes special import and significance.

TO USE WAR SHIPS IN PEACE

The underlying idea is to make war ships available for purposes of peace in a profitable manner, at the same time improving them in a number of features. I am aware of the proposal lately advanced to employ them as carriers of commerce, but this is not feasible and would be an impediment to further perfection. My project primarily contemplated the instalment of the electric drive and the use of the turbo-dynamos for light and power supply and manufacture of various valuable products and articles aboard or on land. This would be a step in the direction of present development meeting the objects of both military and industrial preparedness. I further intended the creation of a type of vessel on radically different principles, which would be a precious asset in peace and ever so much more destructive in war. The new cruisers, if equipped as planned by the Navy Department, will constitute four floating central stations of 180,000 horse power each. The turbines and dynamos are designed for highest efficiency and operate under most favorable conditions. The power they are capable of developing represents a market value of several million dollars a year and could be advantageously utilized at places where fuel can be readily obtained and transport is convenient. The plants would also prove of great value in cases of emergency. They could be quickly sent to any point along the coast of the United States or elsewhere and would enable the government to lend speedy assistance whenever necessary.

But this is not all. There is another and still more potent reason for adopting the electric method. It is founded on the knowledge that at a time not distant the present means and methods of warfare will be revolutionized through novel applications of electric force.

III

AN AUTOBIOGRAPHICAL ARTICLE

SOME PERSONAL RECOLLECTIONS*

I am glad to be accorded this opportunity for two reasons. In the first place I have long since desired to express my great appreciation of the Scientific American and to acknowledge my indebtedness for the timely and useful information which its columns are pouring out in a steady stream. It is a publication remarkable for the high quality of special articles as well as for the accurate review of technical advances. The knowledge it conveys is always reliable and rendered still more valuable through the scrupulous observance of literary courtesy in the quotation of the sources. The services it has rendered in helping invention and spreading enlightenment are inestimable. The Scientific American is a periodical ably and conscientiously conducted, measured and dignified in tone to the point of serving as a model, and in these features, as much as in the wealth and excellence of its contributions, it reflects great credit, not only on its staff and publishers, but on the whole country. This is not an idle compliment, but a genuine and well-deserved tribute to which I add my best wishes for continued success on this memorable occasion.

The second reason is one that concerns me personally. Many erroneous statements have appeared in print relative to my discovery of the rotating magnetic field and invention of the induction motor which I was compelled to pass in silence. Great interests have waged a long and bitter contest for my patent rights; commercial animosities and professional jealousies were aroused, and I was made to suffer in more than one way. But despite of all pressure and efforts of ingenious lawyers and experts, the rulings of the courts were in support of my claims for priority in every instance without exception. The battles have been fought and forgotten, the thirty or forty patents granted to me on the alternating system have expired, I have been released of burdensome obligations and am free to speak.

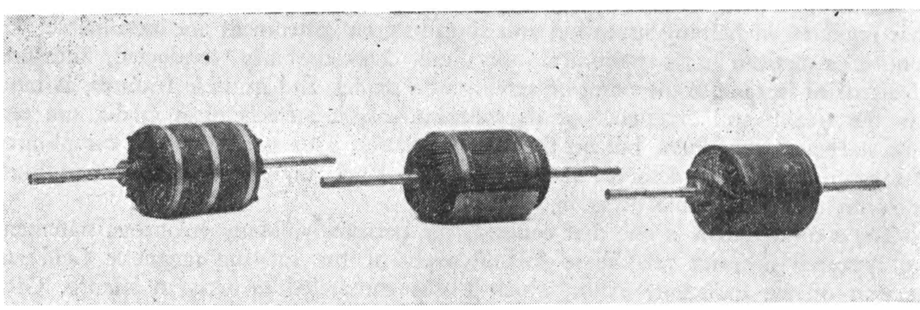
Every experience which I have lived through bearing on that early discovery is vividly present in my memory. I see the faces of the persons, the scenes and objects of my attention, with a sharpness and distinction and in a fullness of light which is astonishing, and is a measure of the intensity and depth of the original impressions. I have always been fortunate in ideas, but no other invention, however great, could be as dear to me as that first one. This will be understood if I dwell briefly on the circumstances surrounding it and some of the phases and incidents of my young life.

From my childhood I had been intended for the clergy. This prospect hung like a dark cloud on my mind. After passing eleven years at a public school and a higher institution, I obtained my certificate of maturity and found myself at the critical point of my career. Should I disobey my father, ignore the fondest wishes of my mother, or should I resign myself to fate? The thought oppressed me, and I looked to the future with dread.

Just at that time a terrible epidemic of cholera broke out in my native land. People knew nothing of the character of the disease and the means of sanitation were of the poorest kind. They burned huge piles of odorous shrubbery to purify the air, but drank

* Scientific American, June 5, 1915.

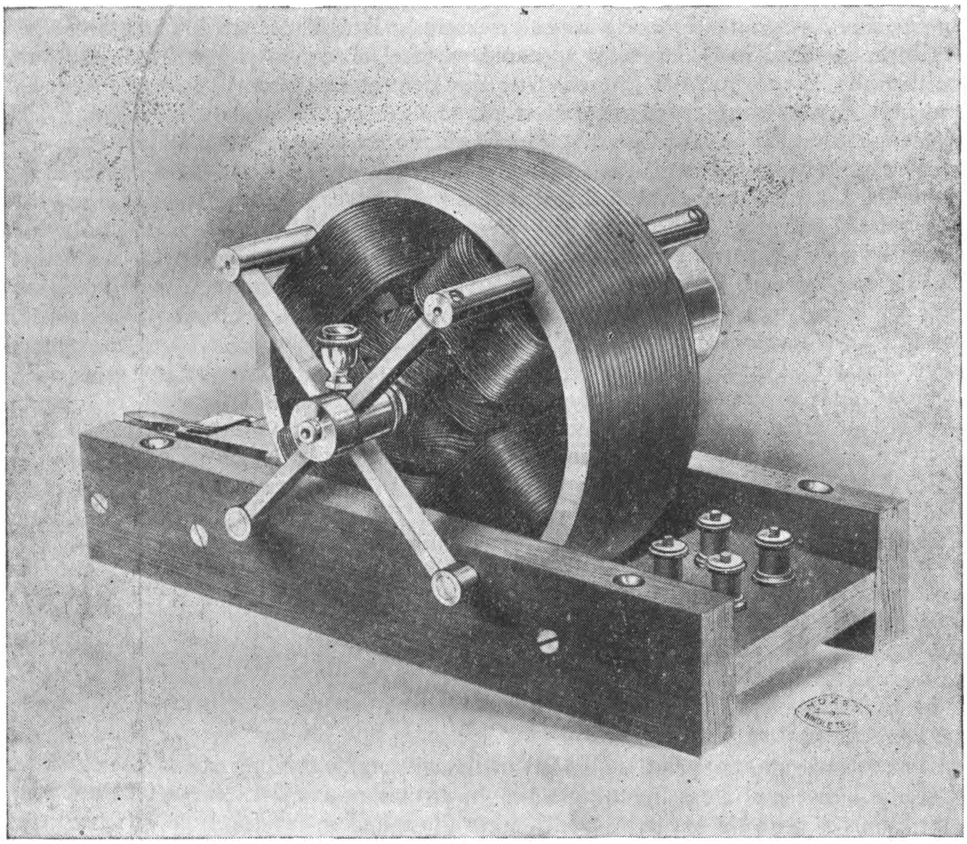
freely of the infected water and died in crowds like sheep. Contrary to peremptory orders from my father I rushed home and was stricken down. Nine months in bed with scarcely the ability to move seemed to exhaust all my vitality, and I was given up by the physicians. It was an agonizing experience, not so much because of physical suffering as on account of my intense desire to live. On the occasion of one of the fainting spells my father cheered me by a promise to let me study engineering; but it would have remained unfulfilled had it not been for a marvelous cure brought about by an old lady. There was no force of suggestion or mysterious influence about it. Such means would have had no effect whatever on me, for I was a firm believer in natural laws. The remedy was purely medicinal, heroic if not desperate; but it worked and in one year of mountain climbing and forest life I was fit for the most arduous bodily exertion. My father kept his word, and in 1877 I entered the Joanneum in Gratz, Styria, one of the oldest technical institutions of Europe. I proposed to show results which would repay my parents for their bitter disappointment due to my change of vocation. It was not a passing determination of a light-hearted youth; it was iron resolve. As some young reader of the Scientific American might draw profit from my example I will explain.



Three rotors used with the early induction motor shown below

When I was a boy of seven or eight I read a novel entitled “Abafi” — The Son of Aba — a Servian translation from the Hungarian of Josika, a writer of renown. The lessons it teaches are much like those of “Ben-Hur”, and in this respect it might be viewed as anticipatory of the work of Wallace. The possibilities of will-power and self-control appealed tremendously to my vivid imagination, and I began to discipline myself. Had I a sweet cake or a juicy apple which I was dying to eat I would give it to another boy and go through the tortures of Tantalus, pained but satisfied. Had I some difficult task before me which was exhausting I would attack it again and again until it was done. So I practised day by day from morning till night. At first it called for a vigorous mental effort directed against disposition and desire, but as years went by the conflict lessened and finally my will and wish became identical. They are so to-day, and in this lies the secret of whatever success I have achieved. These experiences are as intimately linked with my discovery of the rotating magnetic field as if they formed an essential part of it; but for them I would never have invented the induction motor.

In the first year of my studies at the Joanneum I rose regularly at three o’clock in the morning and worked till eleven at night; no Sundays or holidays excepted. My success was unusual and excited the interest of the professors. Among these was Dr. Allé, who lectured on differential equations and other branches of higher mathematics and whose addresses were unforgettable intellectual treats, and Prof. Poeschl, who held the chair of Physics, theoretical and experimental. These men I always remember with a sense of gratitude. Prof. PoeschI was peculiar; it was said of him that he wore the same coat for twenty years. But what he lacked in personal magnetism he made up in the perfection of his exposition. I never saw him miss a word or gesture, and his demonstrations and experiments always went off with clocklike precision. Some time in the winter of 1878 a new apparatus was installed in the lecture room. It was a dynamo with a laminated permanent magnet and a Gramme armature. Prof. Poeschl had wound some wire around the field to show the principle of self-excitation, and provided a battery for running the machine as a motor. As he was illustrating this latter feature there was lively sparking at the commutator and



One of the earliest of induction motors. Although it weighed only a little over 20 pounds, it developed ¼ horse-power at a speed of 1,800 revolutions, a performance considered remarkable at the time.

brushes, and I ventured to remark that these devices might be eliminated. He said that it was quite impossible and likened my proposal to a perpetual motion scheme, which amused my fellow students and embarrassed me greatly. For a time I hesitated, impressed by his authority, but my conviction grew stronger and I decided to work out the solution. At that time my resolve meant more to me than the most solemn vow.

I undertook the task with all the fire and boundless confidence of youth. To my mind it was simply a test of will-power. I knew nothing of the technical difficulties. All my remaining term in Gratz was passed in intense but fruitless effort, and I almost convinced myself that the problem was unsolvable. Indeed, I thought, was it possible to transform the steady pull of gravitation into a whirling force? The answer was an emphatic no. And was this not also true of magnetic attraction? The two propositions appeared very much the same.

In 1880 I went to Prague, Bohemia, carrying out my father's wish to complete my school education at a university. The atmosphere of that old and interesting city was favorable to invention. Hungry artists were plentiful and intelligent company could be found everywhere. Here I made the first distinct step in advance, by detaching the commutators from the machines and placing them on distant arbors. Every day I imagined arrangements on this plan without result, but feeling that I was nearing the solution. In the following year there was a sudden change in my views of life. I realized that my parents were making too great sacrifices for me and resolved to relieve them of the burden. The American telephone wave had reached the European continent, and the system was to be installed in Budapest. It appeared an ideal opportunity, and I took the train for that city. By an irony of fate my first employment was as a draughtsman. I hated drawing; it was for me the very worst of annoyances. Fortunately it was not long before I secured the position I sought, that of chief electrician to the telephone company. My duties brought me in contact with a number of young men in whom I became interested. One of these was Mr. Szigety, who was a remarkable specimen of humanity. A big head with an awful lump on one side and a sallow complexion made him distinctly ugly, but from the neck down his body might have served for a statue of Apollo. His strength was phenomenal. At that time I had exhausted myself through hard work and incessant thinking. He impressed me with the necessity of systematic physical development, and I accepted his offer to train me in athletics. We exercised every day and I gained rapidly in strength. My mind also seemed to grow more vigorous and as my thoughts turned to the subject which absorbed me I was surprised at my confidence of success. On one occasion, ever present in my recollection, we were enjoying ourselves in the Varos-liget or City Park. I was reciting poetry, of Which I was passionately fond. At that age I knew entire books by heart and could read them from memory word by word. One of these was Faust. It was late in the afternoon, the sun was setting, and I was reminded of the passage:

> "*Sie rückt und weicht, der Tag ist überlebt,*
> *Dort eilt sie hin und fördert neues Leben,*
> *Oh, dass kein Flügel mich vom Boden hebt*
> *Ihr nach und immer nach zu streben!*
>
> *Ach, zu des Geistes Flügeln wird so leicht*
> *Kein körperlicher Flügel sich gesellen!*"

As I spoke the last words, plunged in thought and marveling at the power of the poet, the idea came like a lightning flash. In an instant I saw it all, and I drew with a stick on the sand the diagrams which were illustrated in my fundamental patents of May, 1888, and which Szigety understood perfectly.

It is extremely difficult for me to put this experience before the reader in its true light and significance for if is so altogether extraordinary. When an idea presents itself it is, as a rule, crude and imperfect. Birth, growth and development are phases normal and natural. It Was different with my invention. In the very moment I became conscious of it. I saw it fully developed and perfected. Then again, a theory, however plausible, must usually be confirmed by experiment. Not so the one I had formulated. It was being daily demonstrated every dynamo and motor was absolute proof of its soundness. The effect on me Was indescribable. My imaginings were equivalent to realities; I had carried out what I had undertaken and pictured myself achieving wealth and fame. But more than all this was to me the revelation that I was an inventor. This was the one thing I wanted to be. Archimedes was my ideal. I admired the works of artists, but to my mind, they were only shadows and semblances. The inventor, I thought, gives to the world creations which are palpable, which live and work.

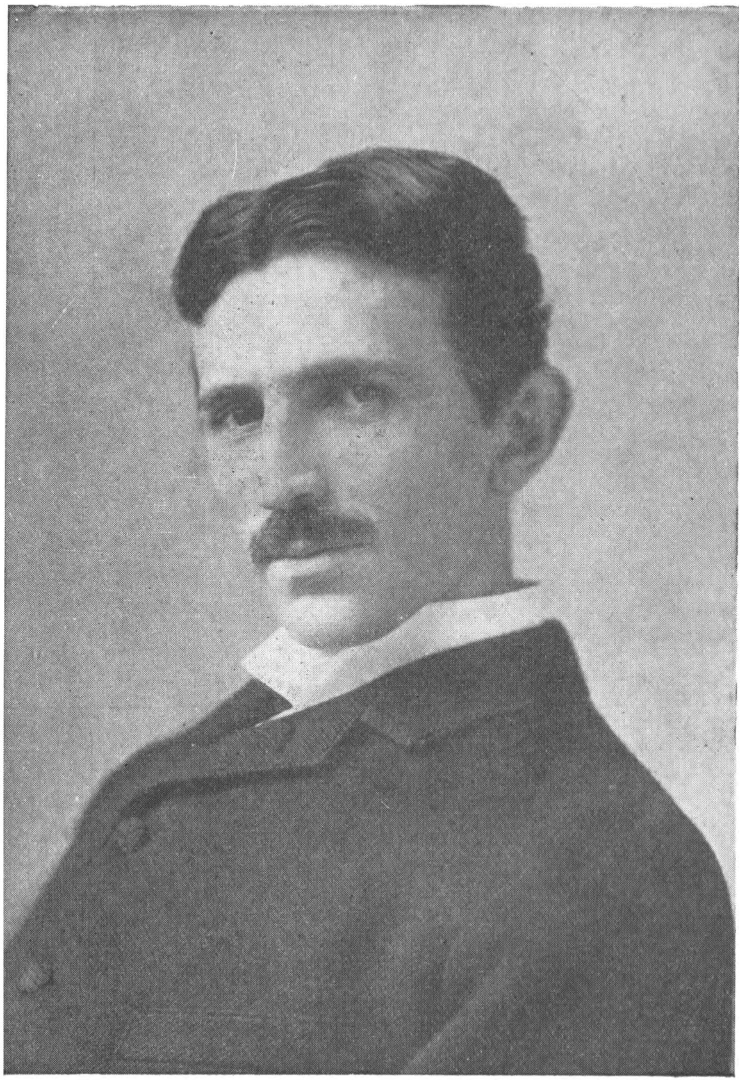
The telephone installation was now completed and in the spring of 1882 an offer was made me to go to Paris, which I accepted eagerly. Here I met a number of

Americans whom I befriended and to whom I talked of my invention, and one of them, Mr. D. Cunningham, proposed to form a company for exploitation. This might have been done had not my duties called me to Strasburg, Alsace. It was in this city that I constructed my first motor. I had brought some material from Paris, and a disk of iron with bearings was made for me in a mechanical shop close to the railroad station in which I was installing the light and power plant. It was a crude apparatus, but afforded me the supreme satisfaction of seeing for the first time, rotation affected by alternating currents without commutator. I repeated the experiment with my assistant twice in the summer of 1883. My intercourse with Americans had directed my attention to the practical introduction and I endeavored to secure capital, but was unsuccessful in this attempt and returned to Paris early in 1884. Here, too, I made several ineffectual efforts, and finally resolved to go to America, where I arrived in the summer of 1884. By a previous understanding I entered the Edison Machine Works, where I undertook the design of dynamos and motors. For nine months my regular hours were from 10:30 A. M. till 5 A. M. the next day. All this time I was getting more and more anxious about the invention and was making up my mind to place it before Edison. I still remember an odd incident in this connection. One day in the latter part of 1884 Mr. Bachelor, the manager of the works, took me to Coney Island, where we met Edison in company with his former wife. The moment that I was waiting for was propitious, and I was just about to speak, when a horrible looking tramp took hold of Edison and drew him away, preventing me from carrying out my intention. Early in 1885 people approached me with a proposition to develop an arc light system and to form a company under my name. I signed the contract, and a year and a half later I was free and in a position to devote myself to the practical development of my discovery. I found financial support, and in April, 1887, a company was organized for the purpose, and what has followed since is well known.

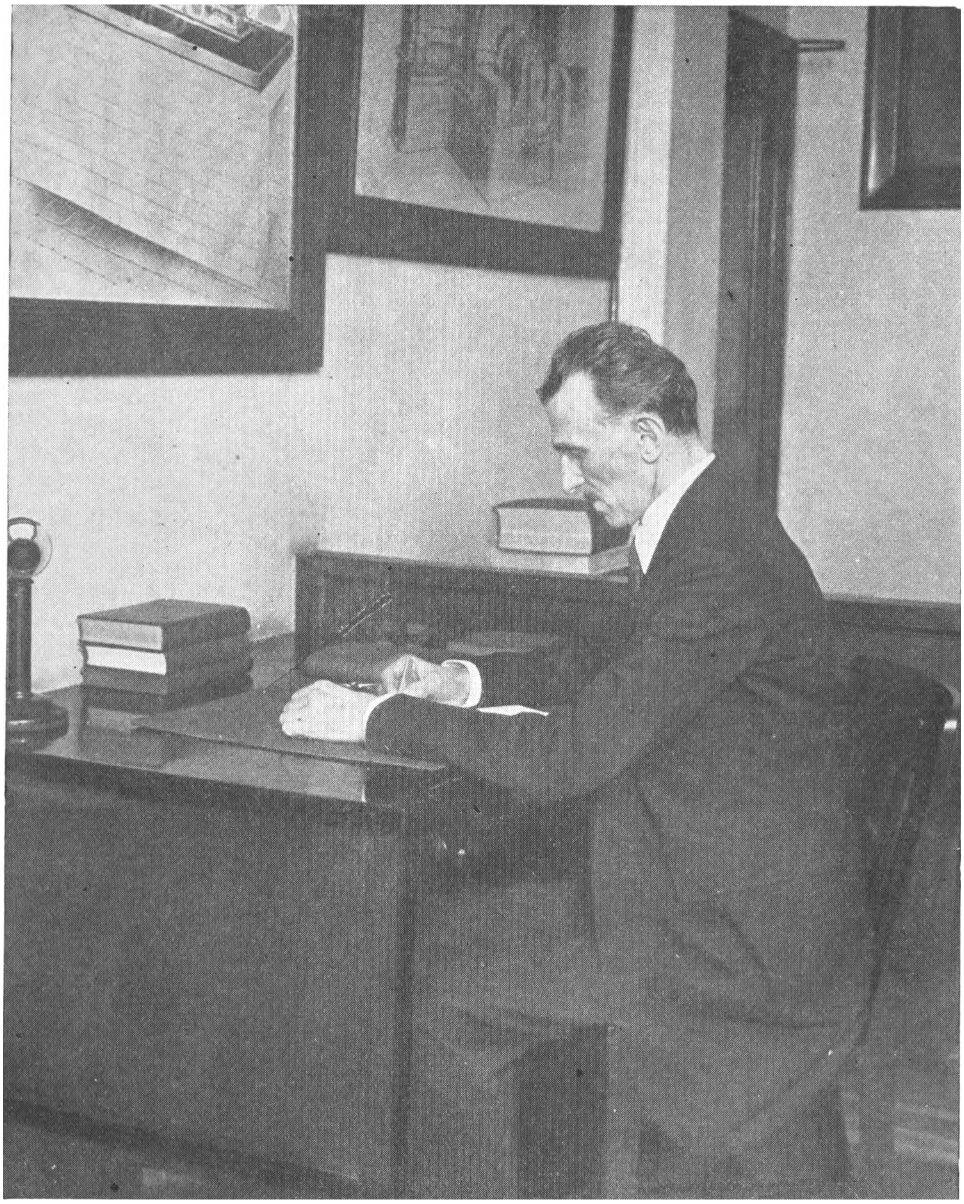
A few words should be said in regard to the various claims for anticipation which were made upon the issuance of my patents in 1888, and in numerous suits conducted subsequently. There were three contestants for the honor, Ferraris, Schallenberger and Cabanellas. All three succumbed to grief. The opponents of my patents advanced the Ferraris claim very strongly, but any one who will peruse his little Italian pamphlet, which appeared in the spring of 1888, and compare it with the patent record filed by me seven months before, and with my paper before the American Institute of Electrical Engineers, will have no difficulty in reaching a conclusion. Irrespective of being behind me in time, Prof. Ferraris' publication concerned only my split-phase motor, and in an application for a patent by him priority was awarded to me. He never suggested any of the essential practical features which constitute my system, and in regard to the split-phase motor he was very decided in his opinion that it was of no value. Both Ferraris and Schallenberger discovered the rotation accidentally while working with a Gaullard and Gibbs transformer, and had difficulty in explaining the actions. Neither of them produced a rotating field motor like mine, nor were their theories the same as my own. As to Cabanellas, the only reason for his claim is an abandoned and defective technical document. Some over-zealous friends have interpreted a United States patent granted to Bradley as a contemporary record, but there is no foundation whatever for such a claim. The original application only described a generator with two circuits which were provided for the sole purpose of increasing the output. There was not much novelty in the idea, since a number of such machines existed at that time. To say that these machines were anticipations of my rotary transformer is wholly unjustified. They might have served as one of the elements in my system of transformation, but were nothing more than dynamos with two circuits constructed with other ends in view and in utter ignorance of the new and wonderful phenomena revealed through my discovery.

PHOTOGRAPHS

Nikola Tesla at the age of 23



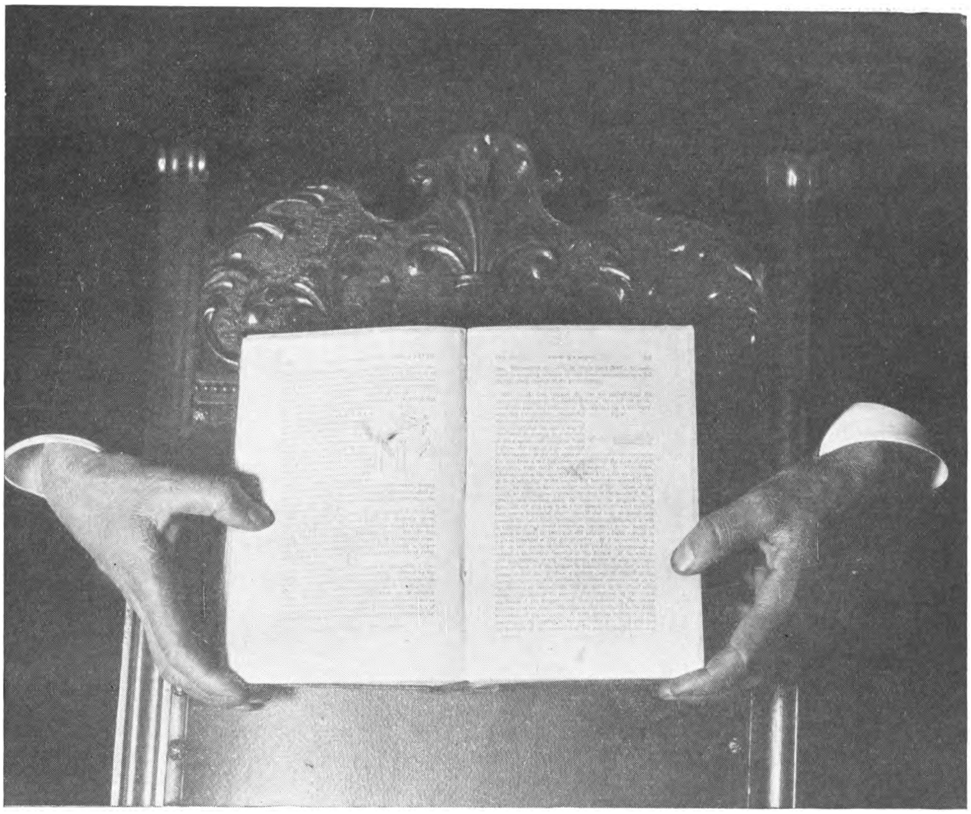
Nikola Tesla at the age of 39



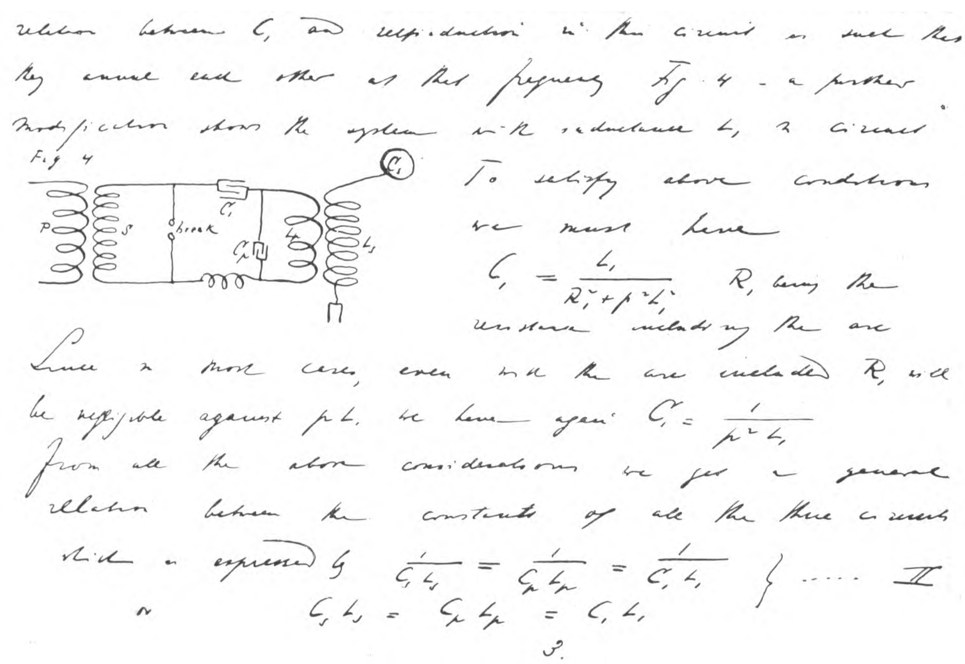
Nikola Tesla in his working room

Nikola Tesla in his laboratory

Nikola Tesla with his "artificial daylight"



Tesla's "*artificial daylight*" *was used in taking this photograph of Tesla's hands*



relation between C_1 and self-induction in the circuit is such that they annul each other at that frequency. Fig. 4 - a further modification shows the system with inductance L_1 in circuit.

Fig 4

To satisfy above conditions we must have

$$C_1 = \frac{L_1}{R_1^2 + p^2 L_1^2}$$

R_1 being the resistance including the arc.

Since in most cases, even with the arc included R_1 will be negligible against pL_1 we have again $C_1 = \frac{1}{p^2 L_1}$

From all the above considerations we get a general relation between the constants of all the three circuits which is expressed by

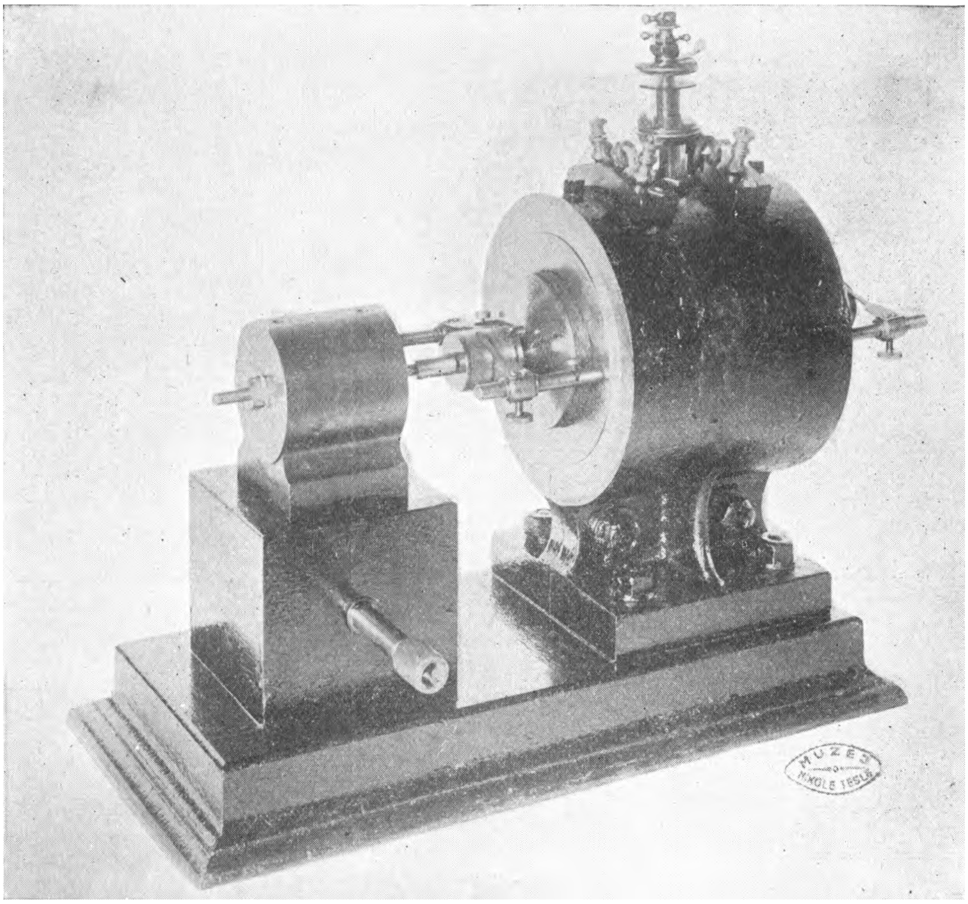
$$\frac{1}{C_s L_s} = \frac{1}{C_p L_p} = \frac{1}{C_1 L_1} \quad \} \ldots\ldots \text{II}$$

or $$C_s L_s = C_p L_p = C_1 L_1$$

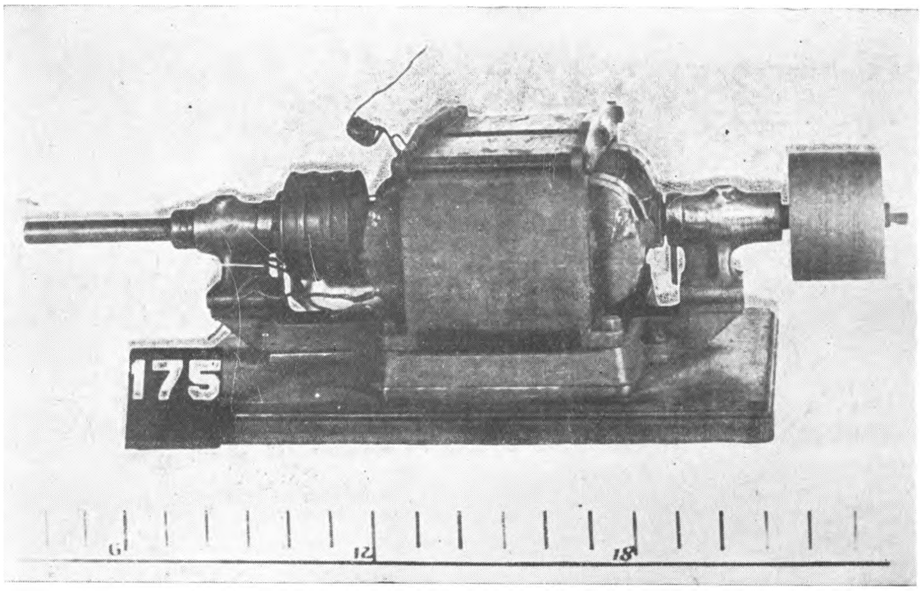
3.

One page of Tesla's notebook from Colorado Springs

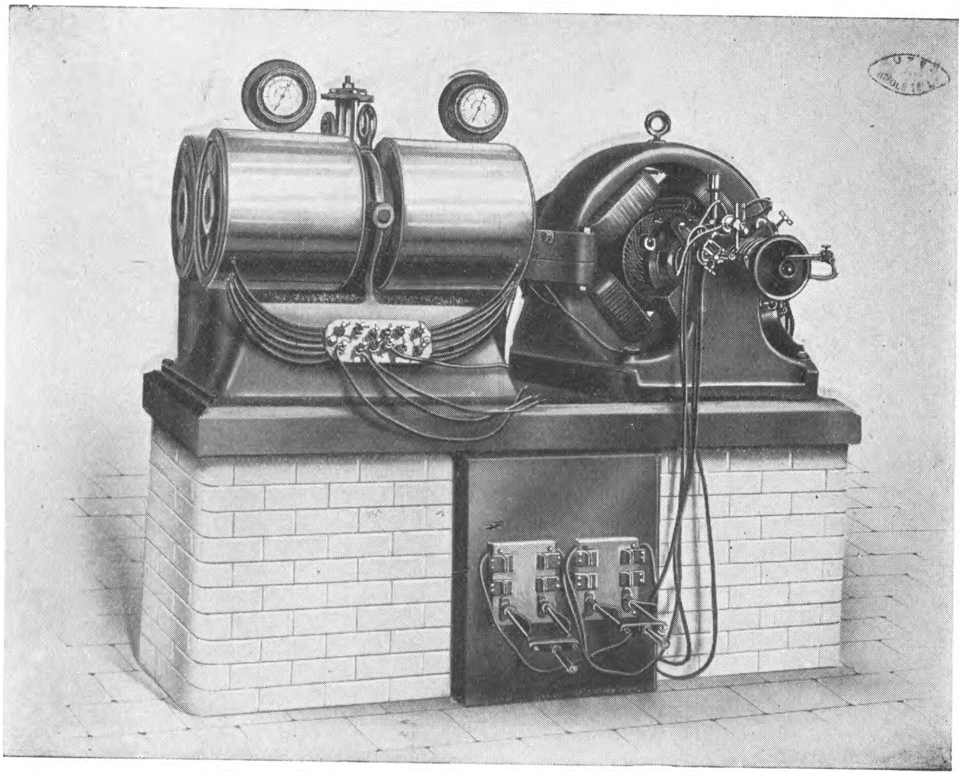
Tesla's laboratory lighted by Tesla's "artificial daylight"



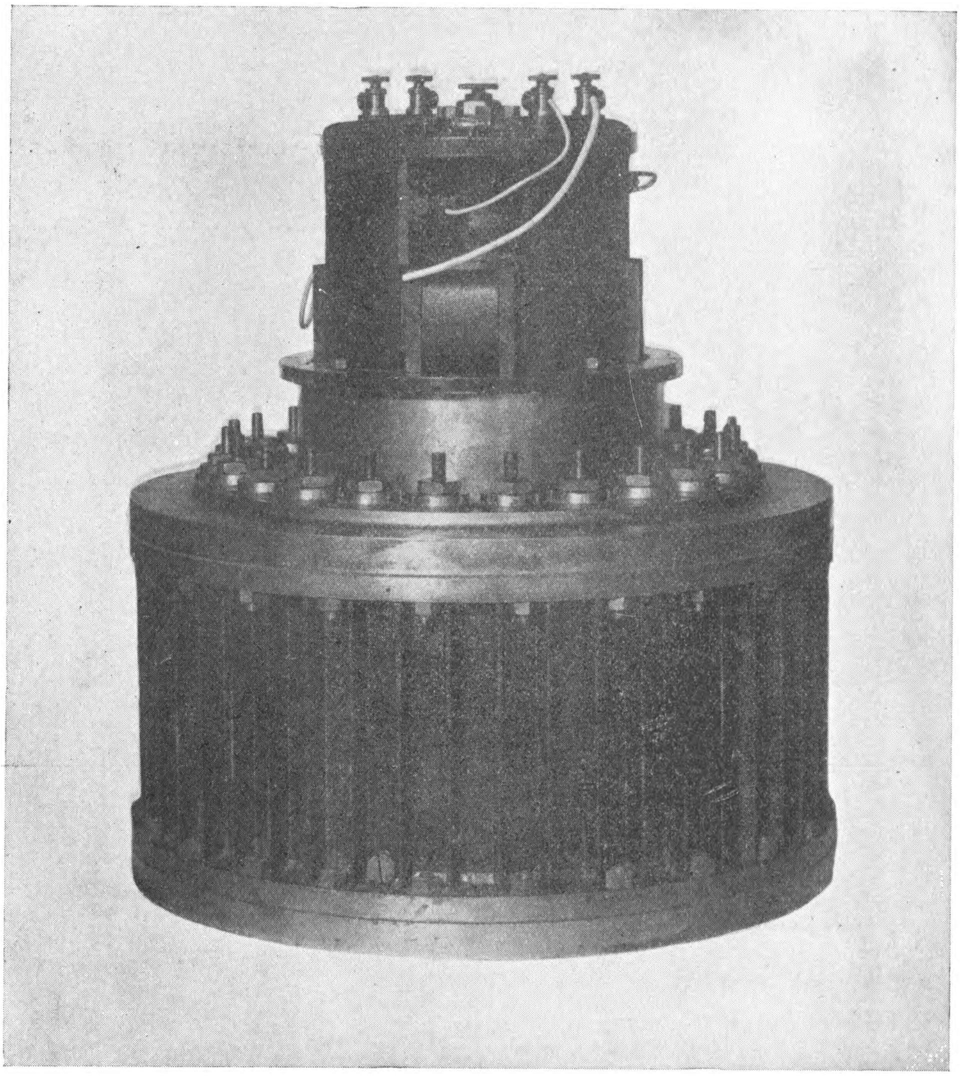
Small dynamo-electric oscillator for scientific uses



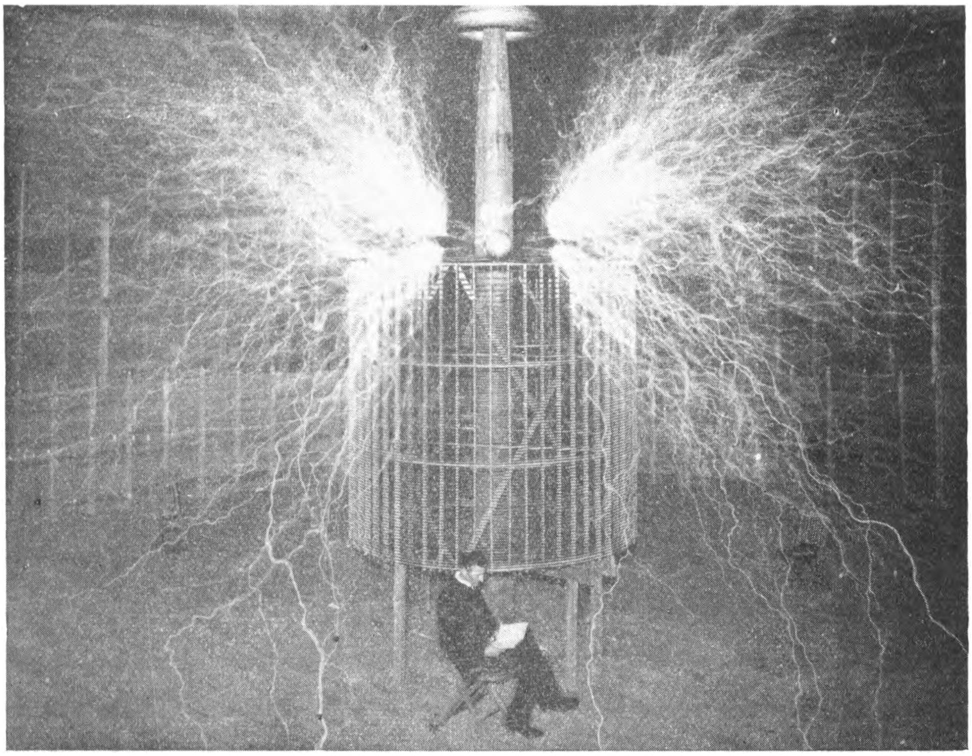
Early laboratory model of Tesla motor with round rotor and slip rings



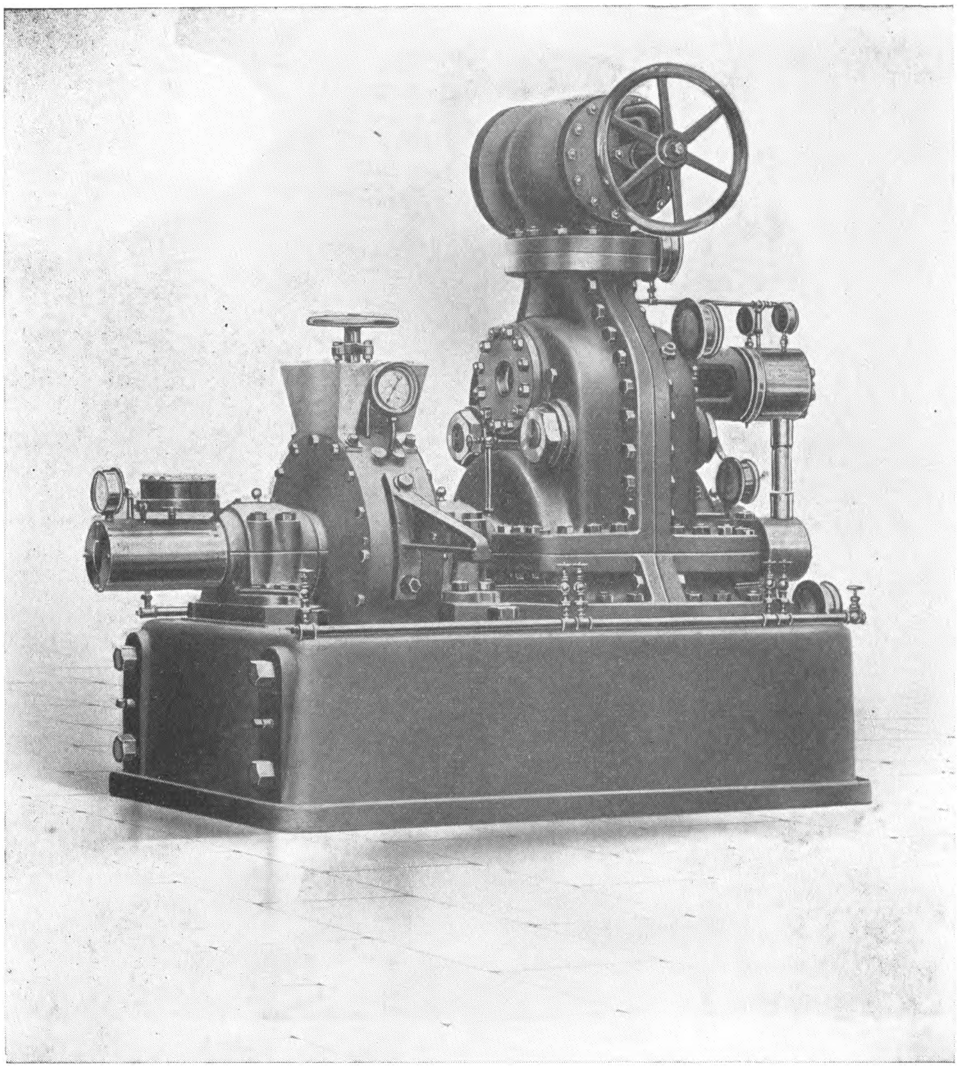
Large dynamo-electric oscillator



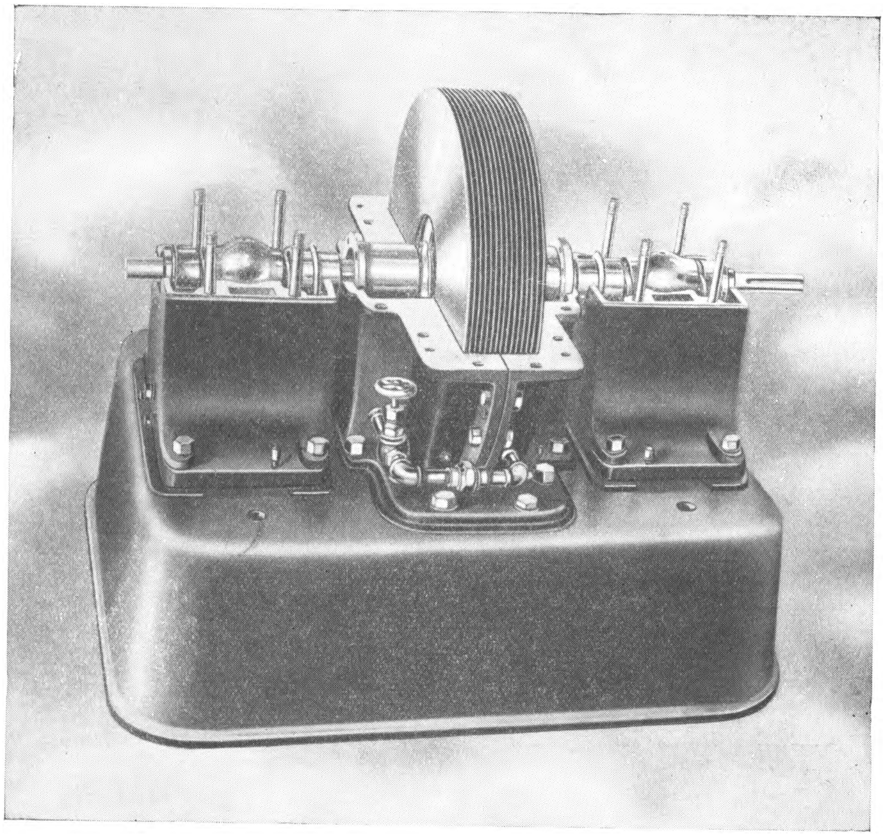
Very fast mercury interrupter for industrial uses



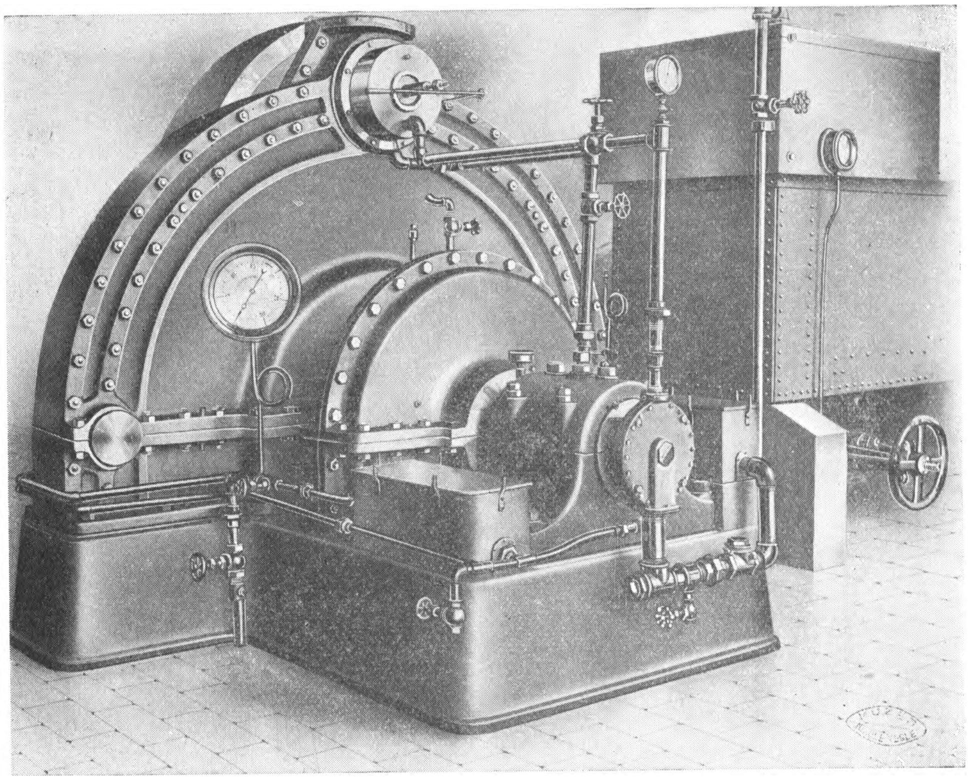
In his laboratory at Colorado Springs Tesla produced extremely high voltages up to 12000000 volts (at a frequency of several hundred thousand cycles per second)



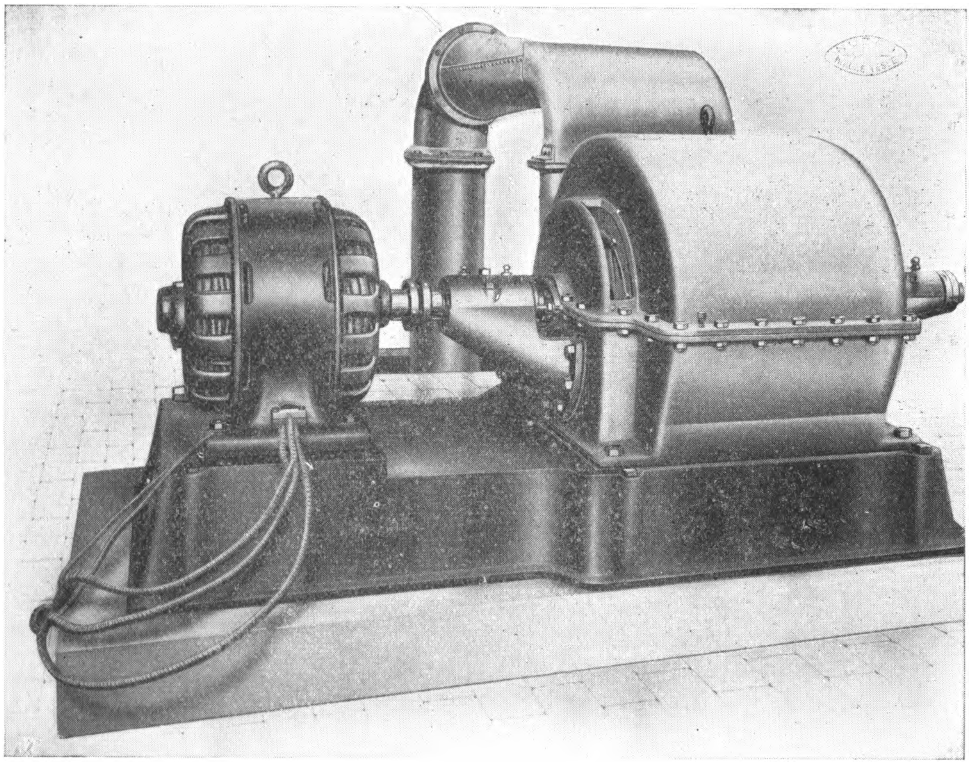
Tesla’s 10000 HP steam turbine



Lower part with rotor of Tesla’s steam turbine



Tesla's turbo-pump



Tesla's blower and three-phase motor

NIKOLA TESLA

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