BIBLIOGRAPHY

AUTOMATION

Automation is described in a variety of ways. Ostwald and Munoz (1) describe automation as automatic handling between machines and subsequent continuous automatic processing. They suggest that automation only exists when a group of operations are linked together. Hill (2) defines automation as the automatic control of one or more machines by extending and linking the basic forms of mechanization. Hill gives a basic example as loading a machine, processing a component, and unloading and transferring to another machine for further processing. From these descriptions it is clear that the key factors are linking and automatic processing.

Groover (3) identifies three basic classes of automation: fixed automation, programmable automation, and flexible automation. Fixed automation is appropriate for high production volumes where the investment can be defrayed over a large number of production units. Fixed automation is inflexible and designed to produce one product or a limited range of products in sequence.

Programmable automation is appropriate for manufacturing small batches of a wide variety of components using similar production processes. The ability to produce a wide range of products is provided by a programmable controller which can reconfigure the system as required. Computer numerically controlled (CNC) machine tools and industrial robots are examples of programmable automation.

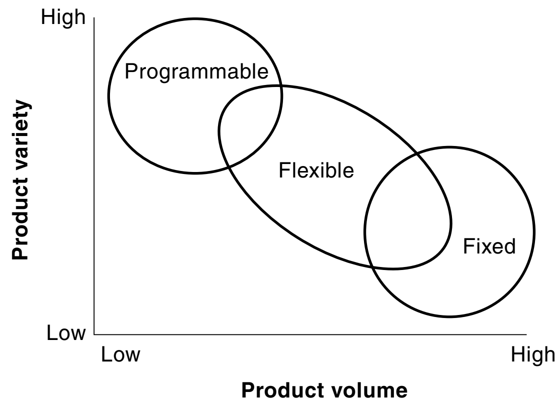

Figure 1. Classes of automation relative to production volume and product variety.

Flexible automation comprises a number of work stations which are linked by a materials handling system and controlled by a central computer. Flexible automation, which is closely associated with the concepts of group technology (4) and cellular manufacture, has led to the development of flexible manufacturing systems (FMSs). By limiting the range of parts which can be manufactured, the FMS has less downtime due to changeovers than a programmable system and produces higher production volumes. The relative positions of the three types of automation in relation to production volume and product variety are shown in Fig. 1.

The implications of the descriptions proposed by Groover are that automation is expensive and factory-wide. This is not the case, and major improvements in performance can be achieved by the introduction of partial automation. Partial automation involves (1) the automation of simple manual operations and (2) the integration of these automated components into the production process.

The level and type of automation introduced is related to the business and manufacturing strategy adopted by the organization. This article will use case studies to explore the relationship between business and manufacturing strategy and the introduction of the appropriate level of automation.

BUSINESS STRATEGY

To examine the impact of automation, it is useful to examine the relevance of the strategic model proposed by Porter (5) and explained in Fig. 2.

Porter identifies three generic strategies which can be used to out perform the competition:

- Overall Cost Leadership
- Differentiation
- Focus

To obtain an overall cost leadership position, a company needs to minimize production costs and maintain a relatively large market share. In this case, automation is often justified purely on reduced labor costs and higher productivity. Although this is the case in labor-intensive industries, a cost breakdown of a typical product, as shown in Fig. 3, suggests that automation has wider applications.

Figure 3 demonstrates that labor costs are often not the most significant factor in the cost of manufacturing a product. Significant savings can be achieved by reducing the cost of raw materials and overheads. Introducing automation produces products of consistent quality, which leads to reduced scrap rates and lower raw material costs. Automation also reduces the cost of in-process inventory, releasing capital for investment and reduces overheads.

Although a cost leadership is a strong position for a large company, it is a difficult position for a small company to achieve. In the case of a small company the focused strategy in which products are manufactured to meet the requirements of a particular sector of the market is a more appropriate strategy to adopt. In this case the introduction of appropriate levels of automation can be used to reduce manufacturing costs and achieve a cost leadership position in a particular market sector. Alternatively, automation can be used to differentiate the product offered in terms of product quality and speed of delivery. The focused strategy is often adopted by small companies in traditional industries who gradually increase the range of products manufactured over time and find that they are trying to serve a diverse market. Adopting a focused strategy enables them to reduce the range of products produced and concentrate on a limited range of products, which can then be manufactured competitively.

Before the introduction of automation can be considered, the logistics of moving components around the factory must be addressed. Many traditional factories use a process layout in which consecutive production operations are carried out in different parts of the building. Reorganization of the factory into cells making similar products, using production flow analysis (6), is a first step in automating a production facility. When a logistically friendly plant layout has been adopted, adjacent processes can be brought together and methods of automating and linking them can be considered. The opportunity to introduce partially automated systems is easily recognized when the product line has been simplified and the manufacturing facilities are integrated into cells.

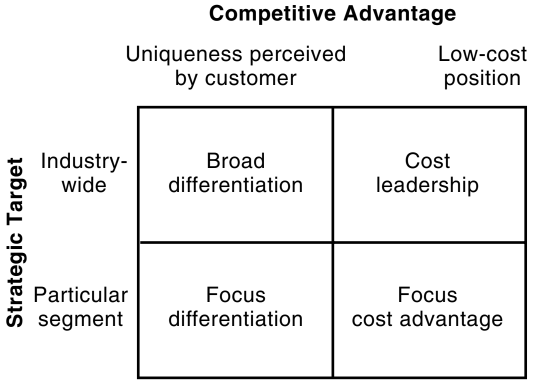

Figure 2. Diagram indicating the relative position an organization can adopt with reference to market sector and product differentiation.

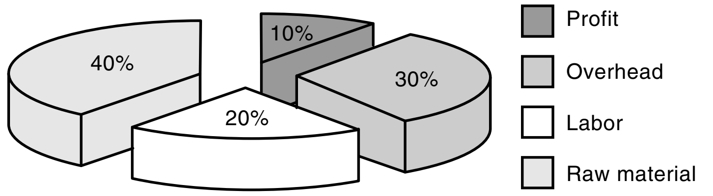

Figure 3. Typical manufacturing cost breakdown, showing the relative impact of labor and material costs.

CASE STUDIES

To illustrate the introduction of appropriate levels of automation, several case studies are presented.

Automatic Data Capture and Integrated Computer-Aided Design (CAD)/Computer-Aided Manufacture (CAM) Systems

Case study company 1 manufactures agricultural wear parts such as plow blades, points, and scrapers. A typical product is cut from a 6 mm to 10 mm steel sheet and then heated, cropped, punched, and bent before quenching in oil. The product is shot-blasted, cleaned, and painted before packing and dispatch. Traditional profitability exercises look to reduce labor costs by automating handling processes. In this case, most improvement can be gained in the design and manufacture of press tooling.

A two-dimensional personal computer (PC)-based CAD system and surface digitization software has been introduced. Because many tools are combinations or modifications to existing designs, the CAD system reduces the time needed to produce accurate drawings of tool sets. Where possible, tool designs have been standardized and setup times have been reduced. A computer numerically controlled (CNC) electron discharge machine, a CNC lathe, and a CNC machining center have been introduced to manufacture punches and dies in house.

Press tools are usually manufactured from samples provided by the customers. Although CAD can be used to produce engineering drawings for the tool room, the complex shape of many products makes the production of working drawings a time-consuming task. With only a sample to work with, it is difficult and time-consuming for the draftsman to calculate the coordinates of a complex surface. In this case, surface data are collected using a probe fitted to the spindle of the CNC machining center. The digitized surface data are transferred to a local PC, and the complex surface is reconstructed in the CAD/CAM system. After selecting tooling and the tool path, the surface data are fed back to the CNC machine tool controller and the press tools are manufactured. In this case the automated system links surface data collection to tool path generation and reduces the time to produce press tools from 4 to 6 weeks to a matter of days. The process demonstrates the benefits of linking and automating data processing, which enable the company to differentiate from its competitors by reducing delivery time.

Cellular Layout and Partial Automation

Case study company 2 manufactures leaf springs for the automotive and railway rolling stock markets. Due to the changing spring market and the rise in popularity of coil springs, the company realized that they needed to segment the market and focus their attention on the supply of replacement leaf springs to commercial vehicle operators. In this market, commercial vehicle operators wish to keep their vehicles on the road as much as possible, and the factors that differentiate potential suppliers are delivery times and responsiveness to customer demand.

A low level of technology is used in the manufacture of leaf springs, and the company uses a high level of manual labor. The inherent flexibility of the manual labor can be used to their advantage because the operators can change quickly from job to job. Because all leaf springs pass through the same production processes, the main area for improvement was the introduction of a cellular layout and partial automation, including conveyors and jigs, to load and unload work stations and provide a link between individual processes. These changes, improved manufacturing logistics, reduced throughput time and enabled the company to maintain an adequate but not excessive level of stock to meet immediate customer requirements. A computerized stock control system was also introduced to monitor the level of finished stock and provide a link to the production scheduler. Partial automation has enabled the company to provide a better service to its customers and differentiate itself from its competitors.

Bar Code Reading

Case study company 3 manufactures cutting tools for the aerospace industry. The key business variables are the technology incorporated in the cutting tool and the quality of the tool produced. The market for specialist aerospace cutting tools is small, but the customers are willing to pay premium prices for tools designed to meet a particular machining requirement. To meet this demand the company must manufacture small batches or single tools. Producing small batches increases the number of machine setups and ultimately manufacturing costs. Originally, many of the tools were manufactured on multiaxis CNC tool grinding machines which took up to 3 h to set up.

The priority for the company was to reduce the setup time to acceptable limits, and a setup time reduction and investment program was introduced which eventually reduced setup times to 3 min. The ability to manufacture small batches enabled the company to pursue the high-value aerospace market and highlighted a new market opportunity. If the company could change tools quickly, they could consider introducing a resharpening service. The main problem associated with resharpening is the difficulty of locating previously machined surfaces. This was solved when the company introduced an automated system to load the tool and identify datum surfaces using a touch-sensitive probe. The touch-sensitive probe and concentricity software have linked and automated the set up processes and provided the company with the opportunity to exploit a niche market.

To further improve the level of service offered, the company placed individual bar codes on all tools manufactured. The bar code is used to record the history of the tool, including details of the number of times it has been resharpened or recoated. As a further enhancement of the system, the bar code information is used at the customers' tool store to monitor tool usage and perform feedback of information directly to the tool supplier. The bar code information is fed directly into the computerized production management system, and replacement tools are manufactured and delivered on a just-in-time basis to the customers' tool store. The bar code has enabled the company to identify individual tools, record relevant historical data, and provide a link to the manufacturing processes.

In Process Inspection

The final case study describes work carried out with a leading manufacturer and supplier of enameled and textile covered winding conductors. In an attempt to improve the enameling plant, the production methods used the company took radical steps to improve its ability to continuously test the product on-line. The aim was to meet the increasingly stringent quality standards imposed by customers. In this case, experience has shown that the most important parameter that influences product quality is enameled wire cure. This is measured using an established technique known as the "Tangent Delta Method" (7). This is an off-line method where wire samples are tested at the end of the curing process. It is apparent that the cure of the enameled wire is a function of (1) the curing oven temperature and (2) the speed of the wire through the oven. By developing a model of the process, it is possible to predict the cure of the wire continuously throughout the manufacturing process and thus provide an on-line quality measure.

Test methodologies relating to the enameling process are still performed very much off-line. As such, quality information relating to the process is acquired after a time lag which is dependent upon (1) the frequency of testing and (2) the time taken to perform the tests. This is obviously unacceptable. Recent developments in on-line test equipment have enabled surface defects to be monitored more readily; and the repeatability, availability, and cost of the equipment are such that on-line test facilities have become feasible. Trials with color (cure) recognition systems have proven difficult to set up, due to the variety of enamels, which vary in color as a result of their physical nature and the amount of cure. However, there is still a big gap between this and the most meaningful test of product quality, Tangent Delta.

Enameling Process Description. The process consists of an enameling/curing oven, an annealer, and an in-line wiredrawing/take-up unit. Bare copper wire, previously drawn down, is fed into the wiredrawing unit of an enameling oven. The wire is then drawn down to the required conductor size, whereupon it is cleaned and passed through a bath of enamel. This coats the wire, which is subsequently passed through a control die to regulate the diameter of the coating applied. The enamel-coated wire is then passed through the enameling oven where the enamel is cured onto the wire. The wire is then cooled, and the process is repeated until the required enamel thickness is achieved.

Enameling Oven. The enameling oven is either horizontal or vertical in orientation depending on the size of wire being enameled. Horizontal ovens are commercially capable of producing wire in the range <0.8 mm diameter, whereas vertical ovens are capable of producing enameled wire of >0.5 mm diameter. The reasons for this include wire sag, surface tension, choice of applicator, and wire tension.

Once the product has been finished to the required specification, the wire is fed back to the wiredrawing/take-up unit at the start of the process. At this point the wire is wound onto a reel, weighed, and bar-coded, prior to being put onto a pallet and sent to the warehouse.

Process Control. Each oven is heated via a bank of electric catalyst heaters, controlled using a three-term on/off control. The warm air produced by the heaters is circulated around the oven by a constant-speed, warm-air recirculation fan via a catalyst plate. A negative airflow into the oven at both ends is produced to ensure that solvent fumes do not escape.

Air is passed into the wire section of the oven, which is split into two zones. The first one is the evaporation zone, where the solvent is separated from the enamel, thereby producing additional heat in the oven and hence preparing the enamel for curing. The other zone is the curing zone, where the enamel is cured onto the wire. The exit temperature of the oven is controlled by a second three-term control loop on the oven, using two variable-speed fans, a cold-air inlet, and a warm-air exhaust.

To maintain the set oven temperature, the warm air recirculation is exhausted and replaced by the cold air inlet fan. The resultant airflow of both fans is balanced to maintain airflow equilibrium. The temperature profile across the oven is controlled by a set of airflow dampers which ensure that there is a decrease in temperatures from the oven control set point in the curing zone to the evaporation zone where the wire enters the oven.

Tangent Delta Test Methodology. The measurement of tangent delta was performed using modern electronic test equipment. Wire samples were placed in a carriage with graphite contacts and inserted into a test oven. Test information relating to the sample was entered into a computer, and the test was started. The result of the test, a tangent delta temperature graph (see Fig. 4), was printed out, with the dielectric loss factor (tan delta value).

The appearance of the graph illustrates the relationship of the dipoles inherent in the molecular structure of the enamel. Since the behavior of these dipoles is dependent upon the internal bonds of the molecules and the temperature, the graph plots the trend line, which monitors the changes in the molecular bonds as a function of temperature.

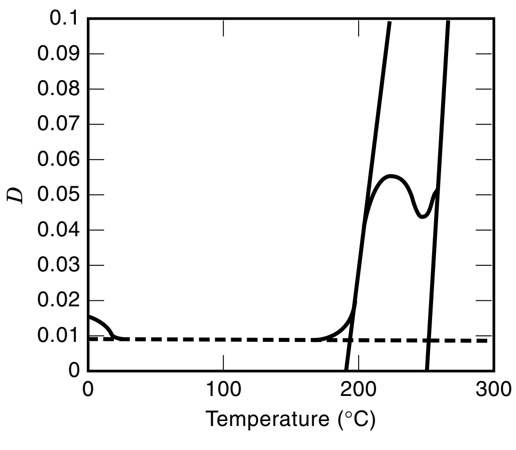

Figure 4. Tangent delta temperature graph, displaying dielectric loss factor for a polyesteramide enamel.

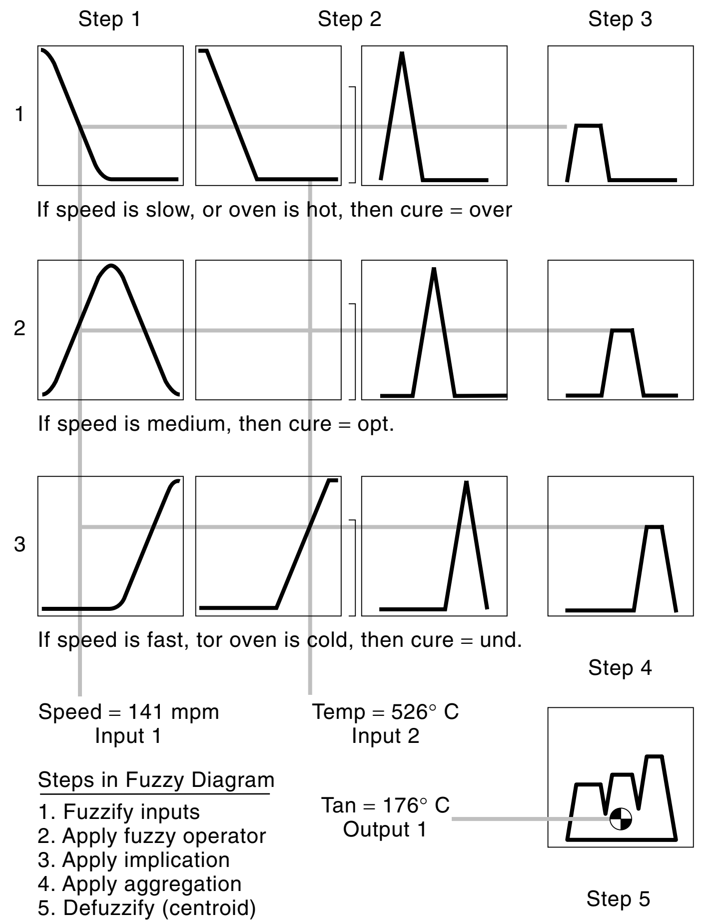

Figure 5. Fuzzy inference diagram for the enameling process.

Because the molecular structure of each enamel varies, and the graph of each enamel varies depending upon the curing characteristics (i.e., wire speed and oven temperature), the general characteristics for each enamel and optimum tan (cure) can be predicted.

In Fig. 4, it can be seen that the graph exhibits the characteristic valley on the steep gradient of the graph. This can be attributed to the change in oscillation mode of the dipoles, which signifies the transition of the enamel. The placement of the valley with respect to temperature indicates the cure of the enamel.

Quality Models and Fuzzy Logic

Fuzzy logic, first proposed by Zadeh (8), starts with the concept of a fuzzy set. The fuzzy set by definition is not crisp or clearly defined. The very nature of the enameling process is thus ideal for modeling using fuzzy methods.

Application of Fuzzy Inference Systems. The process can be broken up into five distinct parts as shown in Fig. 5.

1. Fuzzify inputs.
2. Apply fuzzy operator.
3. Apply implication method.
4. Aggregate all outputs.
5. Defuzzify.

Artificial Neural Networks. Neural networks are composed of many simple elements operating in parallel. These elements are inspired by biological nervous systems. The functionality of the network is determined largely by the connections between elements. A network can be trained to perform a particular function by modifying or adjusting the values of the connections between elements. Neural networks have been trained to perform complex functions in various fields, including pattern recognition, identification, classification, speech, vision, and control systems. Today, neural networks can be trained to solve problems that are difficult for conventional computers or human beings.

One of the first and most popular neural network training algorithms is *backpropagation* (9). For simplicity, a neural network architecture based on the multilayer perceptron, trained using the backpropagation algorithm that was used in this work.

Linear Modeling

The simplest of all paradigms is that of linear modeling. The system or process to be modeled is monitored and a characteristic equation is derived through graphical or mathematical representation. The derived characteristic equation is then used to model the process, around specific operating conditions. Because the model is in fact a linearization, the accuracy of it can and does vary. It is therefore best used as an indicator of a process rather than a true model.

Results

Product type, oven temperatures, fan speeds, and wire speeds for each of the eight individual "heads" of the machine were time/date-keyed to the tangent delta quality information, which was measured off-line. This information was sorted into a time series related to each specific head, and surplus/spurious information was discarded. To prove the process, an initial set of key parameters was selected. These parameters included two inputs (i.e., oven temperature and wire speed) and one output (i.e., tangent delta value).

Analysis of the raw data demonstrated that a variation in oven conditions in relation to wire speeds over time influences the quality of the product. This was obviously due to changes in operating conditions—in particular, different product mixes and enamel batches. However, the amount of variation did not significantly impair the accuracy of the quality models at this stage.

For this trial the product chosen was a 0.355 mm diameter copper wire, with a polyester-imide enamel coating, designated 0.355N1.

For each of the methods described, models were derived from the recorded data with the objective of assessing the ability of the methods to make an on-line prediction of tangent delta value. Thus the data sets were used to create fuzzy, neural, and linear prediction models, and these were tested against actual tangent delta values evaluated off-line using standard laboratory tests. The results for a typical data set are shown in Fig. 6, which displays the actual tangent delta values for wire products manufactured at the plant against the predicted values from the proposed on-line methods. An examination of the time-series histories displayed in Fig. 6 indicates that the fuzzy and neural methods offer considerable improvement over a linear modeling approach which is inadequate for this application.

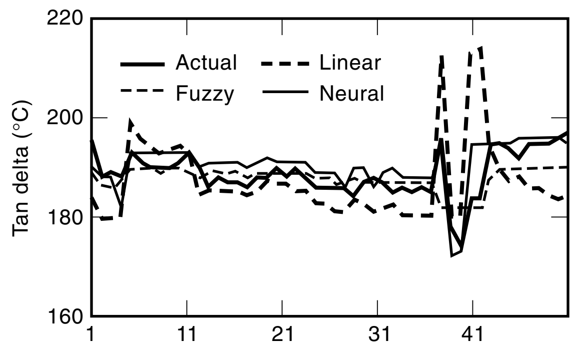

Figure 6. Time series of predicted tangent delta for 0.355N1 enameled wire.

Case Study Conclusions. This case study has addressed the problem of developing an on-line model-based approach to assessing quality in finished products. Data have been acquired from a plant and used to develop three types of prediction model for tangent data value—the preferred quality indicator in the wire enameling industry. A simple linear model relating oven temperature and wire speed to tangent delta value has proved incapable of capturing the input–output relationships between these variables. However, the two methods based on fuzzy logic and neural networks have provided much better prediction ability, and these newer "intelligent computing" methods offer considerable promise for the future.

CONCLUSIONS

The case studies have demonstrated the wide range of projects, which can be considered as automation. In all cases, processes were linked and automated to make the company more competitive and meet the requirements of the business strategy. In all cases the level of automation introduced was classed as partial automation; and although the level of investment was relatively small, the impact on the company was substantial.

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AUTOMATION. See Mechatronics.