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Component Manufacture and Joining Techniques [and Discussion]

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Component manufacture and joining techniques

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In the first part of this paper, an analysis is made of the relative roles of machining on the one hand and forging and casting on the other as means of producing form. Specific reference is made to the newer methods such as electrochemical machining and pressure die casting of ferrous materials. A similar analysis is made of joining processes, contrasting fusion with bonding methods.

In the second part it is pointed out that manufacturing technology is available; the need is for exploitation and application. It is emphasized that this can only be achieved by an involvement from within the manufacturing unit itself. A proposal is put forward for achieving this objective.

Part I. Technology

The paper deals primarily with methods of manufacturing individual components and their subsequent integration to form a completed product or a module of a product. Component manufacture thus involves two basic activities: means of generating form and means of integrating individual components. These will be considered separately.

(*a*) *The generation of form*

A sculptor produces form by chiselling stone or carving wood. With a relatively small number of tools, he produces an endless variety of contours, limited only by the boundaries of his imagination. His two essential assets in achieving this flexibility are: the degrees of freedom of tool approach; and the direct dialogue between the tool and the material.

There is also a time benefit. The artist can start producing his sculpture almost immediately he acquires a block of marble of the required size. So it is with *machining* as a means of component manufacture.

Machining has the following basic assets: Geometrical freedom of form generation. Short lead time; components can be produced almost immediately a drawing is available. Precision of form; accuracies achieved by modern machine tools in the normal course of events can be as high as a fraction of a thousandth of an inch (a few micrometres).

Further, there is the accumulated expertise and the momentum of continued development, both of the machines themselves, and the cutting tools. There are probably more men engaged today in metal cutting than in all other methods of component manufacture put together. There is nothing on the horizon that can effectively challenge this commanding position.

But, there are weaknesses:

Waste. Consumer demand today is so vast as to require the greatest economy of raw material utilization. True, swarf metal can be recycled, but the recovery price is only a sad proportion of the cost of the primary product. There is also the waste associated in duplicating the manufacturing of the primary product. It is significant that products made of plastics are not machined – they are moulded.

Metal cutting is slow, in two fundamental ways. Even the largest and most sophisticated machine tools of today are capable of cutting with only one edge at any one time. To produce the required form, it is therefore necessary for a cutting edge to perform a series of excursions all over the surface of the workpiece. Secondly, once the form has been produced, the whole cycle is repeated each time a similar component is required. This seems somewhat futile and might go someway towards explaining the reason why there are so many machine tools in the world today and so many men operating them.

There are mechanical limitations. High strength alloys are difficult to machine because of weaknesses in the cutting edge itself and the risk of damage to the material. It is interesting to note that certain heat-resisting alloys can be machined only by grinding and that the grinding wheel wears at a rate faster than that of metal removal. This is probably not so serious a point, as most products are manufactured from materials of moderate toughness.

There are limits to the intricacies of form that can be produced by machining, particularly internal configurations.

The above weaknesses are likely to be exploited by other manufacturing techniques. Consider, for example, the question of the single cutting edge. It seems reasonable to explore machining processes that are capable of producing complete areas simultaneously. Such processes do exist, for example:

Chemical milling, i.e. removal of metal by chemical attack over a large wetted area. Although the original surface topography is reproduced, selectivity can be secured by masking, and gradients achieved by controlling the time of exposure of the metal to the acid. Applications exist in the electronics industry (printed circuits) and in airframe manufacture.

Electrochemical machining. Here, a complete departure from the original shape can be achieved. The electrode merely imprints its contours on the workpiece by displacing metal electrochemically. The process overcomes the difficulty of conventional metal cutting in handling tough materials. It has made a valuable contribution to the aero-engine industry, but little impact elsewhere. Recent applications in the motor-car industry, however, include certain deburring operations and the manufacture of drop stamping dies.

Electrical discharge machining. Again, an electrode imprints its image by the erosion effect of an electric spark. The process is particularly suitable for intricate applications, is relatively easy to apply although there are difficulties associated with electrode wear.

Of the above three, the electrical discharge machining process (e.d.m.) is the one that is likely to find wider application in the 1980s. It must be recalled, however, that all three are metal removal processes, leading to material waste. They further suffer from the drawback of the difficulties of material recycling and the problems of disposal.

The processes that are likely to effectively challenge conventional machining are those: capable of producing form more or less in one operation; capable of conserving material; and that are relevant to the needs of larger markets. These are the processes of forming by metal deformation and casting.

Forming and casting processes are not without certain drawbacks. Generally, the precision of form is not high and some finishing by machining is often required.

Again, no useful productive work can be started until a die or mould is produced. There is thus a delay equal to the lead time required for producing the die. Further, the die when available may not produce the required shape and some trial-and-error must come into play, leading to die correction and further delay. Total lead time may be up to several months. Even then, dies suffer wear from continued use and they have to be either replaced or reshaped. But perhaps the most significant factor is their cost. It is not unusual for a die made in tough steel, incorporating complex contours and a multiplicity of subsections, to cost upwards of £10000. In spite of all these factors, the application of casting and forging continues to grow. Certain recent advances will ensure that an even greater proportion of components will be produced by these processes. But before dealing with those novel features of casting and forging that are likely to influence trends in the 1980s, the bottleneck of die making must be emphasized. The long lead times, the trial-and-error and the cost, must all be dealt with effectively so as to allow the true benefits of these processes to be appreciated. Casting and forging processes can be economically attractive and they suit the demands of modern times by providing large quantities of products with the minimum of plant and at high rates of production. If there is one endeavour to be singled out that would benefit the cause of manufacturing technology in the 1980s, this would be die making technology.

There is another reason why it is easier to machine than to cast or forge. It is the question of cost of capital plant. It is relatively easy to acquire a machine shop, but quite costly to erect a foundry or a forge. We thus have concentrations of service facilities for forging and casting. This is no disadvantage, particularly as it makes the task of modernization easier when justified by the high volume of production.

Returning to the question of die making, convincing demonstrations have confirmed the feasibility of a direct link between a computer feeding design data to numerically controlled machine tools which cut the die. Casting (instead of machining) for die making is another alternative. The use of cast steel dies is likely to become more widespread over the next 20 years. Their introduction will undoubtedly reduce the lead time and cost of die manufacture.

Reference can now be made to certain recent advances in forging and casting technology that are likely to be exploited during the next 10 to 20 years. They are both dependent, on the application of molybdenum alloys as die materials. These alloys have good thermal fatigue properties, so that they can withstand the heating and cooling cycles of a repeated casting or forging operation. They also possess good strength at temperatures well in excess of 1000 °C. In the field of casting, these alloys are being used, following development work at G.K.N. and elsewhere, in pressure die casting of steel components. The process is still in its early days, but it opens new horizons of application for mass production of accurate components in ferrous alloys possessing good surface finish. Thus the benefits of pressure die casting which have been enjoyed over many years in components made of aluminium, zinc or magnesium alloys, are now extended to stainless steel. Applications could be found in component manufacture in the process industries, domestic goods and marine applications.

Molybdenum alloy dies are also used in forging at high temperatures. Depending on the material to be forged, greater formability can be achieved by forging at higher temperatures which may be beyond the strength capability of die steels. Greater plasticity leads to a number of basic benefits such as the ease of forging requiring simpler plant, good die filling leading to better accuracy and less die wear, leading to cost reduction and better accuracy of repeatability.

(*b*) *Component integration*

The modern trend in component integration is to produce permanent joints, as it is often more economical to replace a product or a module than to repair it. This trend will continue, demanding the following features from joining methods: speed, precision, and reliability. It is remarkable how the process of resistance welding can achieve effectively all of these objectives. The process has served the motor-car industry and consumer durables very well. This will continue to be the case during the 1980s and beyond. In addition to speed and precision, resistance welding is remarkably simple to operate and suits applications in sheet metal – a material widely used in the industries just mentioned. Perhaps simplicity of operation is the strongest advantage of the process.

For a number of technical reasons, however, resistance welding cannot provide the ultimate in joint strength. Fusion methods have been developed where a heat source melts both edges to be joined. The evolution of fusion methods is closely related to the power density of the heat source. The last 10 years have seen an increase in power density of two orders of magnitude – from 1000 to 100000 W/mm^2. Was this increase necessary, or even useful, and is this trend to continue in the 1980s? The power densities of well-focused electron beams have contributed greatly to the achievement of precision, speed and reliability of joint strength. However, the capital cost of the plant is high and it is likely that the next few years will see some positive progress in the application of laser welding. Power densities, and possibly total beam powers, equal to those of electron beam, are expected to be achieved within the next 5 to 10 years. The need of a vacuum is obviated in the case of the laser, leading to simpler operational procedures.

It is hard to see the need for even higher power densities. Steel plates 10 cm thick can be penetrated and welded in one pass by an electron beam. Indeed, there are fundamental physical reasons why a greater concentration of power cannot be achieved, e.g. the mutual repulsion of electrons when forced by a magnetic field into a narrow pencil. It is likely that developments will occur in a different direction.

What the high-power-density heat sources have achieved is to reduce the width of the distributed layer, namely, the fusion and heat-affected zones. This layer can be as narrow as a few millimetres in the case of a good electron beam weld. But is it really necessary to fuse the metal? The answer is that it is not. Joints with good properties can be produced by diffusion processes occurring between the two parts at the interface. The width of the disturbed layer is then no more than a few thousand atoms across. What is even more rewarding from a practical viewpoint is that the two component parts need not suffer any thermal distortion. It should be possible therefore to bond finished parts. Friction welding, and its derivative inertia bonding, are simple and effective solid state bonding processes that will find extensive applications in the years ahead. Now the diffusion process can be fairly rapid, given an adequately high temperature. The speed of diffusion can be increased by either plastic deformation of the material, which causes atomic mobility; or the presence of a thin layer of another material of more mobile atoms such as boron or silicon. Serious work is in progress in these areas, with good prospects of successful applications in the years ahead.

Part II. Exploitation

But much of what has been said so far is generally known. No revelations have been made or secrets broken. The relative potential roles of the various form-generating and integrating methods have been simply outlined. No one process stands alone, neither is any one process capable of entirely displacing another.

The truth is that technology is available; the open question is the selection of the alternative or combination of alternatives that is likely to prove relevant. Even then, one option may be right today, but inappropriate tomorrow, or again, it may be valid in the United Kingdom now but not elsewhere because of economic, human or environmental considerations. Thus wisdom of choice between alternatives is the heart of the matter. The optimization process of selection will have its objectives in a variety of directions; reductions in labour content, economy in material utilization, response to a novel design or a novel material, improved reliability of the product, higher productivity, and so on. It is my belief that there is adequate technology to choose from. The art is how to choose wisely. To illustrate the abundance of technology, reference can be made to a technologically advanced industry, much dependent on the latest in manufacturing technology to meet the demands of new materials and design concepts. In the last 10 years, some 30 new processes have been introduced to its manufacturing facilities. All but one or two were already available. Existing processes were merely selected, evaluated and applied. It is worthy of note that none of the 30 or so processes has displaced previously existing ones. But returning to the main theme, namely, how can modernization be achieved through the introduction of those new methods that are appropriate to a given industry at a given time in a given situation?

It may be suggested that the Government has to provide more funds for manufacturing research. It is my view that this is not the answer. In spite of the hundreds of millions of pounds spent on research by successive Governments in Britain since the war, we have failed to achieve an adequate industrial growth, and what is even more significant, our share of world markets continues to decline. There are many causes for this, but it is clear that the cure is *not* in providing more public funds for manufacturing research. The hidden loss is even greater and more profound than the actual pounds and pence dissipated. It is the combined talent of the thousands of highly trained scientists and engineers, locked within our research associations and Government research establishments. We generally consider money as an asset, but money used to occupy the brain power of a high proportion of the scientific talent in this country can ironically be a millstone.

So productive, in a research context, have the last 25 years been, that this country can claim to be second perhaps only to the United States in technological know-how. Where else in the western world are manufacturing industries so well supported, in a research context. But what is the end product of a research programme? Generally, it is a report – a recommendation. This is not the end, but the beginning. Innovation is easy, research is even easier; the real issue is the exploitation of innovation to the extent that it can find effective application within an existing commercial and social framework. And this can only be achieved from within. It cannot be imposed by outside effort, however plausible the recommendations may be. It is only within the individual industrial unit, i.e. a company, can we find the elements required for wise decision making. Nobody outside the unit can appreciate the balance of financial and human (or political) forces. And even after the decision is made and an element of risk accepted, the new process or innovation has to be fathered along, stage by stage, over a period of perhaps 5 or even 10 years – modifying its approaches and even its objectives, bringing about gradually, a corporate conviction in the worth of the new. Ensuring by achievement, a credibility that eventually matures into complete acceptance. How can this be achieved without direct and complete involvement? How can it be achieved but from within the unit itself?

This is the crucial issue. The sooner it is realized and accepted, the sooner will this country reap some of the benefits of many years' research expenditure, and recover its position among the leading industrial nations in the world.

But accepting a principle is not sufficient. How, in practice, can the objective of modernization be achieved?

These are the basic ingredients:

A conviction by the directors of individual companies that there are better ways of manufacturing their product and an acceptance that it is their duty to find these out.

The creation of a small dynamic squad – a small team whose terms of reference are clearly defined. They should sift through existing manufacturing methods, assess what is likely to be relevant, evaluate the consequences of application, technical, human and economic. They should also consider the timing of introduction. This is not a research unit. It is not even a development unit. It is an *application* team. The size of the team must be small – no more than $\frac{1}{2}$ % of the payroll of the company.

A budget of no more than $\frac{1}{2}$ % of the turnover of the company. With this budget, the application squad can initiate trial runs on existing plant. They can hire plant for evaluation. If the process proves appropriate, the hire charges can go towards the purchase of the plant. If not, the hire is terminated. Once feasibility has been established, the plant can be handed over to production. Indeed, if the chances of success are rated to be high, the plant or machine could, with advantage, be sited in the production factory. By this means, an early involvement of the production unit can be assured. It is particularly valuable to secure this involvement at an early date, once basic feasibility has been established.

The process of conversion to the new is relatively slow and for the success of application, this conviction must mature into full participation and eventual commitment. In all this, the operator plays an important part. At the earliest opportunity, one or two operators should be brought in for training. They could well participate directly in the process of assessment. Much down-to-earth experience and wisdom in older methods is still relevant to the new.

Discussion

MR D. B. WELBOURN (*Engineering Department, University of Cambridge*) referred to Dr Merchant's acceptance of A.P.T. or similar languages for the transposition of the design to the manufacturing stage, which he believed was unnecessary, and to Dr Meleka's point that an ever-increasing number of dies will be used for production purposes.

He stressed the need for methods to describe cast, moulded and formed parts so that the manufacturing stage would follow easily and directly from the design stage. Castings and mouldings are often designed by draughtsmen who knew how pattern-makers worked 20 years ago but who know little about modern die-sinking machines. He showed that there was a danger of a failure in communication between the two stages if the designer was not allowed to work spatially. He suggested that the solution was a very simple terminal, a storage-type display tube which is relatively inexpensive, a hard copy unit and a keyboard which enables designers to work in three-dimensional coordinates.

On the subject of assembly work, he mentioned the comparative work that was being done on the productivity of automated processes and of factory hands. In practice, he had found that automated processes were faster and more accurate than girls working machines. He was investigating the problems facing an industry which substituted short runs for mass production techniques and the possibility of making machines which could adapt very rapidly to changes in design.

Sir Alastair Pilkington, F.R.S. (*Pilkington Brothers Ltd, St Helens, Lancashire*) referred to Dr Meleka's suggestions for a more effective application of technological innovations. He had not mentioned the aspects of finance or of market requirements, and an understanding of both was very important to medium and small-sized firms. Technologists engaged on development need information about what is required in the market-place, rates of throughput, material and labour costs and so on. The solution must be to employ a squad, combining all the necessary expertise, to obtain and analyse this information.

Dr Meleka replied that there were often problems in obtaining realistic cost figures from accountants because they had failed to analyse the costs of component parts. He had overcome this by working on the cash flow method, taking into account labour, materials and so on.

He referred to the strange means that were sometimes used to circumvent difficult situations with regard to industrial relations: electrotechnical machining had to be called electrochemical forming and friction welding called friction bonding, to avoid disagreements over rates of pay.

Sir Alastair Pilkington said he hoped that accountants could be trained to understand the technology whose finances they were handling and perhaps to become development men.

Another speaker felt that because the accountant is far less easily instructed in technology than vice versa, the technologist should make some effort to become numerate outside his own field. He said that the discussion was bound to develop beyond an analysis of systems engineering to consider the total system, the organization of the firm and the purpose of the firm. Every system ought to be judged by three criteria: whether it can be controlled and judged to serve its own purposes; whether it can be so devised as to serve the purposes of its parts; whether it can serve the environment in which it operates. It cannot be called a systems approach unless it answers these questions satisfactorily.