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ISSUE 2

Reference Manual

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VALUE ENGINEERING

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REFERENCE MANUAL

ISSUE TWO

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VALUE ENGINEERING REFERENCE MANUAL

INTRODUCTION

This Manual is intended to augment the Value Engineering Project Workbook and to assist in the conduct of team studies. It is NOT intended as a complete book on Value Engineering.

The Project Workbook should be read for an introduction to Value Engineering and Cost Targeting and for guidance in the conduct and programming of Value Engineering team studies on products and procedures.

The Reference Manual is not intended as a complete source of technical or manufacturing information, such as a Machinery's Handbook, nor is it intended to provide detailed specialist information.

Its intention is to provide generalised comparative surveys of materials, manufacturing processes and sources of information. Its main objective is to trigger thoughts on alternative approaches and to point the way to more detailed information as required for Value Engineering studies, and to stimulate an awareness of manufacturing costs among all concerned with product design, development and planning.

It is a first attempt at a Reference Manual in this form. It is intended that information should be added and amended during the life of this issue. An improved and updated second issue will be produced after experience has been gained on the useful aspects or deficiencies of this one. To this end any comments or suggestions for inclusion will be most welcome.

Each section of this Manual is followed by a number of tabs. The intention of these is to allow for the insertion of additional information which will be circulated for inclusion in the Manual from time to time and can be attached to the tabs, which are pre-gummed.

SECTION ONE

COMMON CAUSES OF AVOIDABLE COST

Various causes of unnecessary manufacturing costs are mentioned in the Value Engineering Workbook. (Pages 7-10 and 28).

Here we discuss in rather more detail some of the more specific common causes of avoidable and unnecessary manufacturing costs originating at the specification stage, during design, production planning or during manufacture.

1. Specifications

Some of the most common causes of unnecessary costs at this stage are :-

a) Excessively stringent environmental conditions.

Usually the majority of environmental conditions specified are firm requirements but often they can be relaxed with regard to one or more specific conditions.

All too often a customer will consider one or two of the conditions that he requires to meet and then calls up a general specification which embodies these but, incidentally, also embodies many other stringent conditions that are not necessary. For this reason a designer should always query the need for any doubtful conditions and point out to the customer the cost of their application.

For example, in a sealed equipment, with perhaps a controlled internal atmosphere, one all too often finds assemblies and components that are themselves sealed. This MAY be necessary to cover their storage as spares, although even in such cases an unsealed spare component or sub-assembly can be supplied in a sealed bag or vacuum formed pack. Proper conditions for its fitment in the equipment will have to be provided in any case and the sealed packing can remain intact until the component is fitted. More often it is an advantage for such assemblies to be ventilated rather than sealed so that they adopt the same controlled atmosphere as the equipment when it is needed. Such a case is illustrated in Case Study No.

Similarly such components may be finished in an unnecessarily expensive manner to withstand humid or other conditions within the equipment.

Or one can cite a cooling fan in an equipment which has to operate over the temperature range -60°C to $+80^{\circ}\text{C}$, say. The cost of the fan and motor may be greatly increased in order to meet the lower end of this range when in fact it may be switched off by a thermostat below 5°C or even 10°C . Depending on the rate of rise in ambient temperature that has to be catered for, the operating lower temperature limit for the fan and motor can be well above the -60°C for the equipment.

- b) Excessively costly paint or other finishes required for appearance.

The specification of 'appearance' finishes is often very subjective and chosen without any awareness of the cost involved. In such cases the effect on price of the finish chosen should be pointed out to the customer or originator of the specification and alternatives offered.

One must also, of course, query the specification of an expensive protective finish which is then to be covered by an 'appearance' paint finish which would itself give adequate protection. It is surprising how often even stainless steel is chosen to avoid corrosion and is then painted with several coats of rubbed and filled paints which would give ample protection of mild steel with a cheap surface preparation.

- c) Over-standardisation on products.

Often when an equipment is offered in a number of variants it is most economic to design or specify a 'standard' equipment which can accommodate additional features or provide extra functions.

However, all too frequently such a concept is adopted without adequate forethought. For example one equipment in every thousand may, on a detailed survey of the market, be found in practice to need a certain facility and it may be found that the other 999 are each housed in an unnecessarily large cabinet, or carry expensive brackets or some other such item, simply to cater for the one variant which needs to incorporate an additional sub-assembly. In such a case it would be better to offer the 999 in a more compact and less costly form and to have, perhaps, a slightly more expensive

2. During Design and Development

One of the first causes of unnecessary costs is, of course, failure to check and query apparently unnecessary or stringent clauses in the specification on the lines outlined; every clause of the specification should be checked and queried in the light of the designer's specialised knowledge.

During the design, the following are some of the most common causes of unnecessary costs :

a) Tolerances

Too little consideration is often given to the effect on cost of tolerances, both mechanical and electrical.

Mechanical Tolerances

Considering first mechanical tolerances, one must always double check before calling up a tight tolerance on any dimension and determine the need for it. Even if this is at first sight an apparent need, consider ways of avoiding it if possible.

For example, one may from habit call up a force or push fit between a pinion or flange and the shaft on which it is mounted. Could the two parts be fitted together using adhesives, friction welding or conventional welding more reliably and at less cost? This will often turn out to be true.

The general effect of tolerances on machining costs is shown in Table 1. This is intended as a guide and of course local conditions, detail of design and other factors will influence the exact shape of the cost-tolerance curve.

Similarly Table 2 shows the tolerances available in cold drawn bright bar. If these are adequate they should, of course, be called up whenever possible to avoid machining.

A designer must always overcome the temptation to apply a tight tolerance "to be safe" or, because a tight tolerance is necessary on one or two dimensions, to apply them across the whole drawing.

Electrical Tolerances

It is surprising how often quite unnecessarily tight tolerances are called for on electrical components, mainly resistors (fixed and variable) and capacitors.

There seem to be several reasons for this, among which are -

- i) Unawareness of the very great effect on cost of the tolerance called up.
(Tables 3, 4, 5 show the effect of the tolerance specified on the costs of resistors, potentiometers and capacitors respectively.
- ii) Confusion between the need for stability and the need for tight tolerances. All too often a tight tolerance is called up unnecessarily when it is only important to select a stable type of component and the actual value can be within quite a wide range. (There may, for example, be adjustment provided for other reasons or it may not even be necessary).
- iii) Confusion between the need for matching of two or more components and the need for tight tolerance. In such a case selection may be the cheaper and more reliable way of ensuring close matching.
- iv) The application of tight tolerances across the circuit because they are needed for one or two components, as with mechanical tolerances, or their application just to play safe.

In the worst cases designers even call up high stability close tolerance resistors across a circuit which are unnecessary.

b) Finishes

Finishes are often called up without realisation of their cost. Often too, a decorative finish is called up on top of a protective finish when the decorative finish could also be protective and vice versa.

Table 5 gives some indication of the cost of finishes. A useful finish for cabinet work is plastic coated metal either mild steel or aluminium coated with P.V.C. or other plastics, various glossy, matt or grained finishes. These are available in various gauges. Dry plastic powder coating can also be an effective finish.

c) Avoidable Machining

The possibility of using bright bar, as produced, to avoid the need for machining has been discussed in

often giving a better product. For example instead of turning to produce a flange or gear blank on a shaft one could consider friction welding a gear blank to a mild steel shaft, saving in material costs as well as machining time and using the more expensive material only where it is needed. The use of composite or clad materials should always be considered in the same way to provide more expensive material only where it is needed, and to save fabrication time.

d) Choice of Materials

The overall design must be considered when selecting materials, and careful thought always given when an expensive material seems to be required.

- i) As mentioned in Finishes an expensive material such as stainless steel is called up to avoid corrosion when the steel is protected by a decorative finish.
- ii) Expensive contact material is used in areas where it is not needed. Careful design, consideration of bi-metal (edge to edge) etc. can greatly reduce the cost of solid contacts. On printed circuit boards, often the contact areas plated are far larger than necessary etc.

e) Layout

Value Engineering studies have often saved considerable cost in material (cabling), labour and maintenance by reconsideration of the location of functions between the "black boxes" composing the equipment and within each box. Extra thought at this stage can minimise the number of inter-connections, connector terminals and length of wiring.

f) Lack of Discussion

The importance of discussion with production engineers, purchasing, suppliers etc. as appropriate at the design stage, cannot be over-emphasised. No design engineer can be an expert in all aspects and, even if he were, another point of view on which to sharpen his own wits always produces a better result. This particularly applies when manufacturing cost is introduced into design as a factor of importance, a factor which is often neglected by designers.

g) Failure to make use of Readily Available Parts

This is a very common cause of unnecessary cost. Within the Company there have been several cases in which special screws, spacers, nuts, pillars etc. have been made

when they can be replaced by purchased items at a fraction of the cost. Always look at catalogues of special fasteners, nuts, etc. before drawing up a new design, especially if only a small to medium quantity is required. Suppliers such as Avdel, G.K.N. etc. are always most helpful.

3. During Production and Pre-production

The Production Engineer should always interest himself in products which are coming to his shop floor as early as possible in the design stage and participate in discussions as early as possible to point out aspects of design which are likely to increase manufacturing cost, or be unsuitable for available machines and tools. To this end he should always be ready to participate in Value Engineering team studies. He will often find that this will save him time later on.

Once the design is finalised it is costly to change it and possible savings may not then be feasible because of the cost of retooling, retesting etc.

However, the production engineer even at this stage should always query particularly tight tolerances, especially when these are widespread in design, expensive finishes, materials etc. which seem to him to be unnecessary in certain areas, depth of holes etc.

These considerations are of course, beyond his normal activity of selecting optimum methods, tools, machine speeds etc. which are outside the scope of this book.

4. Summary

The above gives a few of the many pointers to unnecessary costs in order to stimulate thought. To summarise, when considering a design or hardware of any equipment, assembly or part always ask :-

What is it ? (In the case of a part or sub assembly, is it necessary, can it be combined with another ?).

What are its functions (does it do more or less than required)?

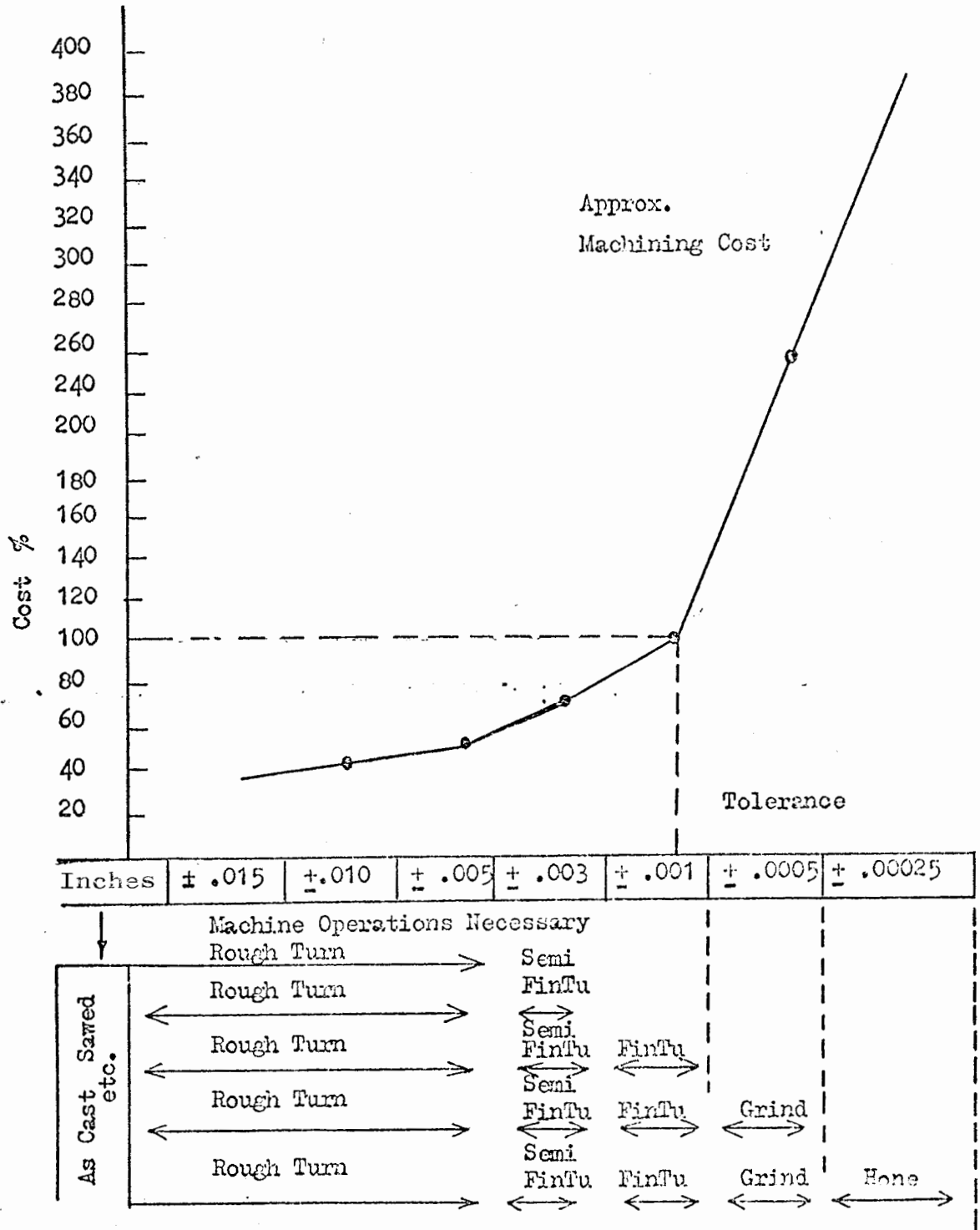
What does it cost ?

What else would perform the required function ?

What would the alternative cost ?

MACHINING COSTS - TOLERANCES

Relative Machining Costs for Steel



To be used as a guide only.

TOLERANCES ON COLD DRAWN BRIGHT BARAll tolerances are + .000 inch, - figures shown below.ROUND BARS

<u>Diameter</u>	<u>Inch</u> <u>Tolerance (minus)</u>
Below $\frac{1}{4}$	.002
$\frac{1}{4}$ - $\frac{7}{8}$	.003
$\frac{29}{32}$ - 2	.004
2 $\frac{1}{8}$ - 4	.005
$4\frac{1}{4}$ - 5	.006
5 +	.007

HEXAGONAL BARS - DECIMAL SIZES

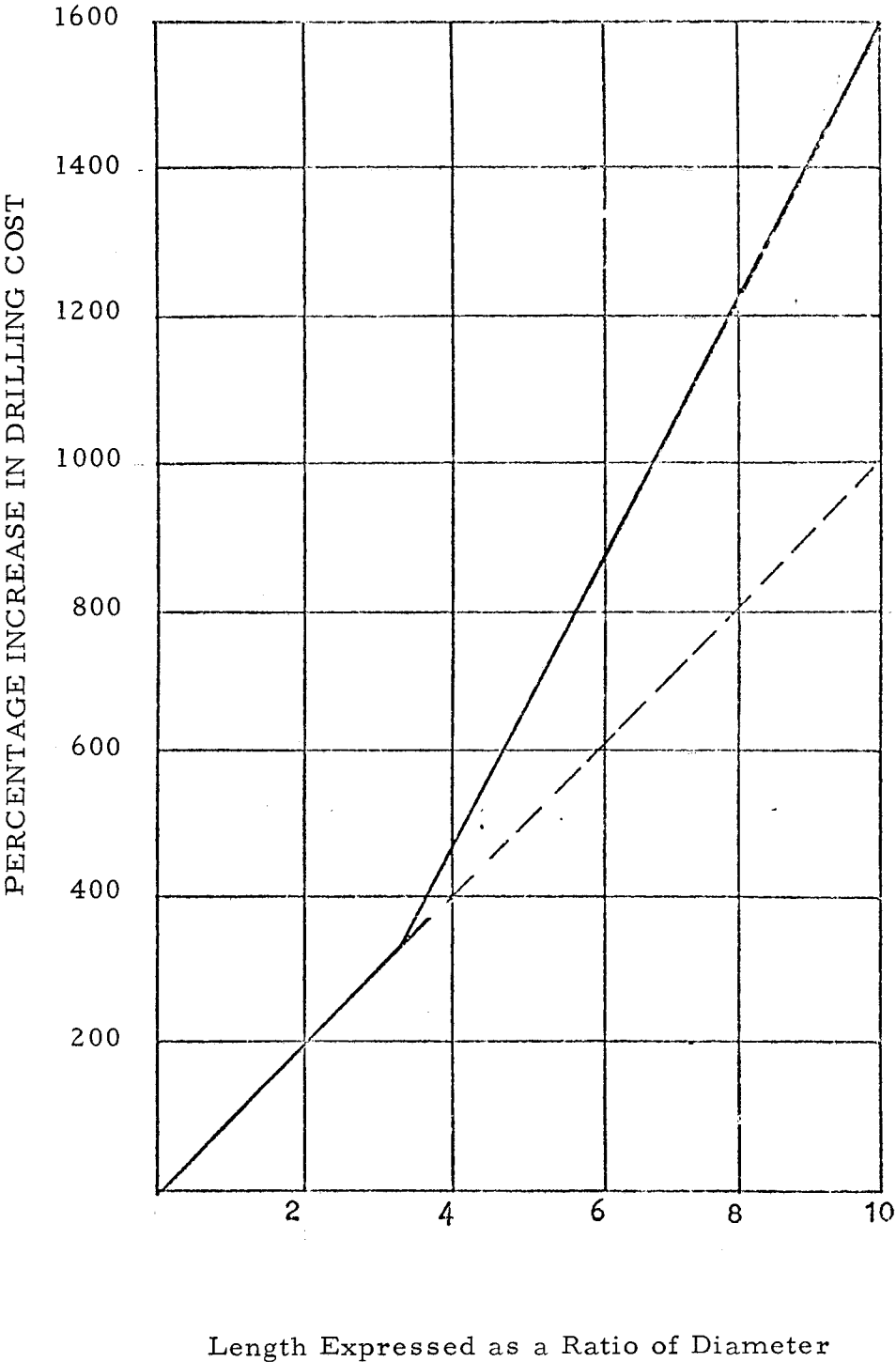
<u>In. Across Flats</u>	
Below .248	.002
.248 - .525	.003
.600 - .920	.004
1.010 - 2.050	.005
2.220 - 3.340	.006

HEXAGONAL BARS - FRACTIONAL SIZES

<u>In. Across Flats</u>	
Below $\frac{1}{4}$	.002
$\frac{1}{4}$ - $\frac{1}{2}$	.003
$\frac{9}{16}$ - $\frac{7}{8}$	.004
$\frac{15}{16}$ - 2	.005
$2\frac{1}{4}$ - $3\frac{1}{4}$	.006

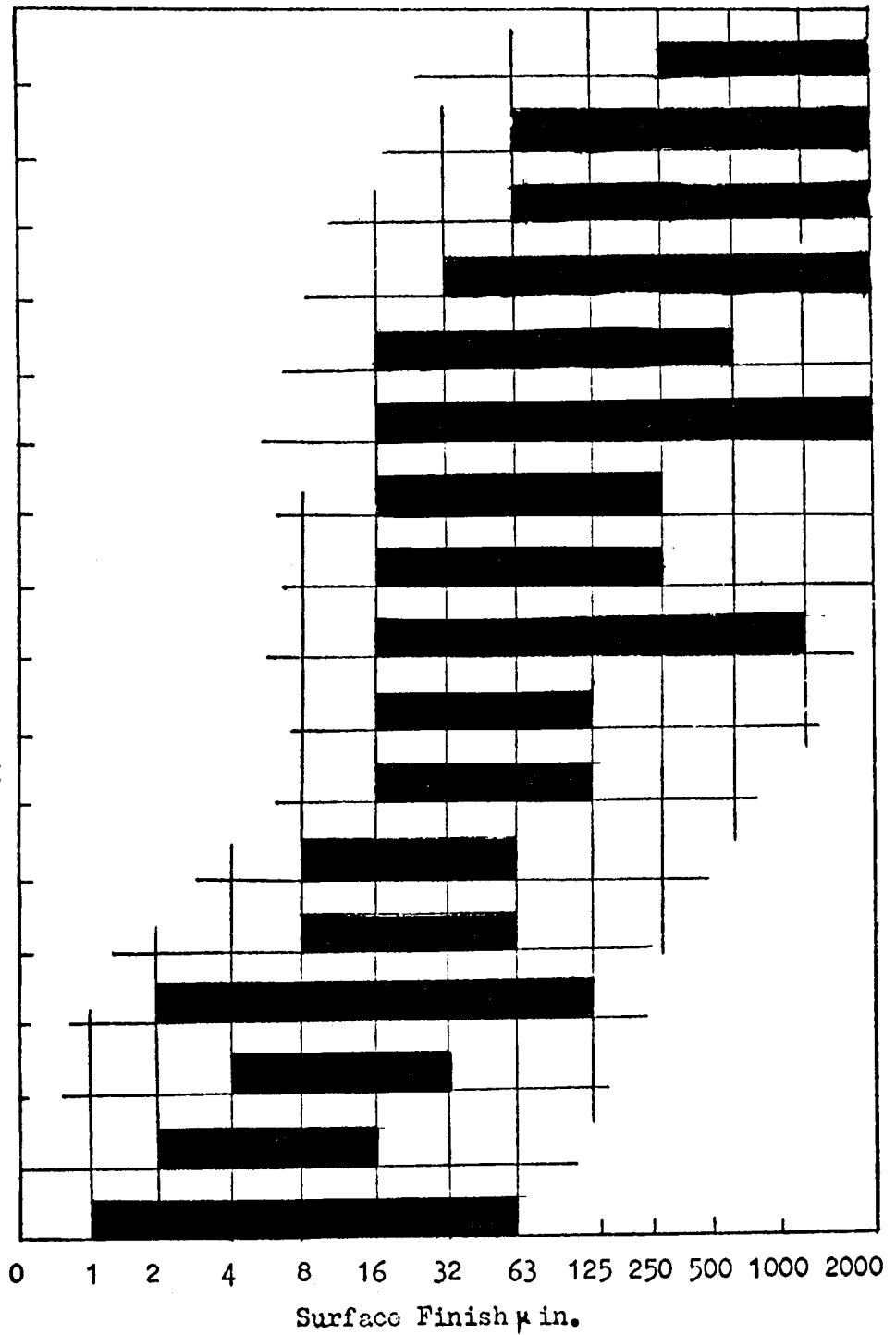
DRILLING COSTS FOR VARYING DEPTHS OF HOLE

————— Actual Cost
----- Projected Cost (Theoretical)



APPROXIMATE RANGES OF SURFACE FINISH
PRODUCED BY VARIOUS MACHINING PROCESSES

- Rough Turning
- Contour Sawing
- Rough Grinding
- Shaping & Planing
- Drilling
- Milling, H.S.S.
- Finish Turning
- Broaching
- Boring
- Reaming
- Commercial Grinding
- Milling Carbides
- Gear Shaping
- Barrel Finishing
- Diamond Turning
- Precision Finish Grinding
- Honing

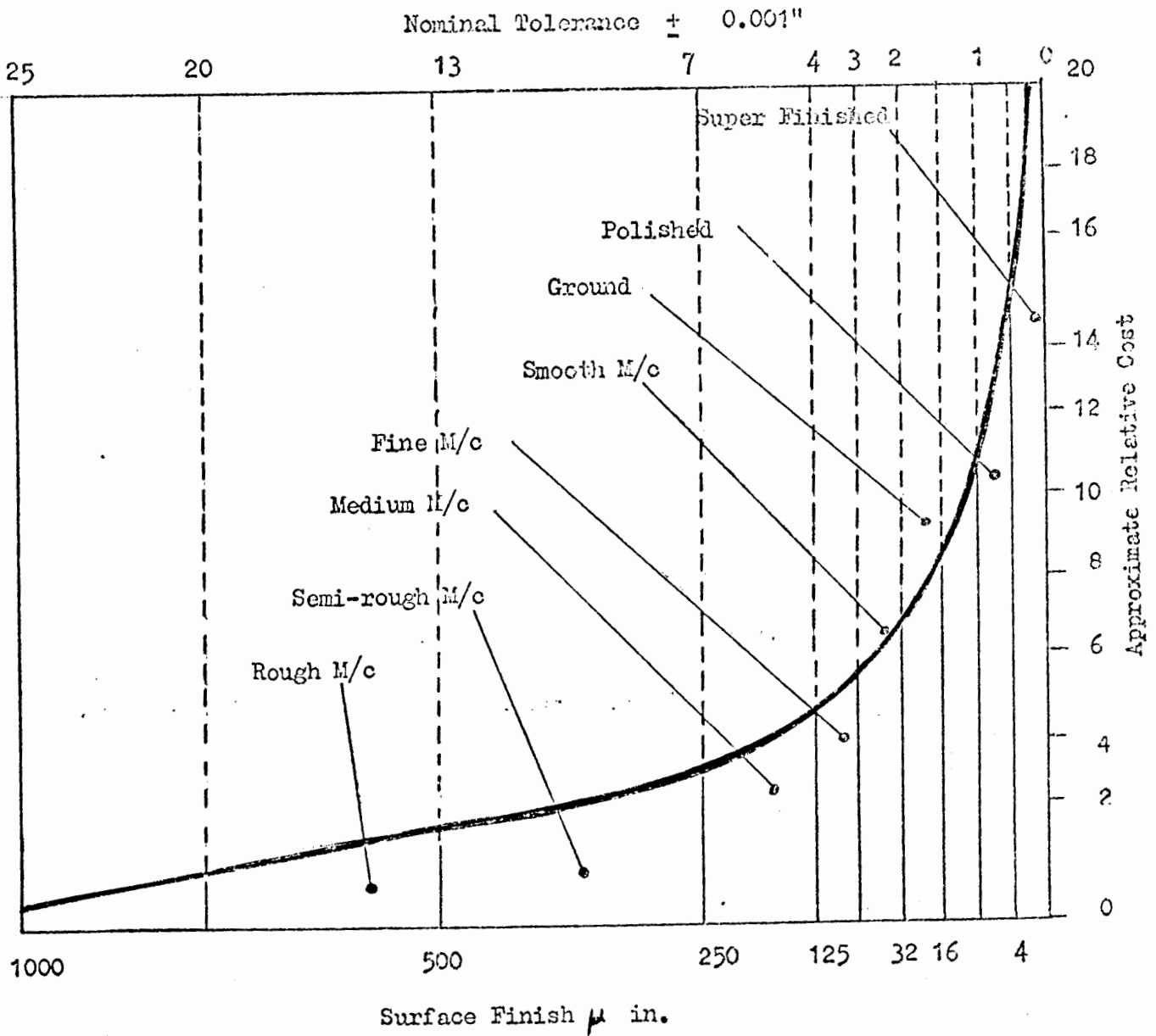


GUIDE TO INCREASING COSTS OF PROVIDING A
FINISH

1.	Oil for storage	(Whizzer)	Low Cost
2.	Oil for storage	(Dipping Tank)	
3.	Chemical Black	(Barrel & Basket)	
4.	Chemical Black	(Jig)	
5.	Bonderise	(Barrel)	
6.	Still Vat Bonderising	(Jig)	
7.	Still Vat Bonderising	(Basket)	
8.	Automatic Bonderising & Enamelling		
9.	Bright Zinc	(Barrel)	
10.	Tin Zinc	(Barrel)	
11.	Copper	(Barrel)	
12.	Cadmium	(Barrel)	
13.	Bright Zinc	(Vat)	
14.	Tin Zinc	(Vat)	
15.	Copper	(Vat)	
16.	Chrome	(Vat)	
17.	Automatic Tin Nickel	(Vat)	

To be used as a guide only

APPROXIMATE RELATIONSHIP BETWEEN SURFACE FINISH AND COST



2.1 GENERAL COMPARISON OF MANUFACTURING MATERIALS

Introduction

In this section a general comparison is made of the strength, weight and cost of materials most commonly used in Manufacture.

The cost figures vary from year to year and the figures given are for guidance only.

Similarly new plastics are being developed year by year and, for very specialised applications, a plastic not included in these lists may be the one to use

These tables are, therefore, intended as a handy reference for initial guidance only. During the design of any major component it is always most important to consult a specialist regarding the most appropriate material and the Purchasing Department for up to date quotations.

STRENGTH/WEIGHT COMPARISON OF VARIOUS MATERIALS

	Material	Factor			
		Thickness	Stiffness	Strength	Weight
Equal Thickness	Zinc	10	10	10	10
	Aluminium	10	12	9-11	4
	Magnesium	10	11	8	3
	Acetal	10	4	3	2
	Polycarbonate	10	3-4	2-3	2
	Nylon	10	2	2	2
Equal Stiffness	Zinc	10	10	10	10
	Aluminium	8	10	7-9	$3\frac{1}{3}$
	Magnesium	9	10	7	$2\frac{3}{4}$
	Acetal	25	10	$7\frac{1}{2}$	5
	Polycarbonate	30	10	7	$5\frac{3}{4}$
	Nylon	50	10	10	10
Equal Strength	Zinc	10	10	10	10
	Aluminium	9-11	11-13	10	$3\frac{1}{2}$
	Magnesium	12%	$13\frac{3}{4}$	10	$3\frac{3}{4}$
	Acetal	35	13	10	$6\frac{2}{3}$
	Polycarbonate	40	14	10	8
	Nylon	50	10	10	10
Equal Weight	Zinc	10	10	10	10
	Aluminium	25	30	25	10
	Magnesium	33	37	60	10
	Acetal	50	20	13	10
	Polycarbonate	50	$17\frac{1}{2}$	$12\frac{1}{2}$	10
	Nylon	50	10	10	10

COMPARISON OF VARIOUS PROPERTIES OF MATERIALS
MANUFACTURED BY "MOULDING"

Factor	Die castings			Investment castings		Injection Mouldings		
	Zn	Al	Mg	Steel	Al	Acetal	Poly-carbo-nate	Nylon
Strength	10	9-11	8	to 100	15-20	3	2-3	2
Weight	10	4	3	12	4	2	2	2
Stiffness	10	12	11	50	15	4	3-4	2
Toughness	10	4	3	to 100	10	6	6-20	7
Ductility	10	5	3	to 35	15-20	20	80	60
Resilience	10	8	9	5	8	25	25	30
Hardness	10	9	8	100	15-20	5	4	3
Dimensional stability	10	10 $\frac{1}{2}$	10	50	10	3	4	2
Abrasion resistance	10	9	8	to 100	10	10	10 $\frac{1}{2}$	11
Fatigue resistance	10	11	10 $\frac{1}{2}$	to 50	15	9	7	8
Creep resistance	10	45	100	100	50	2	3	1
Max. operating temperature	10	15	16	100	15-20	9 $\frac{1}{2}$ -10 $\frac{1}{2}$	11	10

COST, STRENGTH AND DENSITY COMPARISON
OF VARIOUS MATERIALS

1. METALS

Material	Price Pence per lb.	Price Pence per cu. ins.	Density Grms/ C.C.	Tensile Strength lb/sq.ins.
Steel (Free Cutting M.S.)	3.12	0.88	7.8	55,000
Brass 70/30	18.33	5.71	8.4	41,000
Al. Alloy (Casting)	15.00 17.50	1.38 1.62	2.56	11,000/ 26,000
Cast Iron	2.92 5.00	0.83 1.31	7.2	25,000
Stainless Steel	21.25	6.10	7.92	29,000/ 45,000
Copper (Pure)	29.58	9.42	8.82	24,000/ 27,000

To be used as a guide only

COST, STRENGTH AND DENSITY COMPARISON OF
VARIOUS MATERIALS

2. PLASTICS

Material	Price Pence per lb.	Price Pence per cu.ins.	Density Grms/C.C.	Tensile Strength lb/sq.ins.
Low Density Polythene	6.66	0.22	.92	1,650
High Density Polythene	8.75	0.30	.96	4,300
Polypropylene	9.79	0.32	.91	4,900
Polystyrene	6.66	0.25	1.05	7,000
High Impact Polystyrene	10.00	0.37		
A.B.S. Copolymer	17.50	0.67	1.07	5,700
Rigid P.V.C.	10.50	0.63	1.4	7,000
Nylon (6.6)	28.75	1.18	1.14	10,500
Acetal	29.16	1.50	1.42	10,000
Polymethyl Methacrylate	16.68	0.71	1.19	9,000
Cellulose Acetate	15.00	0.69	1.28	5,200
Polycarbonate	33.95	1.47	1.2	8,750
Phenol formaldehyde	6.25	0.31	1.4	8,250
Melamine formaldehyde	12.50	0.67	1.48	10,000
Urea formaldehyde	9.16	0.49	1.5	9,250
Polyester (Casting Resins)	10.00	0.43	1.2	9,500
Epoxy (Casting Resins)	31.66	1.43	1.25	8,500
Poly Phenylene Oxide	50-70	1.9-2.6	1.06	9,200

To be used as a guide only

Introduction

Production of plastics on a world basis is increasing at a phenomenal rate. Already the volume of plastics produced far exceeds that of non-ferrous metals and it is predicted that in the 1980's the volume of plastics produced will exceed the total volume of metals, both ferrous and non-ferrous.

The consumer market was initially responsible for this growth in plastics but more recently the building trade has accounted for a sizeable share. In general engineering the usage of plastics has been comparatively low but it is in this area that the major expansion is expected in the next decade. Every designer and development engineer should be aware of the potential of the plastic materials that are currently available and the new advances that are continually being made.

A vast amount of information exists on plastic materials, processing and applications and the information given here is necessarily brief. It is aimed at giving basic information on the main types of plastic material available and methods of processing in relation to the functional requirements of the end product.

Classification of Plastics

Plastics are generally considered under three broad classes : thermosets, thermoplastics and composites.

Thermosets can be moulded once only into desired shapes. Moulding incurs irreversible chemical change which is produced either by heat and pressure or by mixing appropriate constituents immediately before moulding. Subsequent applications of heat and pressure will, within limits, have no effect but outside these limits degradation occurs.

Thermoplastics similarly can be formed by the application of heat and pressure but in contrast to thermosets can be reformed by the re-application of heat and pressure. They can be recycled many times in this way before significant degradation occurs.

Composites are combinations of plastics (usually thermosets) and non-plastic reinforcing materials such as glass fibre.

Properties of Plastics

Because plastics have slowly replaced metals in a variety of applications they are often thought of as substitutes, the implication being that they are inferior or that they are only marginally acceptable.

Regarding plastics in this way can lead to bad design in that designers are inclined to think in terms of designs for metal manufacturing processes and then specify as plastic material. The more constructive approach, based on the Value Engineering philosophy, considers the functions required in a particular context and the most economic means of achieving them. A plastic part may then be indicated and designed in a shape that matches both material properties and manufacturing method.

It is most important that plastic materials should be considered in their own right on the basis of suitability for function. In this way the optimum use will be made not only of plastics but of all available materials whether metal, ceramic, glass, wood, rubber etc.

The properties of individual types of plastic are given in the following tables but there are some general characteristics, good and bad, of the plastics family which should be borne in mind.

Mechanical

All plastics are low density materials and many of them, on a weight for weight basis, are very strong.

Difficulties sometimes arise when engineers try to describe the mechanical behaviour of plastics using the terms normally used for the properties of metals. Consideration of elastic properties serves to illustrate the point. A stress-strain diagram for steel shows a straight line portion up to the yield point and the slope of this line gives a figure for Young's Modulus which can be regarded as a constant for the material. A typical diagram for a thermo-plastic would show a flatter curve up to a less well defined yield zone and so it is not possible to talk of a Young's Modulus figure in the same way. The strain produced at a given stress depends on the rate of increase of stress and on temperature.

Again the creep characteristics of thermo-plastics need careful consideration when considering operation under load for prolonged periods.

With some plastics the mechanical properties and dimensions vary appreciably with water content, e.g. nylon with a 6% water content performs satisfactorily but in a very dry state becomes extremely brittle.

These points are made to highlight some of the differences that exist between plastics and metals which the designer should bear in mind when considering plastics. Much has been written on the subject and the optimum use will be made of plastics only if the desired components are designed from the start in a particular plastic for a manufacturing method appropriate to that plastic.

Electrical

All plastics are good electrical insulators having both high resistivity and high dielectric strength but it must be borne in mind again that these parameters can vary appreciably with the filler materials used, temperature and humidity. Particular care should be taken to ensure that an electrical parameter quoted is for the material in the form being used and not for the basic unfilled material.

Thermal

The very nature of plastics means that they do not have a precise melting point but become increasingly soft over a wide range of temperature. It is difficult therefore to define accurately the upper limit of working temperature and published figures invariably give a broad range.

Careful consideration should be given during the design stage to determine the maximum working temperature that a component could attain bearing in mind that the thermal conductivities of all plastics are much lower than those of metals.

In contrast the coefficients of expansion of plastics are typically 10 times greater than metals.

Also, use can sometimes be made of the characteristic of certain plastics to expand towards their original dimension on heating if they have, for example, been drawn, or shrunk if they have been irradiated.

Chemical

As a family plastics are comparatively inert chemically and the corrosion problems are quite different to those associated with metals. A guide to the chemical resistance of various plastics is given in the table but more detailed information should always be obtained from individual manufacturers when considering the use of a particular material in a given chemical environment. This makes many of them very suitable for use as protective coatings and obviate the need for any finish on components made from them. Colours can, of course, also be embodied in the plastic.

General

All data given on plastic materials will have been obtained from measurements on specially prepared test pieces. It is obviously desirable that standard test pieces should be used to afford a true comparison of a given parameter for different materials but at the same time designers should be aware that the values of the same parameter obtained on an actual finished component may be different. Tests on a sample of the actual component should be made if any of the material properties are considered marginal for the application.

Processing Methods for Plastics

The following are very brief descriptions of the current methods used for processing plastics.

Compression Moulding

This method is used almost exclusively for the thermo setting moulding compounds which are loaded either as a powder, or a preform, into a split mould. Heat and pressure are then applied. The material first softens and flows to fill the mould cavity and with further application of heat hardens.

Typical pressures and temperatures are 2,000 to 10,000 lb/in.² and 140 to 200 °C. Cycle times vary with the size of the part from 30 seconds to 15 minutes.

Tolerances of ± 0.005 in. are possible, there is virtually no wasted material and finishing costs are low.

Transfer Moulding

This is a modification of compression moulding in which the moulding powders are first softened in a cylinder separate from the mould and then pushed through a series of runners and sprues into a heated mould. Hardening then occurs in the mould as in normal compression moulding.

Tolerances of ± 0.001 in. can be maintained and very thin sections can be moulded. Cycle times are faster than for compression moulding but material wastage is high.

Injection Moulding

This is the method most commonly used for forming thermoplastics.

In this method the material, which is preheated to plasticity, is forced into a split mould which is clamped in a press to keep it closed. The mould is allowed to cool and the plastic solidifies before the mould is opened and the moulded component ejected.

The moulding material is sometimes heated in a cylinder and forced by a ram into the mould or more usually is fed directly from an extruder. (See below).

Rapid production rates can be obtained by this method with very little limitation on size or shape.

Mould costs are high and the method is really only suitable when a long production run is planned.

Extrusion

This method is associated mainly with thermoplastics although it can be used with some thermosets.

Usually the material is fed to a heated barrel with a fitting Archimedian screw where it is plasticised and then forced through a die. Alternatively the material is fed intermittently through a die by a reciprocating ram.

The method is obviously used for producing constant cross-section components.

The method can also be used for coating materials by extruding onto the required substrate.

Another variant is the production of "blown" film. A hollow tube of the material is extruded and inflated by internal air pressure to reduce the wall thickness. The tube is subsequently flattened between rollers and reeled. Films 0.005 to 0.010 in. thick are readily produced by this method.

Blow Moulding

In this method a thermoplastic is extruded vertically downwards in the form of a tube. An appropriate length of tube is then sealed off at both ends by the action of a hollow mould closing on it. Compressed air is then inserted and the "bag" of material is forced against the walls of the mould taking up its shape.

The method is well suited to the manufacture of liquid containers from small bottles to those with capacities of hundreds of gallons.

Thermo forming

This process is also known as vacuum forming.

Although there are variations, the basis of this method is that a thin sheet of the material is clamped at its edges in a frame and heated to softening point by radiant heat. The softened sheet is then drawn into a female or onto a male mould and held against it by drawing a vacuum.

Thermoplastic materials can be processed in this way, in particular acrylics, polythene and polystyrene.

The method is ideally suited for the production of open ended thin walled components and a wide range of surface areas can be handled. Tooling costs are low.

Composite Mouldings

The practice of adding fillers to plastics for enhancement of their properties is almost as old as plastics themselves. However, in recent years, reinforced plastics have become a category of materials in their own right with polyester-glass fibre composites being the outstanding combination. The following are some of the production methods used.

Contact Moulding

In this method a low cost mould in wood, plaster or even reinforced plastic is coated with a release agent and a fine gel coat of the resin applied. Successive layers of precisely tailored mat or woven glass cloth and liquid resin are then built up. The resin may be applied by brush or spraying. The layers are consolidated and air bubbles removed by applying pressure with a hand roller. The process is continued until the required thickness has been built up and the moulding cures at room temperature.

As an alternative to this "hand lay-up" method of contact moulding a "spray-up" method has been developed in which a chopper unit mounted adjacent to the spray gun nozzle feeds strands of glass fibre into the stream of resin. The combined stream settles on the mould and the bubbles are removed and the mixture consolidated as in the hand method.

Yet a further improvement is the "Simplex" method in which chopped strand mat is laid in the mould and resin applied through a hand-held roller from pressurised storage vessels. When the required quantity of resin has been applied the supply is cut off and the roller used as before.

Contact moulding has the advantages that very large mouldings such as swimming pools, boat hulls etc. can be produced on low cost tooling and design modifications are easily carried out. Disadvantages are high labour content and a long cycle time.

Filament Winding

In this method circular, oval or tapered bodies are produced by winding a filament of fibre, which has been dipped in resin, onto a suitably shaped mandrel. The spacing of the windings and the number of layers is adjusted to meet the end requirements. The method produces extremely high strength laminates.

Matched Die Moulding

In contrast to the previous two methods which produce a high quality finish on one side only, this method, as its name suggests provides a good finish on both faces.

A preform of chopped glass fibre roving is made by blowing a stream of chopped roving towards a perforated metal screen having the shape of the final moulding. En route this stream joins a binder spray produced by a spray gun and a binder-fibre preform builds up on the screen with the help of a vacuum drawn on the opposite side. After curing the preform is placed between matching dies mounted in a hydraulic press, a weighed quantity of resin is added and heat and pressure applied.

This method employs metal dies and produces good mouldings at reasonable cost for quantities in excess of 1,000.

Continuous Mouldings

This method is suitable only for shapes of constant cross-section and is sometimes known as "pultrusion".

Continuous lengths of the reinforcing medium are drawn through a bath of resin and then pulled upwards through a die of the required cross-section and a tunnel oven. Fully cured material emerges at the other end.

The method is particularly suitable for rod, tube, flat and corrugated sheet.

Methods for Permanent Assembly of Plastics

The methods available for making permanent assemblies of plastics can be divided into three groups, mechanical, thermal and chemical.

Mechanical Methods

Rivetting can be used successfully for joining plastics to plastics or plastics to metals. Although conventional metal rivets may be used it is often more economical to produce lugs on one component and holes in the mating part :

Rivetting can produce strong joints though not necessarily leak-proof. Application of heat to the punch or the plastic part will improve the strength.

High ductility and resistance to creep are important as well as strength if a material is to be rivetted.

Permanent press fits will produce better joints that are leak-proof for liquids and gases under pressure. When calculating the interference required it is most important to consider the temperature range and the expansion coefficients of the particular parts concerned.

Snap fits can sometimes be used in conjunction with press fits to improve performance over a range of temperature.

Thermal Methods

These are all essentially welding methods in which the faces of the mating parts are heated to softening point and held together under light pressure. The various thermal methods differ only in the method used to produce heat at the mating surfaces.

Hot Plate Welding

In this method each surface is held against a heated plate with an antistick surface. The parts are subsequently clamped together in a jig and the joint solidifies.

Spin Welding

Heat is produced by friction as the two parts are rotated against each other at their mating faces. This method is only suitable for joining parts made from the same material.

Hot Wire Welding

The parts are held together under pressure and an electrically heated wire passed through the joint. The surfaces of the two parts flow around the wire as it passes and solidifies at the time of its emergence on the other side of the joint.

Hot Gas Welding

In this method a welding gun or torch and a local atmosphere of inert gas to minimise oxidation are used with a filler rod of the parent material. This is a slow method and is really suitable only for large structures.

Resistance Wire Welding

An electrically heated wire is buried in the joint to produce heat and when the welding is complete it remains in situ.

Induction Welding

This is essentially the same as the above method except that a metal insert which remains in situ is inductively heated to fuse the parts.

Ultrasonic Welding

Mechanical vibrations at frequencies of about 20,000 cycles per second are transmitted to the joint by means of a welding horn. The heat produces fusion at this point.

Choice of plastic for the application and design of the welding horn require detailed study.

Chemical Methods

A variety of chemical bonding methods exists in the form of solvents, plastic materials in solution and other chemicals.

The precise method of using these "adhesives", the preparation required etc. varies appreciably from method to method and cannot be dealt with in a general manner.

SEE SECT 2.6 PAGE 1 FOR INFO ON
FOAM AND SANDWICH MOLDING.

SUPPLIERS OF PLASTICS MATERIALS (U.K.)

Material		Suppliers Reference No's. (See next page for Names & Addresses).				
		Form of Material				
		Powder /Resin	Rod	Sheet	Tube	Film
THERMOPLASTICS	A.B.S.	15	12	12	12	-
	Acetals	13	19	19	12	2
	Acrylics	13	13	13	4	-
	Cellulosics	3	12	6	12	5
	Nylon 66	13	17	17	17	-
	Phenoxies	10	16	-	22	-
	Polycarbonate	1	-	1	16	-
	Polythene	13	3	3	3	6
	Polypropylene	13	12	12	12	13
	Polystyrene	11	23	3	23	7
	P.T.F.E.	13	9	9	18	18
P.V.C.	13	12	13	12	6	
THERMOSETS	Alkyds	6	-	-	-	-
	Epoxies	21	22	22	22	-
	Phenolics	6	22	22	22	-
	Polyesters	20	14	14	14	-
	Silicones	8	18	18	18	-
	Urethanes	21	-	-	-	-

SUPPLIERS ADDRESSES

Ref. No.	Name	Address	Telephone No.
1	Bayer Chemicals Ltd.	Kingsway House, Richmond, Surrey.	01-940 6077
2	Bexford Ltd.	Manningtree, Essex.	(020-639) 2266
3	B.I.C.C. Ltd.	21 Bloomsbury Street, London, W.C.1.	01-636 1600
4	Bloore (G.H.) Ltd.	480 Honeypot Lane, Stanmore, Middlesex.	01-952 2391
5	British Cellophane Ltd.	P.O. Box 1 A.L., Henrietta House, 9 Henrietta Place, London, W.1.	01-636 8311
6	Bakelite Xyonlite Ltd.	27 Blandford Street, London W1H 3AD.	01-935 9211
7	Castrol Plastics Ltd.	Colharbour Lane, Harpenden, Herts.	(058-27) 61121
8	Cornelius Chemical Co. Ltd.	Ibex House, Minories, London, E.C.3.	01-709 0221
9	Crane Packing Ltd.	Slough, Bucks.	01-839 3521
10	Engineering Polymers	Evelyn House, 30 Alderly Road, Wilmslow, Cheshire.	Wilmslow 29611
11	Hoechst Chemicals	Hoechst House, Kew Bridge, Brentford, Middlesex.	01-995 1355
12	I.C.I. Ltd. Paints Division	Newton Works, Hyde, Cheshire	061-368 4000

Ref. No.	Name	Address	Telephone Number
13	I.C.I. Ltd. Plastics Division	Bessener Road, Welwyn Garden City, Herts.	Welwyn Garden (96) 23400
14	Langley London Ltd.	Faraday Road, Crawley, Sussex.	Crawley (0293) 25955
15	Marbon Chemical Division of Borg-Warner Ltd.	York House, Clarendon Avenue, Leamington Spa., Warwickshire.	Leamington 34121
16	M & B. Plastics Ltd.	23-25 Eastcastle St., London, W.1.	01-592 3060
17	Nylonic Engineering Co. Ltd.	Woodcock Hill, Rickmansworth, Herts.	Rickmansworth (79) 76261
18	Permalit Ltd.	Bristol Road, Gloucester.	Gloucester (0452) 28282
19	Polypenco Ltd.	Gate House, Fretherne Road, Welwyn Garden City, Herts.	Welwyn Garden (96) 21221
20	Scott Bader & Co. Ltd.	Wollaston, Wellingborough, Northants.	Wellingborough (093 33) 4881
21	Shell Chemical U.K. Ltd.	Shell Centre, Downstream Building, London, S.E.1.	01-928 1212
22	Tufnol Ltd.	Perry Bar, Birmingham 22B	021-356 4554
23	Wragby Plastics Ltd.	Wragby, Lincoln.	Wragby (067-34) 383

	MATERIAL	PROCESS					Composite Moulding	COST RELATIVE TO POLYTHENE L.D.	
		Compression Moulding	Transfer Moulding	Injection Moulding	Extrusion	Blow - Moulding		Thermo-forming	Weight Basis	Volume Basis
THERMOPLASTICS	A.B.S.	X	X	X	X	X		2.5	2.9
	ACETALS			X	X	X		4.1	6.3
	ACRYLICS			X	X		X	3.4	4.5
	CELLULOSICS			X	X		X	2.8	3.8
	NYLON 66			X	X			4.9	6.1
	PHENOXIES			X	X		X	7.2	8.6
	POLYCARBONATE			X				7.5	9.8
	POLYTHENE H.D.			X	X		X	1.1	1.1
	POLYTHENE L.D.			X	X		X	1.0	1.0
	POLYPROPYLENE			X	X			1.4	1.4
	POLYSTYRENE			X			X	1.20	1.3
	P.T.F.E.	X			X			20.3	47.5
P.V.C.			X	X	X		1.9	2.8	
THERMOSETS	ALKYDS	X					X	5.7	7.4
	DAP	X	X	X			X	10.8	14.9
	EPOXIES	X					X	4.8	7.4
	MELAMINES	X	X					1.9	3.0
	PHENOLICS	X	X	X			X	0.9	1.4
	POLYESTERS						X	1.5	2.5
	SILICONES	X					X	18.4	3.7
	UREAS	X						1.3	2.2
URETHANES (FOAM)	X						6	-	
							COMPARABLE RATIOS FOR METALS		
							METAL	WEIGHT BASIS	VOLUME BASIS
							Mild Steel (Free cutting)	0.5	4.0
							Brass (70/30)	2.9	26.0

	MATERIAL	MECHANICAL PROPERTIES					ELECTRICAL PROPERTIES				
		Specific Gravity	Tensile Strength	Elongation %	Compressive Strength lb/in. ²	Flexural Strength lb/in ²	Impact Strength Ft. lb. per in. of notch	Volume Resistivity Log. Ohm-Cm.	Permittivity @ 1000 Hz.	Power Factor @ 1000 Hz.	Electric Strength Volts/Mil.
THERMOPLASTICS	A.B.S.	1.07	Up to 9,000	Up to 140	8,000	8,000	6.0	16	2.8	0.008	350
	ACETALS	1.42	10,000	Up to 75	18,000	14,000	2.0	14	3.7	0.001	500
	ACRYLICS	1.19	Up to 10,500	Up to 38	17,000	12,000	2.3	14	3.0	0.04	370
	CELLULOSICS	1.15-1.34	8,000	Up to 70	36,000	8,000	2.6	14	4.0	0.02	400
	NYLON 66	1.14	10,500	Up to 300	74,000	13,000	1.5	15	4.0	0.03	400
	PHENOXIES (P.P.O.)	1.10	9,000	Up to 100	12,000	13,000	12	12	4.0	0.002	450
	POLYCARBONATE	1.20	9,000	Up to 100	12,000	13,000	12	16	3.0	0.002	360
	POLYTHENE H.D.	0.96	4,000	Up to 100	3,200	1,000	1.7	16	2.3	0.0005	500
	POLYTHENE L.D.	0.92	1,500	Up to 800	-	-	No Break	16	2.3	0.0005	600
	POLYPROPYLENE	0.90	5,000	Up to 250	74,000	8,000	2.6	16	2.2	0.0005	600
	POLYSTYRENE (HIGH IMPACT)	1.04	5,500	Up to 80	6,000	7,500	6.0	16	2.5	0.0004	500
	P.T.F.E.	2.15	Up to 5,000	Up to 600	1,700	No Break	3.0	18	2.0	0.0002	420
P.V.C. (RIGID)	1.40	9,000	Up to 40	10,000	13,000	10.0	16	3.0	0.01	500	
THERMOSETS	ALKYDS	1.20	27,000	2.7	22,000	25,000	6.0	16	5.5	0.04	350
	DAP	1.27	5,000	-	25,000	10,000	0.7	14	4.0	0.006	400
	EPOXIES	1.43	21,000	4.0	34,000	40,000	17.0	15	5.0	0.09	330
	MELAMINES	1.48	8,000	-	33,000	13,000	0.4	12	7.0	0.02	250
	PHENOLICS	1.40	4,000	0.5	22,000	12,000	0.8	12	7.0	0.03	200
	POLYESTER	1.55	Up to 2,000	1.8	23,000	40,000	15.0	14	5.0	0.03	300
	SILICONES	1.86	4,500	-	13,000	12,000	9.0	14	4.5	0.01	300
	UREAS	1.50	9,000	0.7	35,000	14,000	0.3	13	7.0	0.03	300
	URATHANES (FOAM)	0.016 - 0.05	10 - 300	6 - 500	10 - 500	-	-	14	1.1 - 2.0	0.006	100

	MATERIAL	THERMAL PROPERTIES									THERMAL EXPANSION PER °C, 10	ORGANIC SOLVENTS	CHEMICAL RESISTANCE			
		RANGE OF MAXIMUM USABLE TEMPERATURES											ACIDS		ALKALIS	
		°C	50	100	150	200	250	300	350	400			450	WEAK	STRONG	WEAK	STRONG
THERMOPLASTICS	A.B.S.										100	Varies	O	X	O	O
	ACETALS										80	O	O	XX	O	O
	ACRYLICS										90	Varies	O	O→X	O	O
	CELLULOSICS										150	X	O→X	X	O	X
	NYLON 66										80	O	O	XX	O	O
	PHENOXIES										65	Varies	O	O	O	O
	POLYCARBONATE										70	Varies	O	X	O→X	XX
	POLYTHENE H.D.										130	O	O	O→X	O	O
	POLYTHENE L.D.										170	O	O	O→XX	O	O
	POLYPROPYLENE										110	O	O	O→X	O	O
	POLYSTYRENE (HIGH IMPACT)										70	Varies	O	O→X	O	O
	P.T.F.E.										125	O	O	O	O	O
	P.V.C. (RIGID)										145	Varies	O	O→X	O	O
THERMOSETS	ALKYDS									35	O	O	O	X	X	
	DAP									80	O	O	X	O	XX	
	EPOXIES									60	O	O	O	O	X	
	MELAMINES									45	O	O	XX	O	X	
	PHENOLICS									70	O	O→X	X→XX	X→XX	XX	
	POLYESTER									70	O→X	X	XX	X	XX	
	SILICONES									36	O→X	O	X	O→X	X	
	UREAS									30	O→X	O→X	XX	X→XX	XX	
	URETHANES (FOAM)									50	O→X	O→X	XX	O→X	XX	

KEY

O Unaffected
X Mild attack
XX Marked attack

(Article extracted from Chartered Mechanical Engineer)

2.3. ADHESIVES IN MECHANICAL ENGINEERING

Introduction

Adhesives can play an increasing part in the cost effective design of mechanical assemblies. Although they were widely used during the last World War in the construction of both wooden and metal aircraft, and although they have since been developed in a much wider variety at lower cost and yielding greater strength, they are not considered as generally as might be expected in the light mechanical and electronic industries, apart from the automobile industry.

Apart from the great advantages and saving in labour costs which they can offer in convenience and ease of assembly they can also often save considerable cost in machining tolerances. For only one example, the necessity for tight tolerances in "push" or "force" fit assemblies can be avoided and the reliability of the assembly can be improved.

Lack of knowledge is one of the main reasons for lack of application of a suitable adhesive selected from the wide range now available.

It is therefore considered worth while to include the following review of progress in the field of adhesives, including a brief summary of the types available. For further reading a suitable bibliography is suggested.

Review of Progress

Adhesive bonding has become established in recent years as a method of joining materials which can replace or supplement soldering, riveting, welding and mechanical fastening. The strength of bonded structures under severe conditions has been demonstrated in aircraft engineering but the use of bonding for other purposes has been relatively restricted. Automotive and marine structures are still largely welded or riveted, and mechanical fastening predominates in the fabrication of constructional metal work, domestic appliances and other mass production items.

Designers have been hampered by a dearth of information on the properties and limitations of engineering adhesives. They have tended to select them on the basis of their suitability for production processes, rather than for their performance and the emphasis in development work has been on the optimisation of bonding processes and on quality control.

Consequently, there is a lack of data on creep properties, fatigue endurance, elastic modulus etc., and their variation with the environment. Nevertheless, adhesives are used in load-bearing structures with considerable success.

A bonded joint produces a distributed stress over the whole adhesive area and this eliminates the local stress concentration attendant upon screws, rivets, spot welds, etc. This factor alone allows designers to reduce weight and cost while improving the joint performance and fatigue properties. Bonded joints also present a smooth external appearance and the adhesive can serve as insulation and sealing compound, damp out sound and vibration and minimise contact corrosion. Bonded assemblies thus have a higher structural efficiency, particularly in thin metals, and the adhesive can absorb a certain amount of shock.

Disadvantages of bonded structures which have militated against their use in engineering include the need for special joint design to prevent cleavage weakness, long processing times for curing and the dependance of joint durability on the quality of the bonding processes. The limited resistance of many adhesives to extreme temperatures and humidities is another factor which has often precluded their use.

Optimum results are not obtained if an adhesive is used with a conventional joint design. The applied service stress must be in the direction of maximum bond strength. With the commonly used overlap joint, the bond strength increases linearly with joint width but not with overlap length.

De Bruyne proposes the use of a 'joint factor' to take into account this behaviour :

$$\frac{\sqrt{\text{adherent thickness}}}{\text{overlap length}}$$

Fixed values for the ratio are constant for a particular adhesive. Later studies have shown that joint failure stresses are usually proportional to the square root of the ratio for a given joint. The strength of an adhesive also increases with the yield strength of the adherent. Standard shear strength can thus be used to calculate the probable joint strength.

Perry outlines an approach to design which combines theoretical considerations with empirical formulae to determine the overlap areas to support given loads.

The provision of useful design data for adhesives presents problems for manufacturers which have yet to be overcome. Available strength data permit the designer to compare the merits of different adhesives or to assess their durability but can rarely be used directly in design calculations. Frequently the performance data quoted depend on the test method and adherend employed, rather than on the adhesive; especially as regards peel and cleavage strength.

Some of the stresses in a single-overlap joint are plotted in Fig. 1. The shear stress is maximum at the leading edge of the overlap and falls to zero at the centre. There is a peeling stress, perpendicular to the tensile stress, which causes compression a short distance from the overlap end. The tensile stress is highest at the beginning of the overlap and is reduced to half the maximum at the centre of the joint.

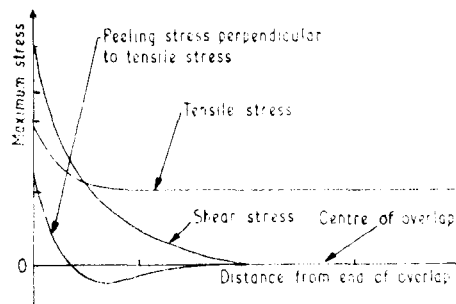


Fig. 1. Stress distribution in a single-lap bonded joint.

Flexure of the joint components further complicates the pattern of stress distribution so that the strength of adhesion is not strictly defined by the tensile failure load of the joint. However, in practice this need not prove a limitation since in testing a lap-joint sample the actual service conditions of the bonded structure can often be simulated.

It was first suggested by de Bruyne that the stress complexity of the lap joint can be avoided by using a napkin ring test specimen for the measurement of shear strength in torsion. This has led to the development of the torsion testing apparatus shown in Fig. 2 by R.A.P.R.A., and a potential technique for measuring actual adhesive strength. Where the ring is narrow, compared to the diameter, virtually uniform shear exists at the adhesive surface under torsion loading. Recorded shear strengths are independent of the ring width and, unlike lap joint specimens in which adherents are subject to stretching and bending, reproducibility of breaking strength is good.

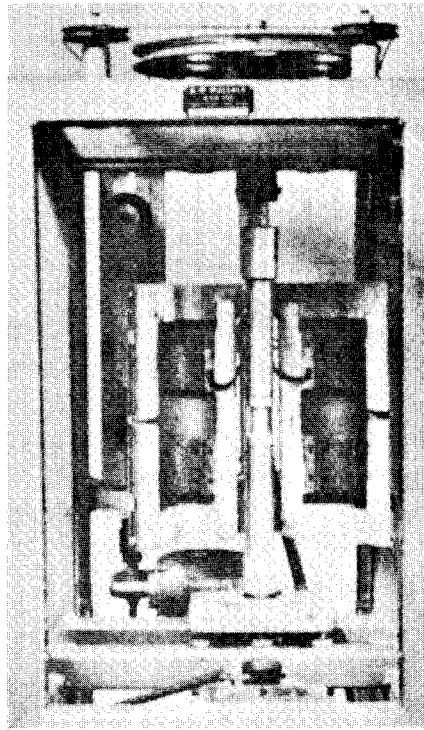


Fig. 2 Shawbury torsional-shear equipment with central cylindrical test specimen in situ.

This specimen design offers potential advantages and appears to be a significant step forward in destructive testing. It has proved useful in the correlation of performance with small differences in the chemical structure of polymeric adhesives; and the assessment of adhesion as a function of temperature. The assessment of structural bonds by destructive methods has been extensively investigated recently.

However, the strength measurements derived from destructive tests are of little value in assessing the durability in service. Recent years have seen the development of accelerated ageing and weathering tests designed to simulate long-term service conditions but much correlative work needs to be done before these tests become widely accepted. Prolonged testing, often for many years, is still mandatory for the stringent requirements of the aircraft industry.

The increasing use of adhesives in aerospace applications has necessitated methods of rapidly evaluating the bond condition, both on components and complete assemblies. A number of non-destructive tests have been the subject of recent development. They rely on previously established correlations between failure strength and some other property of the bond which can be assessed without destroying it. Ultrasonic, radiographic and infra-red testing have been extensively developed and show considerable potential.

The ultrasonic resonance technique measures the response of the bonded joint to low-power ultrasonic vibration and appears to be the most sensitive and reliable method. Comparison between non-destructive predictions and actual strengths to failure have established its reliability and the Fokker bond tester is widely used in the aerospace industry.

Pulse-echo transmission, pulsed-through transmission, and sweep-frequency resonance are other useful ultrasonic techniques. Pulsed-through transmission, which depends on the attenuation of energy when passing through voids in a joint, is in general superior to the other two. It has been applied to a wider range of structures, materials and adhesives and is suitable for metal-to-metal, metal-to-plastic, plastic-to-plastic, honey-comb core and fibre-reinforced plastic structures.

Infra-red inspection methods are of more recent origin and have not been widely employed. They depend on the detection of variations in thermal diffusion which arise in the vicinity of joint flaws. A varying temperature gradient is sensed as an infra-red emission at the component surface.

Many kinds of adhesives are being used, depending largely on the type of materials being bonded and also the service conditions of the bonded assembly. Something like 5,000 products are available today, based on 200 basic polymers. The properties and performances of the more important engineering adhesives have been described in a recent comprehensive Handbook (Ref.1).

For engineering applications, the majority of structural adhesives are of the thermosetting type, cured under heat and pressure. Epoxy resins and their modifications find the widest use for bonding metals because they do not contain solvents and are true liquids.

Single component epoxy resins have become available in the last few years as liquids or films which avoid the need for critical premixing of resin and simplify processing. They rely on heat to initiate the hardening action of a latent catalyst.

Thermoplastic adhesives soften with heat and give considerably lower strengths than the thermosetting types but are frequently employed where lower joint strengths are acceptable. Elastomeric adhesives are rubber-based and used for their high peel-strengths.

The use of sandwich materials has increased during the past decade because they are light and strong. The bonding of a honeycomb core to the two faces of a sandwich panel can result in a structure with very high strength and rigidity to weight ratios.

Vinyl-phenolic, nitrile-phenolic, polyurethanes and modified epoxy resins have been developed for the fabrication of sandwich materials which permit a new approach to many design problems. There is now a comprehensive list of design formulae to give optimum shear and compression strengths, flexural rigidity, buckling stress and bending deflections etc.

The thermal stability for a polymer is defined by the temperature range over which it retains useful adhesion properties. Thermogravimetric analysis (TGA) has emerged in recent years as an important method for evaluating this.

With the exception of silicones and fluorocarbons, all known thermosetting and thermoplastic resins are degraded below 400°C. However, the useful temperature range of a polymer adhesive cannot be ascertained from a thermogram alone because other changes can occur below the breakdown temperature. Thus, a polymer can undergo chemical modification, irreversible decomposition, molecular re-arrangement or reversible melting or softening.

Thermally stable adhesives are based on polymers with high decomposition temperatures, possessing the rigid chain structures associated with polar or sterically interlocking chain substituents, chemical cross linking, or crystallisation.

Many structural adhesives retain their strengths at up to 100°C, including the nitrile-phenolics, epoxy-nylons, vinyl-phenolics and modified epoxy resins. Anhydride-cured epoxies and certain nitrile-phenolics retain their strengths at a continuous 180°C. For above 200°C, modified phenolics, phenolic-epoxies, modified silicones and polyaromatics adhesives are under continuous development to meet the requirements of the aerospace industry. Silicones show good stability up to 300°C but their shear strengths rarely exceed 200 lbf/in; however, by compounding with epoxy or phenolic resins, up to 1,600 lbf/in can be obtained.

Many new basic polymers now under development should result in greatly improved adhesives. At present research is concentrated on thermally stable organic polymers, because of the slow pace of inorganic polymer development.

Thermal stability associated with hydrolytic and oxidation stability is best achieved in polymers formed from fused aromatic rings or by the inclusion of atoms with good thermal properties, such as boron, silicon, nitrogen, and phosphorus.

So far, this research has resulted in commercial adhesives for up to 500°C, based on polyamide (PI) and Polybenzimidazole (PBI) resins. Narmco's Imidite 850, a glass fabric based on PBI and, is capable of retaining about 70 per cent of its strength during continuous exposure to 350°C; and short periods up to 500°C.

Ceramic adhesives, made as fusible frits from boric acid, silica and ferric oxide, appear to offer the answer to the high temperature problem. Tests indicate that bonded joints can operate at 550°C and strength increases with temperature. However, ceramic systems have serious shortcomings. Although their heat and oxidation resistance is better than that of organics, attempts to overcome their inherent brittleness have failed. Thermal shock resistance of all ceramics is poor but can be improved by incorporating a metallic phase.

Ceramic-adhesive brazing alloys show promise and have been used by Boeing for panel bonding. A silver-based brazing foil is sandwiched between panels sprayed with ceramic adhesive. Joints are fired in air under pressure at 930°C. For higher temperatures nickel-based alloys replace the silver and service temperatures up to 820°C are possible.

Most of the ceramic bonds used have been developed to solve specific problems and consequently little general interest has been shown in their development. High curing temperatures and processing difficulties have restricted their use. The future for high-temperature adhesives appears to lie with organic polymers.

Cryogenic applications in electronics, missile materials and nuclear engineering have been extensively developed, primarily to meet military and aerospace requirements. Non-military applications for super-conducting electromagnets, motors, and liquefied gases have now become the concern of several industries. Adhesives for use in such areas represent one class of materials which can be expected to present problems.

Many of these problems arise from stress increases and concentrations in adhesive joints where differences in thermal coefficients of expansion, thermal conductivities and elastic moduli exist between adherends and adhesives. Low-modulus adhesives can relieve such stresses at room temperature by deforming, but very low temperatures increase the modulus to a point where stress relief is no longer possible.

Several classes of structural adhesives are available for cryogenic applications although data on these materials is limited, particularly on peel strength, impact resistance, vibration fatigue, and other physical properties.

Polyurethane systems appear to have received most attention. Peel strengths can approach 100 lbf/in. while tensile strengths reach 10,000 lbf/in. at -250°C although these fall to about 2,000 lbf/in. at room temperature. More recently, epoxy-nylon, polyimides and polyisocyanurates have been explored as low-temperature bonding agents. Epoxy resin systems which contain elastomers or thermoplastics such as polysulphide, polyurethane and polyamide, have proved to be suitable for use down to -196°C at Sira Institute. These materials overcome the problems of embrittlement which are a feature of epoxy-nylon formulations and unmodified thermosetting resins such as the phenolics and phenolic-epoxies.

Liquid-oxygen compatability is another problem: nearly all organic materials react with liquid oxygen. The only exceptions are polymers in which the central carbon chain is protected by non-reactive groups. Fluorocarbons, such as polytetrafluoroethylene and fluorinated ethylene are sufficiently inert and so far they appear to be the only such materials that have been considered as adhesives. But their adhesive performance is very limited.

Anaerobic adhesives are single-component liquids, based on the acrylic acid diesters which polymerise in the absence of atmospheric oxygen, under the catalytic influence of metals. Thus the monomer is able to polymerise to form a tough, resilient bond when confined between closely fitting parts. The Loctite products are the best known example of this type, which can be formulated to give various viscosities, setting times and shear strengths, and bond all common metals, glass, ceramics and phenolic plastics. Viscosities range from 10 to 20,000 CP and shear strengths up to 1,500 lbf/in. Chemical resistance is good and curing times can be reduced to 20 minutes. Recently developed special grades withstand up to 200°C, above 250°C the materials soften, which may be useful in dismantling of joints for repair. The single-component aspect facilitates automatic application and the development of versatile metering and dispensing equipment during the past three years has resulted in a continuous growth in engineering applications.

The most important use is as a liquid lock-washer for screws and bolts. The loosening torque for the strongest grades is superior to that of epoxy resins and several times that of most locknuts and screws.

Van de Vlasakker has recently reviewed engineering applications which include compression gaskets, crack-sealing in castings, retaining bearings and other components, pipe joining for central heating systems and hydraulic fittings. The low fatigue life of high-cost press-fit joints can thus be improved upon by bonding techniques which are also more economical.

The removal of mill oil from steel prior to bonding often results in rapid rust formation; the re-oiling of bonded parts to prevent corrosion often makes the process uneconomical. Vinyl plastisols and other compositions based on polychloroprene rubber have therefore been developed in recent years for bonding directly to oily materials. Shear strengths with metal are usually below 1,000 lbf/in. but current research should improve this. The present main use in the automation industry should then extend to metal fabrications involving large steel panels.

Hot-melt materials are based on thermo-plastics; they are solids which solidify and achieve their strength by cooling. Unlike other adhesives they do not depend on chemical action or solvent loss to effect the setting which occurs within seconds or minutes of application. Melt temperatures range from 65 to 180°C. The hot melts are of considerable importance in the mass-production industries such as paper, packaging, shoe manufacture and plastics bonding and laminating, where speed, simplicity and mechanisation are vital. (See Fig. 3).

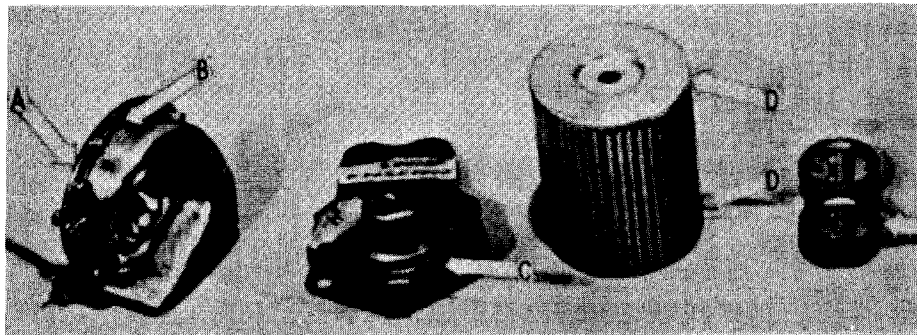


Fig 3

*Applications for polyamide hot-melt adhesives in the automotive industry:
 (a) automobile horn (b) suspension ball joint (c) grease reserve cover (d) oil filter
 (e) choke valve assembly*

The growth rate of thermo-plastics applications has been rapid during recent years due to the concurrent development of versatile mechanical applicators. Progressive feed equipment is also available which feeds the cold, solid adhesive continuously through a hot nozzle with an orifice profile of the required band width.

Ethylene vinyl acetate (EVA) copolymers, polyamides, ionomer, and phenoxy resins among such materials have significance as future engineering adhesives. The EVA copolymers readily adhere to polyethylene, polypropylene and reinforced polyester composites with peel strengths up to 30 lb/in. Cross-linked resins based on copolymers of ethylene with monomers other than vinyl acetate, are also being investigated. These materials offer the prospect of an adhesive that can be applied as a hot melt but is nevertheless capable of thermosetting at a later stage.

Polyamides have already proved satisfactory rubber substituted for metal bonding automotive components such as are shown in Fig. 3. Temperature and viscosity factors limit their shear strength with metals to about 1,000 lbf/in. at 70 per cent of the melt temperature but strengths are improved by epoxy-resin addition. Munn has recently reviewed these versatile materials.

Phenoxy resins are capable of shear strengths approaching 4,000 lbf/in. when bonded for 2 to 3 minutes at 200°C and are under consideration for side-seaming conventionally soldered tinfoil cans which are normally produced at 500/min.

Continuing industrial needs for faster assembly on the production line have engendered the development of rapid-setting adhesives, automatic applicators and faster curing processes.

One-component cyanoacrylate and polyacrylate adhesives which set in seconds or minutes have become available in the past few years. They are expensive and lack the strengths of the conventional structural adhesives but are suited to small bond areas in fine engineering work. The polyacrylates are useful sealants for close-fitting cylindrical or threaded joints and permit less critical production tolerances.

Film adhesives are a recent development. The advantage of using solvent or heat-activated dry film has been discussed by Cooper.

To avoid the problems of batch mixing two-component adhesives in production, automatic mixing and metering equipment is frequently used. Ejector valves control the dispensation of the adhesive and the rate of application. Newer methods of avoiding component mixing and handling problems include encapsulation and the use of molecular sieves. Pre-mixed adhesive is surrounded by a protective plastics wall and before bonding the capsule is crushed by pressure or melted by heat. Molecular sieves are fine silicate powders which retain catalysts or curing agents by surface absorption while dispersed in the adhesive resin. Heat or atmospheric moisture releases the hardening agent when bonding is to be carried out.

For heat curing processes, conventional sources such as gas, oil, steam, electrical resistance, infra-red and hot-air ovens are widely employed. Heat transfer is relatively slow and depends on the type and dimensions of the assemblies. Recent techniques for fast, localised heat input include HF or induction heating; and the use of metal substrate material as electrodes for resistance heating; and the placing of metal, carbon fibre or graphite resistance elements actually into the joint.

However, with very rapid heat curing of adhesives there is a risk of disruptive bubbling where heat control is poor. Optimum performance is obtained by slow heating and cooling.

Another new curing method which is particularly suitable for thermoplastics is ultrasonics. The high frequency vibrations within metal parts generate frictional heat at the joint interface.

In the aerospace industries the bonding of structural metal parts has been accepted for over two decades. Not only did they speed up fabrication and assembly of structures such as wings and fuselages but design improvements became possible. Early European examples include the Fokker "Friendships", de Havilland "Mosquitos" and "Comets" and the SAAB "Drakens". Recently, structural bonding has been extensively employed for the "Hustler", Boeing 727, "Jindivik" target aircraft, Lockheed "Tristar" and "Concorde".

"Ariel 3", the first all-British satellite, was bonded with a silicone rubber adhesive. The "Apollo" spacecraft was the first large airborne vehicle to employ epoxy carborane adhesives with high heat-stability for the primary load-bearing structure. The command module is constructed mainly of epoxy-phenolic bonded honeycomb sandwich.

One consequence of these advances has been a steady growth in commercial and mass production applications. Many different types of adhesives are currently used in the automobile industry, both in structural and other applications, but the use of thermosetting structural adhesives has been minimal.

Brake lining and clutch plates are now bonded with advantage; the use of heat and oil-resistant phenolic nitrile adhesives in place of rivets extends the service life of the lining by letting the friction material wear down to the shoe, rather than the rivet heads. Elimination of rivets also increases the contact area and reduces the possibility of drum scoring.

The undersides of bonnets and boot lids are reinforced with a bonded member as shown in Fig 4 (below) to provide structural rigidity, improve noise dampening, reduce weight, and lower assembly costs. The need for sound insulation panels is eliminated and joints are formed without external protuberances.

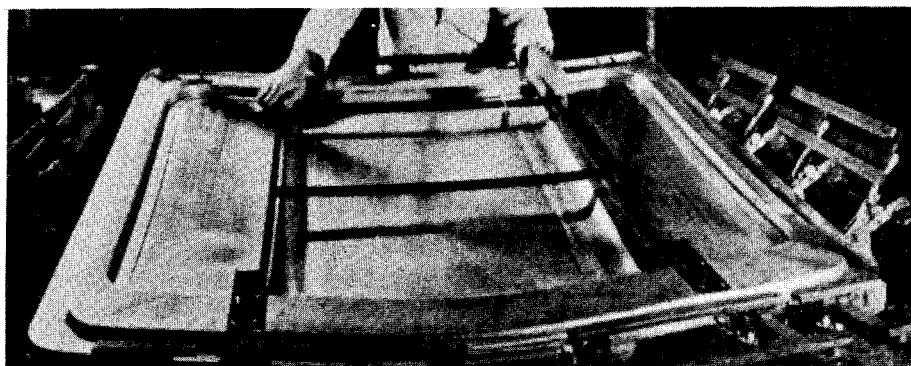


Fig 4

Frame reinforced bonnet assembly of the Aston Martin DBS bonded with Araldite epoxy resin

Adhesives are being considered for bonding a steel wear plate to aluminium suspension parts and V-belt drive shears; the bonding of diecast or permanent mouldings in place of semi-permanent mould-cast cylinders; and the assembly of transmission output shafts to bell housings.

The use of adhesives for body parts, plastic components, engine components, as sound dampers and body solders has been reviewed by Twiss and, more recently, by Wick.

The replacement of steel by glass-fibre composites will probably result in the use of adhesive bonding as the primary method of joining body parts. Polyester and epoxy adhesives have already been used successfully in the fabrication of glass fibre body panels in the Chevrolet "Corvette" and Marcos Sports cars. Duke has noted that many GRP boats contain similar structural bonds and that the "Bluebird" car in which Donald Campbell survived after crashing at speed had an extensively bonded construction - unhappily his last vehicle did not.

A polyvinyl formal phenolic composition (Redux) was the first adhesive system in the world to be employed for aircraft primary structures and is widely used today as a general-purpose structural adhesive. Its merits for metal-to-metal and sandwich bonding were recognised early in the development of marine hovercraft. The Westland SR-N5 and the larger SR-N6 make extensive use of bonding for the fabrication of the buoyancy chamber which forms the basic load-carrying structure. High strength and low weight are achieved by employing honeycomb, one of the many improvements in design made possible by structural bonding.

The use of polyester adhesives for bridge construction was pioneered in Germany in 1955, and several steel and aluminium bridges which rely on bonding for the cross-brace assembly have been erected since then.

Other applications are in railways where nitrile-phenolics are used to assemble the corrugated side panels of diesel locomotives. Since the 1950's the Dutch State Railway have employed bonded cross-braces in place of sleepers for stretches of track.

In the assembly of pressure vessels structural adhesives have been used for such diverse applications as missile-rocket motor cases and the Picard deep-sea bathysphere.

Epoxy adhesives with good gap-filling properties are used for bonding pumps, compressors and cast-iron casings with significant savings in weight and design complexity.

Evaluation of modified epoxy film adhesives at Sira established their suitability as a more economic alternative to brazing for the assembly of aluminium chassis housings for instrumentation. (See Fig. 5 below).

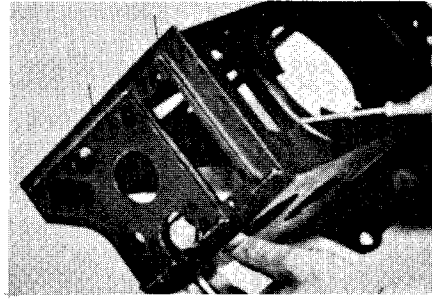


Fig 5

This photograph illustrates the use of a modified epoxy adhesive to replace an expensive brazing process for edge jointing of aluminium chassis components

A heat reactivated adhesive in dry-film form has been used successfully for bonding resin-asbestos clutch linings to aluminium die-cast clutch plates in the main drive motors of automatic washing machines (See fig. 6 below).

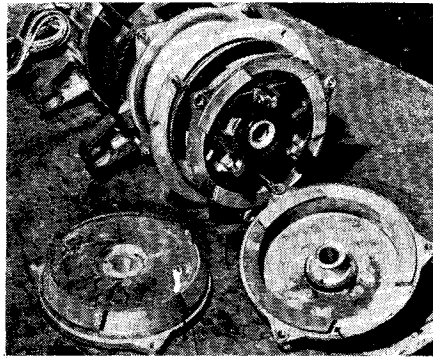
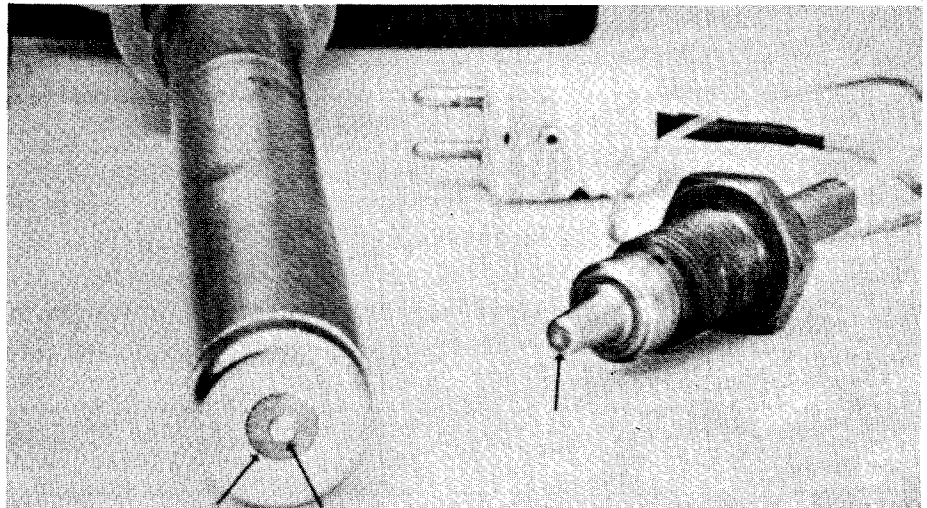


Fig 6

A dry-film adhesive is used to bond the clutch plate components of an electric motor unit at Hoover Ltd

Polyamide adhesives have also provided a heat resistant bond in the fabrication of thermocouple probes for injection moulding and rubber mixing machines. (See Fig. 7 below).



Thermocouple probes for rubber mixing (right) and plastics injection moulding machines (left). A heat-resistant polyimide adhesive bonds a ceramic shroud to the

Fig 7

Radar equipment is another application of epoxy-resin bonding in the electronics field.

The use of adhesives in optical, electronic and mechanical instrumentation has recently been reviewed and other engineering applications have been discussed comprehensively in articles and recent books.

Nuclear engineering, gas turbine research and vibratory test equipment are other areas incurring severe service conditions in which adhesives have been exploited to advantage.

The major advances in adhesive bonding have resulted from development work for the aircraft industry and this has led to a continuous extension of these techniques to other applications.

Increasing labour costs have emphasised the labour-intensive nature of assembly operations and focused attention on better techniques. This factor has promoted the development of mechanisation and faster curing methods for adhesives and considerable progress is being made in this direction.

Currently, the emphasis in the development of new adhesives is on materials which are easy and quick to cure. Single component liquids with latent catalysts, film materials and encapsulated resins, are among the many new adhesives that have emerged in the past few years. Other development work is concerned with the synthesis of adhesives able to bond new materials and withstand more extreme service conditions, including very high and very low temperatures, radiation, humidity, and other hazardous environments.

There is a growing demand for adhesives with satisfactory bulk properties which can function as engineering materials in addition to fulfilling a bonding function.

Designers have been restricted by insufficient information on engineering properties and adhesives limitations. Fundamental studies on joint behaviour and recent advances in testing bonds by destructive and non-destructive means promise to remedy the deficiency but the selection of adhesives on the basis of known parameters is still largely in the future.

Nevertheless, bonded joints can today be extremely reliable and offer the possibility of rapid and economic assembly.

Summary of adhesive properties and engineering applications

Type	Physical Forms	Application Method	Setting Process	Service Temperature °C	Strength Peel (lb/in)	Strength Shear (lb/in ²)	Uses
Thermosets Epoxy polyamide	2 part liquid systems	Spatula extrusion gun	Polymerisation at room temperature up to 100°C	-70 to 120+	10 to 15 (metals)	2 200 (metals)	Metal seaming and weld sealing. Aircraft, automotive and general industrial application for metals, glass plastics and rubber.
Epoxy polysulphide	2 part liquid systems	Spatula extrusion gun	Polymerisation at room or high temperature up to 100°C	-100 to 60	5 to 10 (metals)	2 000 (metals)	Metal structural assemblies where resilient bond required. Low temperature or severe weather conditions. Encapsulants.
Epoxy nylon	1 part, 100% solids, tape or film on fabric interliners	Sandwich assembly	Polymerisation at temperature up to 150°C	-75 to 95+	100 aluminium	5 800 aluminium	Structural assemblies requiring high peel strengths. Aluminium honeycomb fabrications in aircraft industry. Cryogenic adhesive.
Phenolic epoxy	Viscous liquids or glasscloth supported films or tapes	Brush, sandwich assembly	Heat cured to form thermoset at 165°C	-60 to 260	Low peel and impact strength	2 300 (steel) 3 200 (aluminium)	High temperature structural adhesive for metals, honeycomb sandwich materials in aircraft. Bonding titanium.
Phenolic nitrile	1 part solvent-resins, film materials with glasscloth/nylon interliners	Brush, sandwich assembly	Heat cured up to 260°C to form thermoset	-50 to 150 250 (short term)	20 to 45 (metals)	5 500 (metals)	Structural adhesives for metals, rubber, plastics. Automobile brake linings and clutch faces.
Phenolic-vinyl formal	Films, liquid/powder systems	Sandwich assembly. Powder sprinkled on liquid coated substrate	Formation of a thermoset on heat curing up to 177°C	-60 to 100	34 (metals)	2 500 to 5 000 (metals)	Structural adhesives for metals — metal in aircraft assembly; honeycomb panels and sandwich construction. Vulcanised rubber to metals.
Polyesters (unsaturated)	2 part systems, resin in solvent and associated catalyst	Brush roller	Copolymerisation of resin and solvent at 20 to 100°C	+30 to 100	Low peel strength	250 to 3 200 (metals)	Major application is in glass fibre composite manufacture. Limited usage for metals, ceramics and wood.
Polyimides	Solvent solution of prepolymer, films	Brush coating or film sandwich assembly	Polycondensation at high temperatures approaching 260°C	-196 to 260 (about 20 hr at 350°C)	22 to 33 (metal)	2 750 (metal)	Structural adhesive for high and low temperature. Bonding of steel, aluminium, titanium in aircraft assembly.
Thermoplastics Acrylic acid diesters	1 part low viscosity liquids or pastes	Dispensed from containers or automatic applicators	Polymerisation on exclusion of air. Cure in 24-72 hr at 20°C to 10 min at 120°C	-55 to 150	1 to 15 (aluminium)	1 500 to 3 000 (aluminium)	Small assembly work with metals and plastics. Joining cams, shafts, screws, subject to torsion. Long term moisture resistance usually poor.
Cyanoacrylate	1 part low viscosity liquids	Dispensed from containers	Polymerisation in presence of moisture on substrate at room temperature. Cures in seconds or minutes	-20 to 80	10	3 200 (steel) 1 500 (aluminium)	Rapid assembly of light structures based on metals, glass, plastics, and ceramics. Instrument components in electronics/optics involving close fitting parts. Limited by poor moisture resistance.
Ethylene vinyl acetate	1 part 100% solids in tape, film pellet and block form	Used as film adhesives or applied from melt reservoirs or feed applicators	Solidification on cooling the melting adhesive. Cures in seconds or minutes	-100 to 80	10 (metal) 40 (polyvinyl chloride)	150 (aluminium) 150 (polypropylene)	Limited usage in automotive industries. Suitable for many plastics, and metal foil laminations. Good water resistance. Cryogenic applications feasible.
Phenoxy	1 part solid in powder, film or pellet form. Solvent solutions	Hot-melt applicators or brush coating of solvent types	Solidifies on cooling. Bonded for 30 min at 192°C to 10 s at 300°C	-60 to 80	10 to 15 (metals)	3 500 (aluminium)	Pipe jointing of aluminium or steel. Metal foil lamination and seaming. Automotive applications; bonding of polymeric materials such as polyester film phenolic composites, acrylics.
Polyamides	1 part solid in film, cake or granule form. Solvent solution	Hot-melt applicators	Solidifies on cooling; melting point within range 100 to 190°C	-150 to 80	10 to 35	1 000 (metals)	Fast assembly processes. Automotive industry; radiator body solders. Plastics components based on polyolefines. Low temperature structural adhesives.
Elastomers Acrylonitrile-butadiene	Solvent-based viscous liquids	Brush, spray, roller	Solvent released from coated adhesives. Heat or solvent reactivation before joining	-50 to 80	17 (aluminium)	150 to 2 000	Bonding nitrile and neoprene rubbers to metals—gasket applications. Vinyl plastics. Painted metal in automotive applications.
Polychloroprene	Viscous liquids with additives	Brush, spray, roller	Contact bonding after solvent evaporation. May be heat reactivated.	-40 to 70	34 to 45 (aluminium)	700 (metals, wood)	Lamination of thin steel or aluminium sheets; vulcanised rubber to metal primed with the elastomer
Polyurethane	1 part solvent based liquids. 2 part liquid systems.	Brush, spray, spatula	Contact bonding after solvent loss. Chemical polymerisation	-200 to 80	10 to 40	1 100 (steel)	Assembly of metal structures for cryogenic service. Rubber to metal bonding.
Silicone	1 part pastes. 2 part pastes, liquids.	Spatula, extruder gun	One-part systems cure at 20°C. Chemical polymerisation	-75 to 250	5 to 30 (metals)	280 to 700 (metals)	Adhesive-sealants for welded joints. Bonding silicone rubbers, gaskets. Heat resistant seals for insulants. Moisture and corrosion resistant coatings.

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POWER SOURCES

The selection of the optimum source of power for a portable or transportable equipment is often very haphazard because of lack of knowledge of the range of types available. The power source can contribute a very large part of the initial equipment cost and of the cost of maintenance.

In the following tables comparison is made between available types of Primary cells and of Secondary cells and static generators (some types appear in both categories). The Tables do not include solar or heat cells because their application is limited to fixed installations or to very specialised applications such as satellites, in which they are extensively used (in conjunction with other batteries of cells such as silver zinc or nickel-cadmium to cater for periods when the solar cells are in shade.) They are also much used on sea marker light or sound buoys, although the difficulty of keeping them clean has detracted from their attractiveness for this application.

Detailed information on all cell types cannot be given in the manual but some sources of information on the various types are given on Page 4. These are by no means exhaustive and further sources of information should always be sought from the Purchasing Manager in the Business, the Library or other local facilities.

CELL TYPE	*CARBON-ZINC*	*ALKALINE-MANGANESE*	*MAGNESIUM DRY*	*MERCURY*
WET OR DRY AVAILABLE	Dry	Dry	Dry	Dry
CATHODE	Carbon Manganese Dioxide	Manganese Dioxide Carbon	Manganese Dioxide Carbon	Mercuric Oxide Carbon
ANODE	Zinc	Zinc	Magnesium	Zinc
ELECTROLYTE (Main constituents)	Ammonium Chloride Zinc Chloride	Potassium Hydroxide	Magnesium Bromide Sodium Chromate	Potassium Hydroxide
NOMINAL CELL VOLTAGE (open circuit)	1.5	1.5	1.8	1.35
ENERGY DENSITY (Watt.hr. per lb)	5 to 35	20 to 30	20 to 70	10 to 40
ENERGY DENSITY (Watt.hr. per cu. in)	1 to 3	3 to 4	3 to 5	5 to 7
POWER CAPACITY (sustained)	Low	High	Low	Moderate
POWER CAPACITY (pulsed)	Low	High	Low	High
NORMAL DISCHARGE VOLTAGE	1.25 - 1.35	1.2	1.6	1.25
VOLTAGE REGULATION	Fair	Good	Very good	Excellent
NORMAL OPERATING TEMP.	0 to 45°C	-30 to 45°C	0 to 70°C	0 to 60°C
NORMAL STORAGE TEMP.	-20 to 20°C	-10 to 45°C	-10 to 60°C	-10 to 55°C
SHELF LIFE (Room Temp.)	18 months	18 months	5 Years	5 Years
MECHANICAL INTEGRITY	High	High	High	High
CONSTRUCTION OPTIONS	Cylindrical, rectangular, square, wafer, flat.	Cylindrical	Cylindrical, wafer, flat	Cylindrical, wafer, rectangular.
INITIAL COST	Low	Moderate	Moderate	High
GOOD FEATURES	Low cost; wide variety of shapes, sizes and terminals; discharge characteristic falls off gradually.	Good low temperature performance; low impedance; good shelf life.	Excellent shelf life; excellent high temperature characteristics; very high energy densities.	Excellent high temperature performance; long shelf life; flat discharge characteristics; high capacity-to-volume ratio.
LIMITATIONS	Poor low temperature performance; voltage drops sharply with discharge time; inefficient at high current drains.	Expensive for low drain applications. Mechanical integrity is not good at high temperatures.	Very poor low temperature performance. Slight delay on switching on.	Poor low temperature performance; high cost; heavy.
APPLICATIONS	Portable communications. Radios, clocks, flash lights, paging systems, signaling circuits.	Radios, T.V. sets, tape recorders, walkie-talkies, movie cameras, electronic photoflash.	Portable communications, flash lights and others as in previous two types	T.V. sets, radios, hearing-aids, walkie-talkies, secondary voltage standard.
RATING for 24 V. Military Men Packs	3 (If refrigerated storage available.)	1 up to about 30W if wide temperature range needed.	1 up to about 30W except in arctic climate	- - - -

PRIMARY SYSTEMS

CADMIUM MERCURY	*SILVER ZINC*	*SILVER CADMIUM*	*MAGNESIUM PERCHLORATE* *	*LITHIUM COPPER SULPHIDE*	*LITHIUM COPPER CHLORIDE*
Dry	Wet or Dry	Wet or Dry*	Wet (activated)	Wet	Wet (activated)
Mercuric oxide carbon	Silver Oxide	Silver Oxide	Manganese Dioxide carbon	Cuprous Sulphide	Cupric or Cuprous Chloride
Cadmium	Zinc	Cadmium or Cadmium Oxide	Magnesium	Lithium	Lithium
Potassium hydroxide	Potassium hydroxide	Potassium hydroxide	Magnesium perchlorate	1,2 DME in THF	LiAlCl ₄ in MCC
0.94	1.8	1.4	1.5	2.15	2.2
15 to 20	30 to 90	20 to 35	40 to 50	45 to 140	50 to 120
3 to 3.5	4 to 8	1.5 to 3	1.5 to 3	5 to 12	5 to 10
Moderate	High	Moderate	Moderate	Low	Moderate
High	Very high	High	High	Low	Moderate
0.8	1.5	1.1	1.3	1.5	1.5
Excellent	Excellent	Excellent	Very good	Good	Good
-62 to 160°C	-10 to 45°C	-10 to 45°C	-40 to 75°C	-10 to 45°C	-40 to 55°C
-62 to 100°C	-10 to 35°C	-10 to 35°C	-40 to 50°C (unactivated)	-10 to 20°C	-40 to 50°C (unactivated)
10 Years	1 Year	3 Years	5 Yr. unactivated 7 days activated.	1 Yr.	5 Yr. unactivated 7 days activated
Very high	High	High	High	High	High
Cylindrical, Wafer	Cylindrical, wafer, rectangular.	Cylindrical, rectangular	Rectangular vented	Rectangular vented	Rectangular vented
Very high	Very high	Very high	Moderate	Moderate	Moderate
Extreme low and high temperature performance and shelf life.	Very high power densities; very good shelf life; flat discharge characteristics.	Excellent shelf life	Excellent temperature range; very high energy densities. Safe electrolyte.	Exceptionally high energy densities at low currents	Exceptionally high energy densities at moderate currents.
High cost, heavy. Low cell voltage and energy density.	Very expensive. Capacity varies greatly with rate of discharge.	Very expensive	Needs activation before use.	High internal resistance Shelf life unproved.	Needs activation
High temperature applications. Aero space vehicles.	For miniature application. Hearing aids, electric watches, reference voltage sources, instruments, moderate power appliances. Aero-space vehicles.	Space vehicles	Wide temperature range, portable radios.	Applications in which high energy density is of prime importance.	Air sea rescue equipment, portable radios.
- - -	3. Miniature only. Refrigerated storage.	- - -	1. For over 40W Wide temperature range.	- - -	2. For low power man packs or 1. For emergency radios.

* UNDER DEVELOPMENT

PRIMARY SYSTEMS

THIUM BROMINE*	*ZINC-AIR*	*WATER ACTIVATED SILVER CHLORIDE*	*WATER ACTIVATED COPPER CHLORIDE*	*SOLID CELLS*	*SOLID CELLS*
Wet or Dry	Wet or Dry	Wet or Dry	Wet or Dry	Dry	Thin Film
Bromine	Oxygen (air)	Silver chloride	Cuprous Chloride	Carbon Rubidium Iodide mixtures	Silver Iodide
Lithium	Zinc	Magnesium	Magnesium	Silver	Lithium
Not disclosed	Potassium hydroxide	Water, Salt or Tap	Water, salt or tap	Solid $RbAg_5I_5$ or other silver halide compounds	Lithium Iodide
3,2	1,4	1,6	1,5	0,56	2,1
10 to 100	60 to 150	60 to 120	40 to 60	2 to 16	2 to 16
5 to 8	3 to 7	5 to 7	3 to 6	.5 to 2,7	3 to 10
High	Moderate	Excellent	Very good	Milliwatts only	Milliwatts only
High	High	Excellent	Very good	Milliwatts only	Milliwatts only
2,3	1,2	1,45	1,4	0,5	1,6
Good	Very good	Very good	Very good	Very good	Moderate
-20 to 45°C	-40 to 50°C	-20 to 60°C	-20 to 60°C	-60 to 75°C	-45 to 45°C
-20 to 25°C	-40 to 65°C (unactivated)	-40 to 60°C (unactivated)	-40 to 60°C (unactivated)	-40 to 45°C	-40 to 35°C
Approved, but expected to be one year.	5 year unactivated 2 months activated (without air access)	5 year unactivated	5 year unactivated	Several years (unproved)	Several years (unproved)
High	High	Very high	Very high	Excellent	Excellent
Cylindrical sealed, tangular	Flat, rectangular	Rectangular, cylindrical	Rectangular, cylindrical	Bead or button	Flat
Moderate	Moderate	High	Moderate	High	High
High energy density sealed "dry" cell.	High energy density	High energy density operation on immersion	High energy density operation on immersion	Miniaturisation Extreme temperature range.	Extreme Miniaturisation
Approved shelf life	Needs activation. Needs air for operation.	Short operation time which cannot be stopped. Maximum 48 hours.	Short operation time which cannot be stopped. Maximum 48 hours. Slow activation.	High internal resistance. Low current. Low voltage per cell for silver type.	
Portable equipment	Portable equipment with high capacity requirement.	Air sea rescue equipment. Marine Markers.	Air sea rescue equipment. Marine Markers	Medical and nuclear instrumentation and other miniature applications	
Under development, but attractive if claim substantiated	1. over 40W except in arctic conditions.	-----	-----	-----	

SECONDARY

	"NICKEL-CADMIUM"		"LEAD — ACID"		
	Sealed. Dry	Vented	Vented	Sealed Wet.	
CATHODE	NICKEL HYDROXIDE	NICKEL HYDROXIDE	LEAD DIOXIDE	Lead Dioxide	
ANODE	Cadmium	Cadmium	Lead-Antimony	Lead Calcium	
ELECTROLYTE	Potassium Hydroxide	Potassium Hydroxide	Sulphuric Acid	Sulphuric Acid Gell or Fibreglass Matting.	
OPEN CIRCUIT VOLTAGE	1.35	1.35	2.1	2.1	
CLOSED CIRCUIT VOLTAGE	1.25	1.25	1.95	1.95	
ENERGY DENSITY on 1st charge. (Watt hr per lb.)	12 to 17	12 to 20	7 to 12	10 to 15	
ENERGY DENSITY on 1st charge (Watt hr per cu in.)	1.0 to 1.4	1.0 to 1.5	0.5 to 2.0	0.8 to 1.1	
PEAK POWER DISCHARGE RATE	15C	50 C	20 C	20 C	
AVERAGE DISCHARGE VOLTAGE	1.20 (1 Hour Rate)	1.22 (1 Hour Rate)	1.80 (1 Hour Rate)	1.9 (2 hour Rate)	1.0
NORMAL OPERATING TEMP.	-40 to 60°C	-50 to 60°C	-50 to 55°C	-50 to 70°C	
NORMAL STORAGE TEMP.	-50 to 70°C	-50 to 75°C	0 to 20°C	0 to 20°C	
VOLTAGE STABILITY DURING DISCHARGE	Good	Good	Fair	Medium	
CHARGING METHOD	Constant Current	Constant Voltage or Constant Current.	Taper Current or Constant Voltage	Taper Current	Cons Cons
CHARGE RETENTION (50% Capacity @ 60F)	60 Days	1 Year	90 Days	15 months	
CYCLE LIFE	100 to 1,500	100 to 3,000	10 to 600	100 to 150	1
CONSTRUCTION OPTIONS	Rectangular, cylindrical.	Rectangular, cylindrical.	Rectangular, square.	Rectangular, square	
INITIAL COST	High	High	Low	Low	
FEATURES	Fast recharge capability. Excellent cycle life, good high and low temperature performance; good power capability; shock resistance; low self-discharge rate; stands overcharge. Very low internal resistance.	Excellent cycle life; good reliability; excellent power capability; good charge retention.	Lowest cost of rechargeables; high voltage per cell; rugged construction.	High cell voltage; low cost per watt hr of capacity; high discharge capability; low impedance; good voltage regulation; good storage life.	Exce rugg reli life
LIMITATIONS	Moderately expensive	Moderately expensive	Limited low temperature characteristics; low power densities; limited deep cycle life; high maintenance; not spill proof.	Heavy	Poor low t limit high of vo
APPLICATIONS	Radios, T.V. sets, slicing knives, tape recorders, toothbrushes, portable tools, shavers, amplifiers, phonographs.	Radios, T.V. sets, toothbrushes, slicing knives, shavers, tape recorders, portable tools, movie cameras, phonographs	Power mowers, hedge trimmers, starters (out-door appliances).	T.V. sets, tape recorders, radios, record players, portable lawn and power tools, portable power packs.	
SUITABILITY FOR MILITARY MANPACKS	1. Either alone or in hybrid combination.	----	----	3. Inconvenient recharging.	

SECONDARY SYSTEMS & STATIC GENERATOR / BATTERY HYBRIDS

"LEAD -- ACID"		"NICKEL-IRON"	"SILVER-ZINC"	"SILVER-CADMIUM"	"ALKALINE-MANGANESE"	"ZINC"
	Sealed Wet.	Vented	Vented	Vented	Sealed. Dry.	Sealed (mechanical)
DE	Lead Dioxide	Nickel Hydrate	Silver Oxide	Silver Oxide	Manganese Dioxide	Air (oxyg
ny	Lead Calcium	Iron Oxide	Zinc	Cadmium	Zinc	Zinc
id	Sulphuric Acid Gell or Fibreglass Matting.	Potassium Hydroxide	Potassium Hydroxide	Potassium Hydroxide	Potassium Hydroxide	Potassium Hy
	2.1	1.40	1.06	1.4	1.5	1.4
	1.95	1.20	1.70	1.3	1.25	1.2
	10 to 15	8 to 14	40 to 50	22 to 34	10 to 15	50 to 1
	0.8 to 1.1	0.9 to 1.3	1.7 to 3.5	1.4 to 3.0	2.0 to 2.2	2 to 5
	20 C	3 C	10 C	10 C	2 C	C/4 to C
o)	1.9 (2 hour Rate)	1.08 (1 hour Rate)	1.50 (1 hour Rate)	1.07 (1 hour Rate)	1.15 (4 hour Rate)	1.1
	-50 to 70°C	0 to 60°C	-20 to 60°C	-20 to 60°C	-20 to 50°C	-40 to 50°C
	0 to 20°C	-40 to 60°C	-50 to 40°C	-45 to 40°C	-40 to 50°C	-40 to 70°C unactivated
	Medium	Fair	Irregular	Irregular	Poor	Fair
onstant	Taper Current	Constant Current or Constant Voltage	Constant Current or Constant Voltage	Constant Current or Constant Voltage	Constant Current	Replacement of anodes, washing, adding water.
	15 months	25 days	2 Years	18 months	18 months	1 month if al sealed.
	100 to 150	100 to 3,000	10 to 200	100 to 500	25 to 40	50 to 200
re.	Rectangular, square	Rectangular	Rectangular, cylindrical, square, wafer.	Rectangular, cylindrical, wafer.	Cylindrical	Rectangular
	Low	Moderate	Very high	Very high	Low	Moderate
hargeables; all; n.	High cell voltage; low cost per watt hr of capacity; high discharge capability; low impedance; good voltage regulation; good storage life.	Excellent cycle life; rugged construction; good reliability; long service life.	High energy densities; high cell voltage; excellent power retention; high power capability.	Good energy densities; excellent charge retention.	Low cost; good shelf life.	Very high energy density. Fast recharging (5 to 10 minutes).
ature low power deep maintenance;	Heavy	Poor charge retention; poor low temperature performance; limited ability to yield to high pulse currents per unit of volume.	Highest cost of rechargeables; poor cycle life; poor low temperature performance.	High cost; uncertain cycle life; low cell discharge voltages; poor low temperature performance.	Limited cycle life; low power capability; special care required for cycling.	Must have air Short storage in charged state
ie trimmers,	T.V. sets, tape recorders, radios, record players, portable lawn and power tools, portable power packs.	Motive power.	High power applications; T.V. cameras, hobbycraft (model aircraft, roadracers, etc.)	T.V. cameras, hobbycraft.	Radios, shavers, T.V. sets, walkie-talkies, tape recorders, movie cameras.	Military manpa equipment. Silent generat
	3. Inconvenient recharging.	--	2. For miniature equipment.	2. For miniature equipment.	--	1. High energy density in large sizes

* UNDER DEVELOPMENT

IDS

SECONDARY SYSTEMS AND STATIC GENERATORS

SE*	*ZINC-AIR* Sealed Electrolyte (mechanical recharge)	* NICKEL ZINC Vented	FUEL CELLS *		* THERMO-ELECTRIC GENERATOR (motor fuels)
			HYDRAZINE	HYDROGEN	
	Air (oxygen)	Nickel Hydroxide	Air (oxygen)	Air (oxygen)	--
	Zinc	Zinc	Hydrazine	Hydrogen (bottled or from Metal Hydride)	--
	Potassium Hydroxide	Potassium Hydroxide	Potassium Hydroxide	Potassium Hydroxide	--
	1.4	1.5	1.5	1.5	Any voltage to 50V.
	1.2	1.3	1.4	1.4	Regulated
	50 to 150	12 to 25	25 to 30 on first fuelling rising to 300 with refuelling. (Including NiCd Battery).	50 to 200	200 Watt hr. per pound of fuel. Cell 28 lbs.
	2 to 5	1.5 to 2	1.4 to 5	1.4 to 5	--
	C/4 to C	2C	2 to 5C, with NiCd Battery.	2 to 5C with NiCd Battery.	Up to 20 amps. per unit.
	1.1	1.1	1.4	1.4	--
	-40 to 50°C	-15 to 60°C	-15 to 60°C	-15 to 60°C	-65 to 70°C
	-40 to 70°C unactivated.	-40 to 60°C	-40 to 60°C	-15 to 60°C	-65 to 70°C
	Fair	Fair	Fair	Fair	Good
	Replacement of Zinc anodes, washing and adding water.	Constant current or Constant Voltage.	Refuelling. Periodic change of electrolyte.	Refuelling. Periodic change of electrolyte.	Refuelling.
	1 month if air sealed.	Unproved	Indefinite if air sealed.	Indefinite if air sealed.	Indefinite
	50 to 200	50 to 200	200	200	1,000 Hours.
	Rectangular	Rectangular	Rectangular	Rectangular	--
	Moderate	Moderate	Moderate	High	High
life.	Very high energy density. Fast recharging (5 - 10 minutes).	Good energy density	Very high energy density especially on refuelling. (Fuel yields 330 Watt hr. per lb.) Easy to start. Constant voltage.	Very high energy density. "Dry" fuel.	Very common motor fuel. No change of electrolyte. Robust. Constant Voltage.
ow ial ing.	Must have air access. Short storage life in charged state.	Special care in charging.	Expensive and uncommon toxic fuel, although probably more dangerous than high octane fuel.	Expensive. Uncommon fuel either with chemical generator or bottled cell must be stopped to refuel. Hydrogen refuelling inconvenient.	Some noise in operation. High temperature operation.
sets, as.	Military manpack equipment. Silent generators.	Military Manpacks.	Military silent generators and large manpack equipment. Hybrid power.	Silent generators. Underwater power. Aerospace power. Hybrid power.	"Silent" generator.
	1. High energy density in large sizes.	2. Economical.	1. High energy density for large sets.	--	2. High energy on common fuel.

USEFUL SOURCES OF INFORMATION ON POWER SOURCES

TYPE OF CELL	SOME SOURCES OF INFORMATION			
	BRITAIN & EUROPE	U.S.A. & CANADA	AUSTRALIA	JAPAN
GENERAL (ALL TYPES)	Plessey Ilford, V.E. Executive Plessey Avionics, West Leigh Plessey Central Research Laboratories, Caswell Signals Research and Development Est., Christchurch. R.A.E., Farnborough S.A.F.T. (G.B.) Hampton, Middlesex Centre Nationale d'Etudes Spatiale, France	Department of Army, Fort Monmouth U.S. Naval Research Labs. Bell Telephone Labs. Aero Propulsion Labs. Canadian Dept of Defence, Ottawa	Plessey Ducon Department of Supply, Canberra	Ministry of International Trade and Industry
"DRY" CELLS				
Leclanche Alkaline MaD2 (Primary & Secondary) Magnesium (Primary) Mercury (Primary & Secondary) Silver Chloride (Primary) Vanadium Pentoxide (Prim) Titanium Alloy (Primary) Indium (Primary)	S.A.F.T. (G.B.), Hampton, Middlesex Union Carbide G.B. Ltd. London	Mallory Batterglo, Terrytown, N.Y. Union Carbide Ray-O-Vac Battery Corporation (Magnesium) E.S.B. (Inc.)	Plessey Ducon Union Carbide	Hitachi Maxell Matsushita, Osaka Toyo Dry Battery Co.
WET CELLS WITH "DRY" VERSIONS				
Nickel Cadmium (Secondary) Lead Acid (Sec.) Silver Zinc (Prim. & Sec.) Silver Cadmium (Prim. & Sec.) Lithium Bromine etc. (Prim & Sec.)	S.A.F.T. (G.B.), Hampton, Middlesex All except Lead Acid Union Carbide G.B. Ltd. London (Nickel Cad.) Electric Power Storage Manchester (Lead Acid) Nife-Alcad, London Sonnenchein, Germany	Sonotone (Marathon) S. Paul Yardney Electric Corp. New York G.E.C., Gainsville, Fa. Gulton Industries, Metuchen, N.J. Mallory, Terrytown S.A.F.T. Canada, Toronto Eagle Picher Industries, Joplin, Mo.	Plessey Ducon	Japan Storage Battery Co., Kyoto Yuasa Battery Co. Osaka Shin Kobe Electric Maranouchi Kono Battery Corp. Naka Minato
WET CELLS				
Magnesium Perchlorate High Energy Lithium Nickel-Zinc Nickel Iron Lead Fluoroboric Acid (Reserve)	S.A.F.T. (G.B.), Hampton, Middlesex Union Carbide G.B. Ltd. London McMurdo Instrument Co. Portsmouth	Yardney Electric, New York		
METAL AIR CELLS				
Aluminium, Magnesium, Zinc Iron, Cadmium Air - Primary, Secondary, Reserve	Energy Conversion Ltd., Easingstoke Shell Research, Thornton S.A.F.T. (G.B.) Ltd. Hampton, Middlesex.	Eagle Picher Industries Joplin, Mo. Leesona Moos, Great Neck, New York E.S.B., Philadelphia Yardney Electric, New York S.A.F.T. Canada, Toronto.	Plessey Ducon	Shin Kobe Electric Maranouchi Hitachi Maxell Furukawa Battery Co., Yokohama
WATER ACTIVATED CELLS				
Silver-chloride-Magnesium Copper-chloride-Magnesium	McMurdo Instrument Co. Portsmouth	Eagle Picher Industries Joplin, Mo. Yardney Electric, New York	Plessey Ducon	Shin Kobe Electric Maranouchi
FUEL CELLS				
Hydrogen-oxygen or air Hydrozine-oxygen or air Hydrocarbon Full-oxygen or air	Electric Power Storage Ltd., Swinton	Leesona Moos, Great Neck, New York T.R.W. Systems Redondo Beach		
SOLAR CELLS	Plessey, Caswell G.E.C.	General Electric		Hitachi Nippon Electric Hayakawa Electric
SOLID STATE CELLS	G.E.C. Rome University	Gould Ionics, Canoga Park Mallory, Terrytown		Nagoya University
THERMO ELECTRIC GENERATORS				
Fuel Heated Solar Heated Radio-active Isotope Heated	Plessey, Caswell G.E.C.	General Instrument Co., Hicksville, N.Y. Eagle Picher Industries, Joplin, Mo.		Hitachi Maxell

LOW COST BALL BEARINGS

(Article extracted from O.E.M. Design, June 1972)

Introduction

It is not difficult to see why unground bearings, or commercial bearings as they are sometimes called, have yet to find universal acceptance for those applications where the degree of precision inherent in standard ball bearings is not really needed. For a start, most of them have been developed originally for some specific purpose so that, with few exceptions, there is no great range of sizes offered as standard. Secondly, unground bearings are not generally available through local engineering factors. Thirdly, there are no British Standards governing the dimensions and performance of unground bearings for general purpose use. Nevertheless, the manufacturers' catalogues illustrate a wide and growing range of bearing types, many developed for volume users and available from stock, which can be usefully employed by the designer for one-off or low volume applications.

Where the order quantity reaches two to three thousand then the manufacturers are able to offer an enormous number of variations in bearing design, if necessary incorporating secondary components such as gears, sprockets, cams, flanges, pulleys, etc. as an integral part of the unit.

Principal Bearing Types

There are three basic types of unground bearing, plus a few variations on these. They are pressed bearings, turned bearings and moulded plastics bearings.

Pressed bearings

In these bearings the inner and outer races are pressed out of sheet metal, generally low-carbon mild steel, but in a few cases aluminium and brass have been used. In the case of steel, the races are generally case-hardened to about 60 Rockwell C.

Large numbers of bearings of this type are manufactured for use in conveyor rollers and other mechanical handling equipment. They are also established in light agricultural and office equipment, toys, building accessories and domestic appliances. The cycle industry has been a large producer and user since its birth and possibly some readers will recall instances of bicycle wheel spindles being pressed into service to keep industrial machinery going under war-time conditions when standard ball bearings were in short supply.

Almost invariably bearings of this type have a full complement of balls, as a result of which they may be rather noisy in operation. Most manufacturers list light and heavy duty series and offer seals and protective finishes as optional features.

In a variation of the pressed-race bearing, the pressings do not make contact with the ball but house two pairs of hard wire rings which act as raceways. The four-point contact on the balls provides considerably axial rigidity and reduced friction. This type of bearing is produced by the General Bearing Company, West Nyack, New York, U.S.A., but does not appear to be marketed in the U.K.

Turned bearings

In these bearings the inner and outer races are turned on automatic lathes from carbon steel rings and case-hardened. Occasionally they are burnished. As might be expected, they have a higher load rating than pressed bearings of similar size and the cost is greater, though still well below that of standard ball bearings. Both full-complement and ball retainer designs are offered.

Again, if the order quantity is large enough bearings may be supplied with inner and/or outer races incorporating secondary features. Some manufacturers offer bearings combining a turned inner race with a pressed steel outer race, and a further development is to mould a plastics or elastomer member around the outer race.

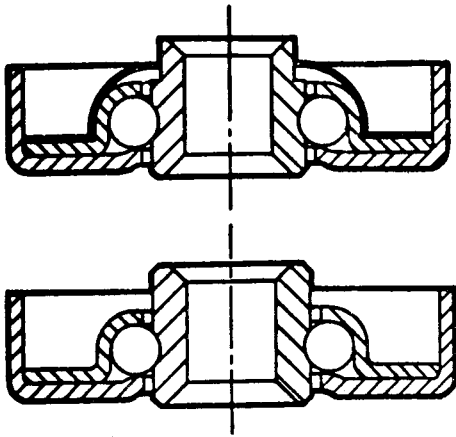
Moulded bearings

A fairly recent development is the production of standard bearing designs in which the inner and outer races are injection moulded from nylon or acetal resin. The balls are normally carbon or stainless steel, but nylon and glass are specified for severe corrosive conditions. No lubrication is needed and if stainless, nylon, or glass balls are used the bearings are able to run immersed. They are also effective electrical insulators, which is of value, for example, in electroplating equipment where these bearings are installed on certain plant beneath the surface of the electrolyte. When fitted with nylon or glass balls, the bearings are, of course, completely non-magnetic and for this reason they have been used successfully in instruments and radar.

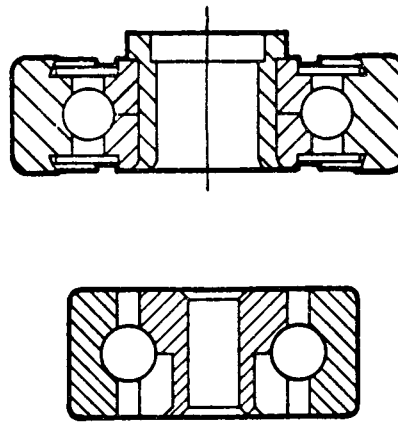
In plastics moulded bearings it is easy to incorporate features such as gears, wheels, pylleys, etc. on the outer bearing race. The load capacity does not, of course, compare with that of metal-race bearings of similar size, but is entirely adequate for a host of light duty applications. The plastics race bearings are cheap, quiet in operation and may be expected to account for an increasing share of the underground bearing market.

Typical examples of bearings are shown on the following two pages.

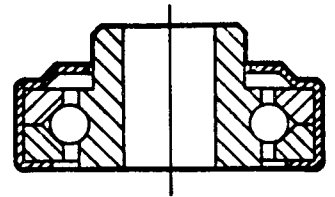
1. Typical light and medium duty pressed race bearings for gravity rollers. With a nominal od of about 2 in and a bore of $\frac{7}{8}$ in, the bearings would have rated loads of about 25 and 40 lb respectively



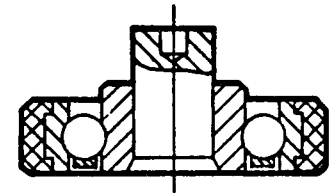
4. A turned race, full complement bearing with divided inner race to allow the balls to be assembled. After assembly, the two inner races are riveted together



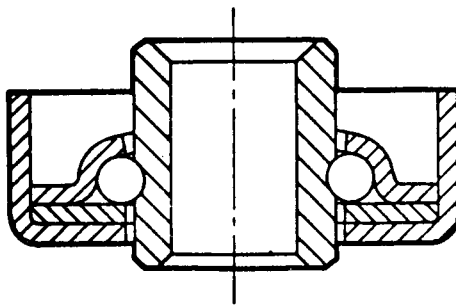
8. A bearing with split outer race retained by pressed steel enclosure



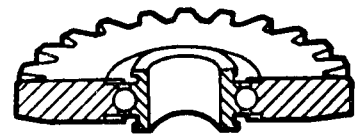
9. Turned race bearing with moulded plastic ball retainer and plastics ty moulded on to the outer race



5. A double row turned race bearing with a pulley groove on the outer track. A separate tubular rivet is used to assemble the inner races



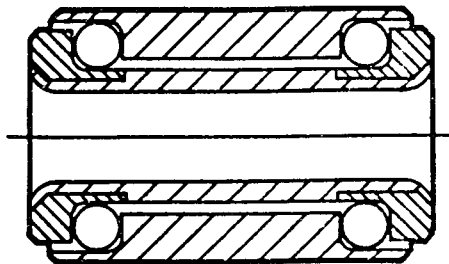
10. Turned race bearing in which the outer race forms an idler gear



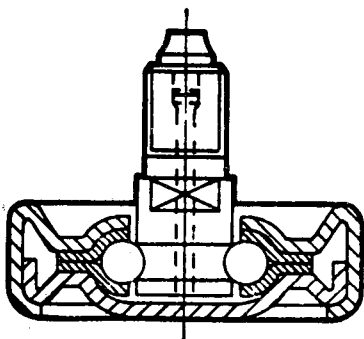
2. A combined pressed race bearing and V-belt pulley for a domestic appliance



6. Another split race bearing assembled by riveting one of the inner members. Four-point contact gives a very rigid construction



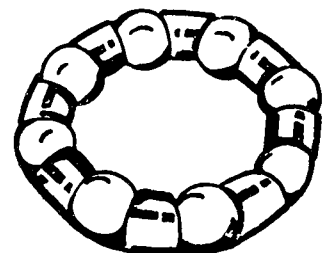
3. A guide roller built up from steel pressings running on a hardened steel pin



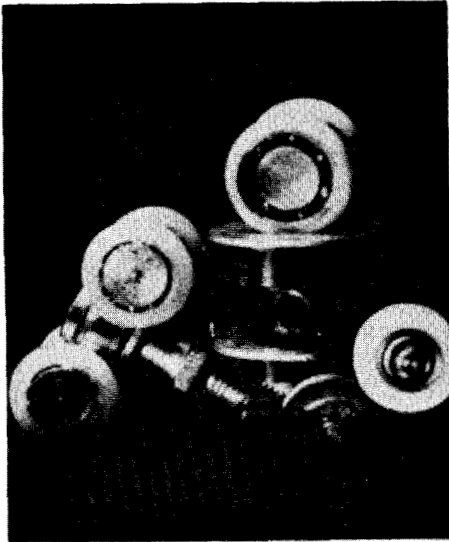
7. A pressed steel bearing in which two pairs of hard wire rings form the raceways



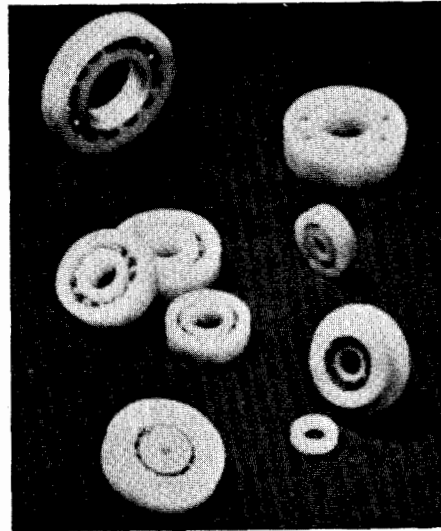
11. Pressed steel claw-type ball retainer supplied by bearing manufacturers or customer-made bearings



12. A selection of Australian-made Anthony bearings for conveyor applications. These have turned inner races and moulded plastics outer races. A wide range of unground bearing types is marketed in the UK



13. Some of the plastics bearings manufactured by Bearings (Non-Lube) Ltd from ICI Kematal acetal copolymer. The range includes ball and roller designs with full complement or acetal ball retainers. Balls may be carbon or stainless steel, nylon or glass



SUPPLIERS

Moulded Plastics Bearings

Bearings (Non-Lube) Ltd., Walton, Boston Spa, Yorks.
E.A. Best & Co., 4 Frith Road, Croydon, Surrey
(Australian Anthony bearings).

Pressed and turned race Bearings

Bridge Bearings (Sales) Ltd., Stour Vale Road, Lye, Stourbridge, Worcs.
Brockhouse Conveyor Bearings Ltd., British Star Works, Toll End Road,
Tipton, Staffs.
Commercial Bearings Ltd., Neachells Lane, Willenhall, Staffs.
M.C. Hives Ltd., Bearing House, Pountney Street., Wolverhampton,
Staffs.
Industria (Bearings) Ltd., Eskdale Road, Uxbridge, Middlesex.
A.H. Jones and Co. Ltd., Alumwell Industrial Estate, Walsall, Staffs.

Additional methods for Processing Plastics

Foam Moulding

In this method a liquid mix of the co-polymers of materials such as Polyurethane, Polythene or Polystyrene are mixed with a foaming agent and injected into the mould. The material sets to the mould shape with a surface skin of material but an internal honeycomb structure. This process can be used to produce flexible or rigid mouldings and the density and strength can be varied according to the proportion of foaming agent. The gas in the bubbles of the foam is usually carbon dioxide but various foaming agents are used. This is extremely useful for light-weight components.

Sandwich Moulding

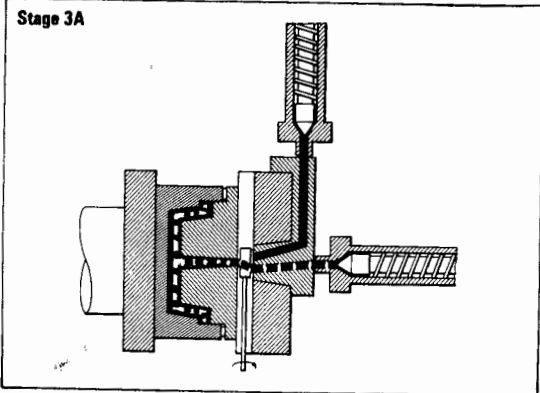
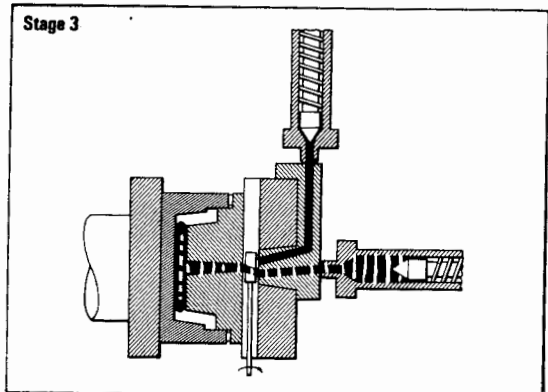
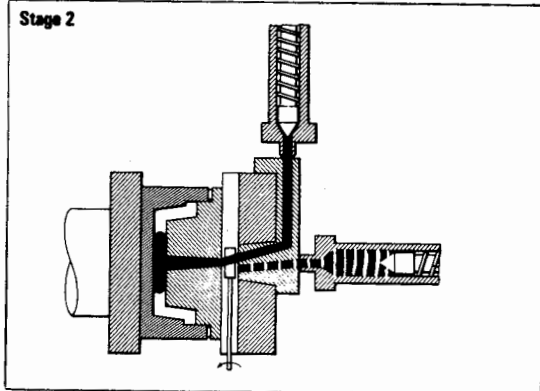
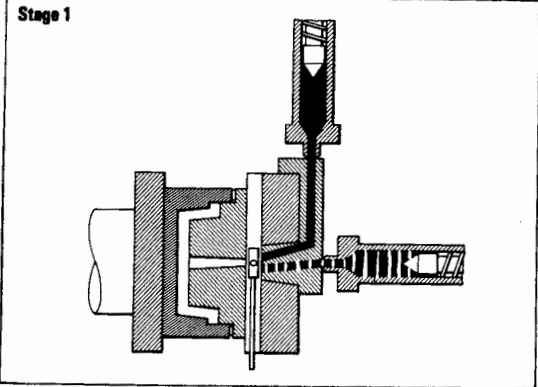
An I.C.I. developed process, this can be used for any plastic that can be injection moulded.

Two polymer formulations are injected from separate units one after the other via the same sprue. The core may be a foamable polymer, which forms a foamed core within a solid plastic shell. Sometimes the mould may be opened to allow greater expansion of the foam.

Wide variations can be made in the proportion of foam to solid and the sandwich can be hard skin on hard core, soft skin on hard core or vice-versa.

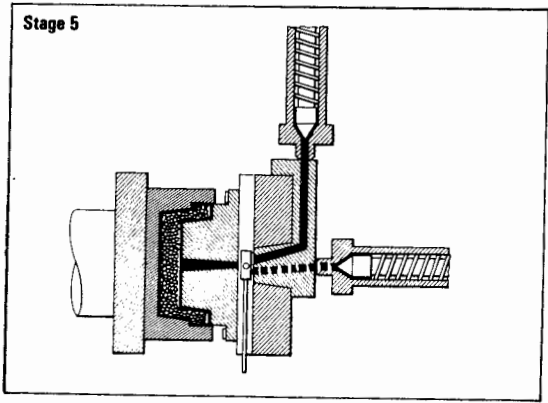
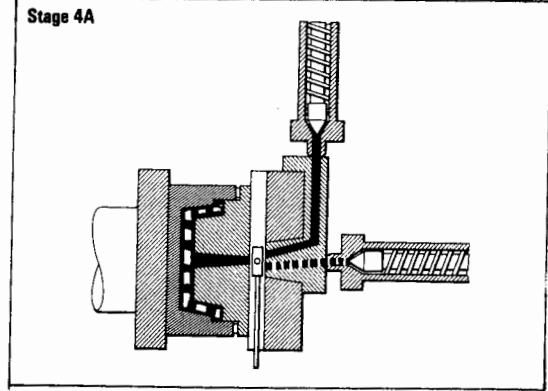
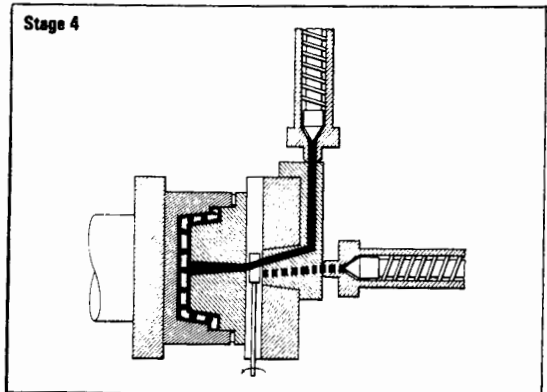
There are considerable cost advantages. For example a gear wheel can be made with expensive fluon-filled or carbon fibre filled nylon in the tooth and other outer areas with a cheaper core to the wheel. Similarly the addition of other expensive additives such as U.V. absorbers, reinforcing fibres, pigments etc. can be confined to the surface, where they are needed. Further information can be obtained from I.C.I. Ref. Pamphlet G55.

The process is illustrated on the next page.



As these illustrations show, the sandwich moulding process is simple in principle, but it depends upon the understanding and proper use of the flow properties of elastic, high viscosity melts. It also depends upon the use of mould cavities which operate on the "piston in cylinder" principle ("vertical flash" moulds) to prevent leakage and to allow expansion for foaming. They are different from the "horizontal flash" moulds normally used in the industry, which prevent pressure leaks by intimate planar contact around the margins of the cavity and which cannot be used in the way described without leaking.

The machinery itself, is, of course, special, although based upon standard injection and hydraulic lock press units.



SECTION 33. MANUFACTURING PROCESSES

Below is given a summarised list of manufacturing processes with a brief description of each.

1. CASTINGS

- A. Sand - most economical casting method but accuracy is not the best. Tolerances of $\pm 1/32''$ up to 12" possible, but because of surface imperfections and inclusions, critical surfaces must include extra material to assure clean up to final dimension.
- B. Shell Mould (Precision) - Similar to sand casting but the sand mould is bound with a resin binder. This process gives perfect pattern duplication, improved detail, smoother surface finish and little waste metal. Tolerances $\pm .010$ first inch $\pm .022$ each additional inch, parting line $\pm .015$ and draft $.5^\circ$ per inch. It is suitable for larger quantity production.
- C. Permanent Mould - assures accuracy and precision in relatively complex castings. Molten metal is poured by hand into permanent metal mould to form casting. Good surface quality possible. Tolerances $\pm 1/64''$ for first inch with $\pm .002$ additional for each linear inch. Minimum draft 2° per inch per side.
- D. Die Casting - Very close tolerance, smooth finish and accurate reproduction of complicated detail. Two major methods used, in the first air injection forces the metal into the mould under pressure and in the second vacuum is applied to the mould and metal is flowed in.
- Tolerances $\pm .002$ for first inch and $\pm .001$ for each additional linear inch. Dimensions affected by die parting line $+ .010$ - $.000$ and minimum draft $.010^\circ$ per inch. Wall thickness of $.050$ possible with this process.
- E. Centrifugal Casting - In this process the mould is spun and centrifugal force is utilised to carry metal to all points in the mould. This process is used particularly for casting rotors for small motors.

- F. Investment Casting - Excellent reproduction and close tolerances possible. Wax is injected into a die under pressure to form exact reproduction of part. After removal many pieces are attached to a central runner or tree. This tree is then invested in a plaster flask. After plaster has been cured, flasks are fired at high temperature to remove wax which melts out and molten metal is then poured into cavity formed by wax.
- G. Frozen Mercury Process - Variation of F. above. Mercury is frozen in moulds to act as wax did above forming exact reproduction of part. This frozen mandrel is dipped into a ceramic slurry several times until a coating approx. 1/16" thick is formed then mercury is allowed to melt and metal is poured into the mould to reproduce the exact part. This process is used extensively in producing complex waveguide shapes.
- H. Al Fin Process - This casting process was developed by Fairchild and consists of bonding tubes or bosses of dissimilar metals into aluminium castings. The principal used for this process is for high pressure hydraulic parts and where it would be an advantage to have a material with either greater strength or greater wear resistance without sacrificing the weight saving of aluminium.

2. FORGINGS

- A. Closed Die Forging - Forging material is heated and formed under a drop hammer to the rough shape of the die, then this billet is inserted into die and hit until die closes. Excess material is left around the part and a secondary operation of trimming this flash is necessary. Tolerances are quite loose especially those affected by the die parting line. Strength of forged materials is usually much higher than cast.
- B. HERF - High energy rate forming. The forging press in this process is powered either by high pressure hydraulics or high pressure gas. The ram is delivered at tremendous velocity and a single impact forms the part. This process gives excellent detail and extremely high tensile strength in the finished piece.
- C. Cold Heading - In this process parts are formed from bar stock, by upsetting the rod into a closed die. Process used extensively manufacturing bolts and screws.

- D. Rotary Swaging - A number of shaped punches are actuated by a cam causing a series of hammer blows in rapid succession. Used to reduce tubing diameter such as choke in shotgun barrel and for assy. such as fastening a metal handle to a tool.

3. POWDERED METALS

Metal powder is compressed in a mould under high pressure to form part. A secondary sintering at high temperature is necessary to bond powder together and increase strength. This material makes an excellent bearing surface and new technology has increased tensile strength to make this process a serious contender for parts previously cast.

4. EXTRUSIONS

- A. Die Extrusion - This process gives you bar stock (produced from a solid billet of material) already formed to part configuration on surfaces. Die cost relatively low. Eliminates much chip removal by supplying material to finished shapes.
- B. Impact Extrusion - Used for tubular or can shapes in aluminium produced from a slug of material. Pressure exerted by a ram forces material to flow upward between punch and die. Excellent for closed end tubes, special shapes, i.e. serrated O.D., flashlight body, or for screening cans with a number of compartments and or channeled guides for p.c. boards, thick film circuits etc.

5. METAL FORMING

- A. Hydroform - Deep drawing of sheet metal. Male die only is used and rubber diaphragm backed by hydraulic pressure forms parts around punch. Good detail and close tolerances possible.
- B. Explosive Forming - Two different processes now in use, first uses explosive power of dynamite to form parts into female die. Second process uses capacitor discharge under water for explosive force.
- C. Magneform - This process uses the power of a magnetic field collapsing around the part to form or pierce light metals. Forces of around 50,000 PSI are possible.

- D. Metal Spinning & Hydro Spin - Flo Turn These are all variations of the same process using power assist to move metal. Suited to large parabolic reflectors, exhaust nozzles for jet engine, etc.
- E. Hobbing or Coining - Hydraulic pressure is used to force male punch into block to produce exact size and detail. This process used in the manufacture of magnetron tube bodies.

6. METAL JOINING

- A. Laser Welding and Soldering - Laser beam has sufficient heat for welding light gauges and can be utilised for drilling tiny holes.
- B. Induction Soldering and Brazing - Part is heated in an electrical field. Very close control of heat and duration of heat cycle.
- C. Friction Welding - Parts are rotated against each other until welding temperature is reached at interface of parts.
- D. Electron Beam Welding - Performed in a high vacuum. Welds dissimilar metals and welds are stronger than parent metal. Used for pressure vessels, etc.
- E. Ultra-Sonic Welding & Soldering - Allows soldering without flux resulting in less contamination of finished part.
- F. Pressure Welding - (Dirty Sheet Method) - This process is used for bonding two sheets of aluminium together. An inhibitor is sprayed in those areas we do not want welded and pressure is applied welding sheets together. Then hydraulic pressure is introduced at the edge to create tubing effect. A good example of this technique is the freezer plate in your refrigerator.
- G. Impact Welding - Similar to F. above but parts are welded by being projected together.
- H. "Cryofit" Heat Shrink (irradiated) Metal Tube - An irradiated metal tube (in various available alloys) is placed over a butt joint and heated to join length of tubing. Particularly useful on high strength high pressure tubing as in aircraft.

7. METAL REMOVAL

(other than conventional machining methods)

- A. Chemical Milling - Parts are masked and then immersed in acid which mills away parent metal. Examples are Wing Panels X15 aircraft and circuit boards.

- B. ECM Electro Chemical Milling - High electric current passed through salt solution flowing over the part actually deplates material.
 - C. EDM Electro Discharge Machining - Capacitor discharge causes dis-integration of metal in front of tool.
 - D. Ultrasonic Impact Grinder - Ultrasonic force drives abrasive into metal ahead of tool.
 - E. Surface Broaching - Piece is secured to table while broach is dragged across face of part. Very good for generating contoured surfaces. This process is used extensively in gun manufacture.
 - F. Ultrasonic Machining - The tool is pressed against the workpiece and ultrasonically vibrated, with or without an abrasive slurry. Very useful for machining operations on hard, brittle, substances such as glass, particularly for drilling non-cylindrical holes.
 - G. Spark Erosion - An electrode is used to discharge a spark between it and a metallic workpiece immersed in a dielectric fluid. This erodes the workpiece. Particuarly useful for drilling holes in very hard metals.
 - H. Hot Turning - The metal workpiece is heated electrically or by gas flame while being turned. This allows much higher machining speeds.
8. METAL ADDITION
(apart from plating).
- A. Metallising - This method uses a hand-held or mounted spray gun. The metal to be deposited is in wire form and fed mechanically into an oxy-fuel gas flame and atomised by a compressed air blast which projects metal particles onto the prepared surface of the workpiece.
 - B. Thermo Spray

This is similar to A. above except that the metal to be deposited is in powder form, gravity fed into the flame and the hot metal liquid particles are projected onto the proposed surface of the workpiece directly by the oxy-fuel flame jet.

- C. Plasma Flame - In this process the metal, in the form of wire, is fed into a lagged water-cooled chamber in the gun, in which an electric arc raises the temperature to about 30,000^oF. A jet of inert gas is also injected into the chamber and the gas-metal vapour mixture is projected from the nozzle in a "plasma jet" which appears like an oxy-acetylene torch. This is passed over the prepared surface of the workpiece.
- D. Vacuum Deposition - A piece of the metal to be deposited is heated in a refractory boat in a vacuum chamber. The object on which the metal is to be deposited is placed in the chamber near to the metal which evaporates and deposits on the cool surface of the object.
- E. Sputtering - This is similar to D above but a high voltage potential is applied between the metal being vapourised and the workpiece. This gives better adhesion and also greatly reduces the waste of metal deposited on other cool surfaces in the chamber.

9. PLASTIC FORMING (For greater detail see Section 2.2)

- A. Vacuum Forming - In this process a sheet of thermo-plastic is placed across the mouth of a chamber in which the mould pattern is placed. The sheet is heated, a vacuum is created in the chamber and the plastic is drawn into the mould. This is a very effective process for small or medium quantity production.
- B. Injection Moulding - A thermo-plastic material in powder or granular form, is heated to near melting point and injected into a closed mould (with suitable vents). This method can be used also for a thermo-setting material when the powder is injected into the mould.

In some high-pressure injection moulding machines, the tool for very fine, small, components has an injection nozzle in the form of a very small orifice, perhaps 0.10" dia. Passage of the semi-liquid plastic material through the orifice causes additional heating at the point of entry into the mould so that the plastic is temporarily liquified.

- C. Compression Moulding - This is used for thermo-setting plastics. A slug of pre-heated plastic is placed in an open, heated, mould which is then closed under pressure to shape and set the plastic in the required shape.

- D. Transfer Moulding - This is used for Thermo-setting plastics of the melamine or formaldehyde type which have a longer plastic flow time. A pre-heated slug is placed in a cavity in the tool in front of a ram and is injected into the closed, heated, mould tool. (Similar to injection moulding except that the injection is from one slug at a time). This process is faster than compression moulding but is limited to fairly simple and small parts of less than 16 oz.

10. WIREFORMING

This process allows the substitution of simple wire forms welded together as an alternative to castings, deep-drawn housings or complete assemblies. Low cost high dependability process.

11. METAL FINISHING

- A. Ultrasonic Plating - Better adhesion - finer grain and less cleaning operations.
- B. Vibratory Deburring - Vibrating parts with abrasive media to generate radii and remove burrs.
- C. Electrostatic Painting - An electrostatic field is created around part being painted and paint coverage is equal front and rear of part without rotating work.
- D. Chlorine Deburring - Parts heated by radiant heat source in a chlorine atmosphere. Since burrs are so small, they heat faster than the mass of the part, and combine with the chlorine and disappear as a gas.
- E. Shot Peening - Glass Bead Blasting - Removes burrs and work hardens surface area.
- F. Electropolishing - Parts are immersed in plating solution and polarity switched resulting in plate and deplate cycles which remove all high spots and polishing marks.
- G. Electroforming - Plating applied over mandrels to generate complex interior configurations. Used for waveguides, etc.
- H. Plastic Coating - Various emulsions and solutions are available spraying on as paint, the coating being cured at various temperatures. A more novel recent innovation is the supply of sheet metal to which P.V.C. sheet has been bonded, with a variety of surface finishes from "high gloss" to "wood grain". In designing for the use of this material, the cut edges must be protected or concealed by folding. Available in various gauges and grades of aluminium, steel, and tin-plate, as Bondene from BX Plastic or Lamiplate from Huntley Boorne & Stevens Ltd., Reading.

JOINT ECONOMY BY ULTRASONIC WELDING

(Extract taken from Engineering Production, 6th July 1972)

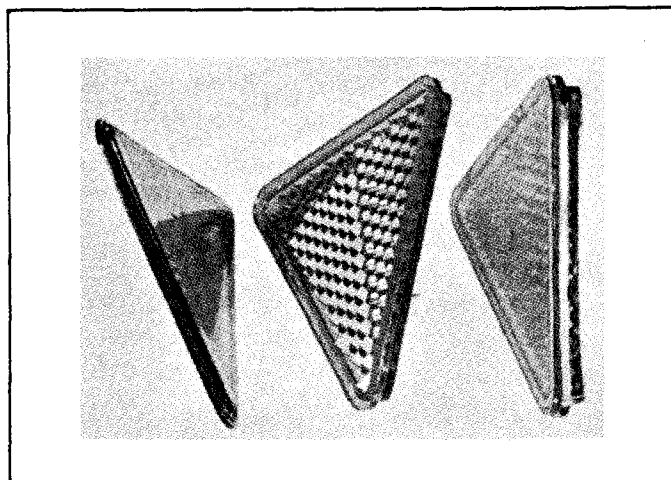
Ultrasonics as a plastics welding tool is becoming more popular as more production engineers see how simple the process is. Understand ultrasonics and design your parts with this assembly method in mind and you too could realise cost benefits.

Cost Reduction and faster production are two phrases every production engineer must have heard time and again in his struggle for profitable manufacture of his company's goods.

Where plastics mouldings are concerned - and this is still the growth area for components - it is often difficult to find ways of cutting costs still further. Value analysis of a part or an assembly can sometimes provide an answer by redesigning what is perhaps a complex component to be injection moulded in two or more parts for subsequent assembly by ultrasonic welding.

Ultrasonic welding is quick, easy to automate and incorporate in production lines and can therefore be an exceedingly cheap method of assembly. Total weld times - including dwell times - are usually only a few seconds per operation. For example, the triangular reflector shown in Fig. 1 (below) needs to be moulded in two parts; the acrylic reflector moulding shown centre with its many reflective facets and the backplate shown to its left which must hermetically seal those facets against moisture. A weld time of 0.8 seconds is all that is required to melt the weld ridge moulded onto the backplate and fuse it against the reflector moulding. A further 0.2 seconds hold time - with pressure retained but with ultrasonic vibration switched off - allows the joint to set as heat diffuses away from it. This component is welded using a rotary table feed system at the rate of 30 reflectors each minute.

Fig 1. Reflectors are moulded in two parts. Reflecting facets are sealed from moisture by welding on a backplate.



When one considers alternative fixing methods such as using adhesives or screwing or bolting, it is easy to see why ultrasonic welding has seen such a high rise to fame. So long as there is not a requirement to separate component parts of a plastics assembly sticking them or ultrasonically welding them would appear to have similar advantages over screwing. Ultrasonic welding wins by incorporating its own adhesive in the form of a concentrator (more about this later) moulded onto the part. Even the cyanoacrylate adhesives cannot make a joint in so short a time as the ultrasonically welded joint.

How does ultrasonics weld ?

Ultrasonic welding is a branch of friction welding really. The two materials at the joint face are rubbed together until the scuffing builds up to such an extent that the materials become molten locally and flow together. Once this has happened there is no need for further ultrasonic action. All that is necessary is for pressure to be retained on the joint until the molten material has solidified. The weld is then complete.

Friction needed to weld is produced by high speed vibration of low amplitude. The speed of vibration is just beyond the frequency that can be detected by the human ear. 20 kHz is chosen by most manufacturers of ultrasonic welding equipment. Sub-harmonics of the frequency can be heard and thus provide a useful clue that the system is working.

Two basic methods of generating ultrasound are in common usage: these are magnetostrictive and piezo-electric methods. Both provide vertical vibration and weld by hammering and squashing the concentrator repeatedly until friction builds up heat inside it and it eventually melts.

Magnetostrictive generation of ultrasound makes use of the property of transformer core material expanding and contracting as magnetic flux changes through the material from one polarity to the other. The generator can thus be likened to a "choke" or transformer with a single electrical winding. Reversal of current through the winding at 20 kHz produces a shortening and lengthening of a specially tuned core at the same frequency. To this core is attached a welding horn which is also tuned to the frequency but is shaped to the form required by the part it has to weld.

The overall efficiency of magnetostrictive ultrasonic welding transducers is in the order of 50 per cent of power required to drive the system.

Piezo-electric transducers rely on the property of piezo-electric materials to change their length when an electric charge is put across two faces. Two such cylinders of piezo-electric ceramics are mounted in a back-to-back configuration and clamped to form a tuned assembly.

Alternating voltage, when applied to these ceramics, makes them vibrate at the drive frequency. In the same way as with magneto-strictive transducers, a horn is mounted onto the end of the assembly and so shaped at its free end that it conforms to the shape of the part it has to weld. In Fig. 2 is the horn used to weld our example shown in Fig. 1. Although photographed on its side, the horn is mounted vertically beneath the transducer on a Kerry welder. Another example of a component welded by a Kerry Machine is the uni-coil shown in Fig. 3. It is used for line-balancing in telephone installations and needs to be hermetically sealed and humidity tested after sealing.

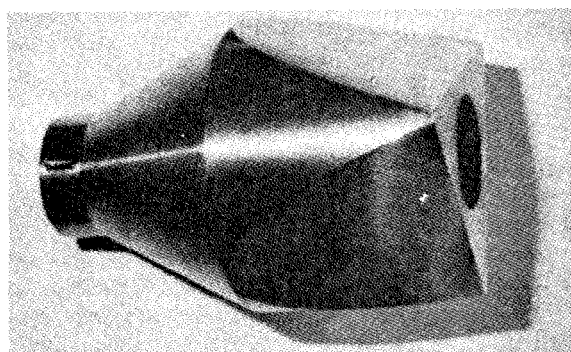


Fig 2. This is the horn used to weld the reflector shown in Fig 1.

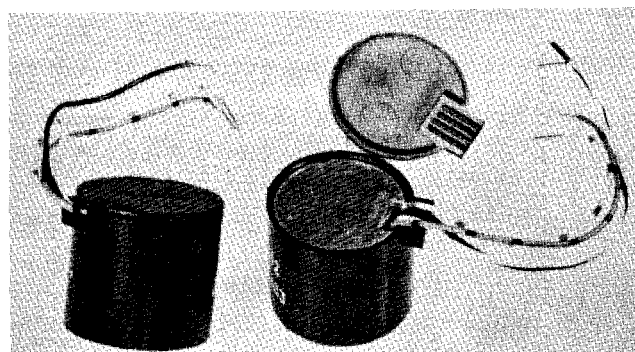


Fig 3. Another hermetic seal application.

Piezo-electric transducers suffered from a tendency to unreliability in the early days of ultrasonics, but now they are as robust as their magneto-strictive sisters. Efficiency of the piezo-electric system is 95 per cent.

Transducers of both types are always mounted at a position of zero amplitude to minimise vibration transfer to the rest of the machine. This position is termed a nodal plane, and is situated half a wavelength (of sound through the material) from the nodal plane that occurs at the centre of the transducer element.

In some cases a step-up or step-down transformer is required to adjust the amplitude of vibration to match a particular job. Such a transformer can be incorporated in the horn design. A horn that tapers from large section at point of attachment to a small one at the work face will serve to step up the amplitude at the workface.

Horn material is usually titanium, particularly if long production runs are envisaged. This might appear to be unnecessary expense, but stresses are very high within the horn and a high strength is required to resist fracture after long periods of use. Another reason is that titanium does not leave traces of itself on the work as does aluminium for instance. Aluminium is used for feasibility studies on horn design or suitability of the process to certain jobs as it is easy to machine, is light and is relatively cheap.

Whilst a certain amount of science goes into horn design, so does a lot more experience. It is difficult to predict just how a certain shape of horn will function. Once it has been machined to shape it can only be rectified by removing more material. If it is already too small the only answer is to start again.

Design for success

To ensure a successful weld between two plastics component parts both the part design and the materials must be right. So too must the design of the horn.

Material and design are interrelated to a certain extent. Some materials weld best when the horn is close to the joint; others can be welded almost as well when the joint is remote from the horn. Fig. 4 shows weldability of most suitable thermoplastics. A.B.S., polycarbonate, polystyrene, nylon, rigid P.V.C. and S.A.N. all leave the designer free to choose his joint design uninhibited. Other materials, acetal, acrylic and polyester also weld very well but only close to the horn.

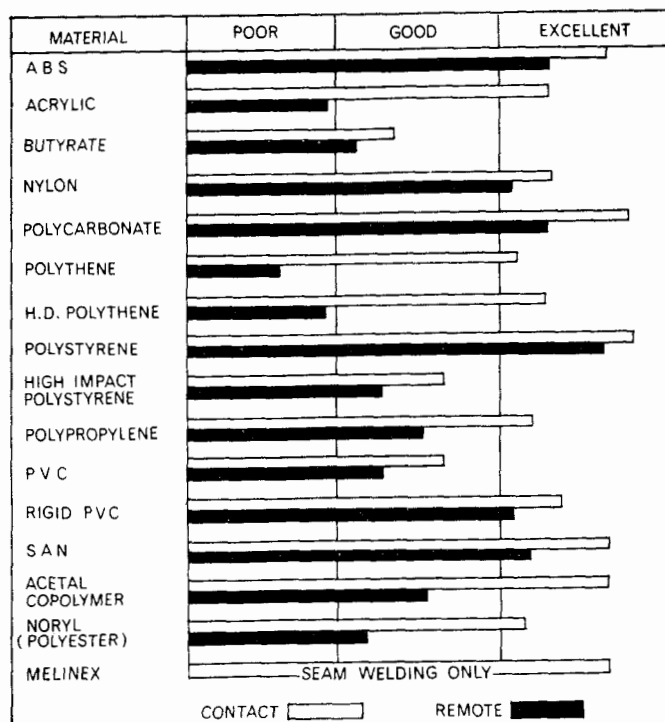


Fig 4. Weldability of some well-known plastics.

Joints should be properly designed for ultrasonic welding techniques. It is not enough to design for adhesive assembly or screw fixing and expect a perfect weld. Earlier we mentioned the concentrator on the reflector. This is present in all good joints. It is a raised ridge of triangular or trapezoidal form that is between $\frac{1}{2}$ and $\frac{1}{3}$ of the width of the final weld. It serves to concentrate the action on a fixed boundary. The concentrator material forms the eventual weld "adhesive" when the parts are pressed together. Fig. 5 shows a selection of good joint designs.

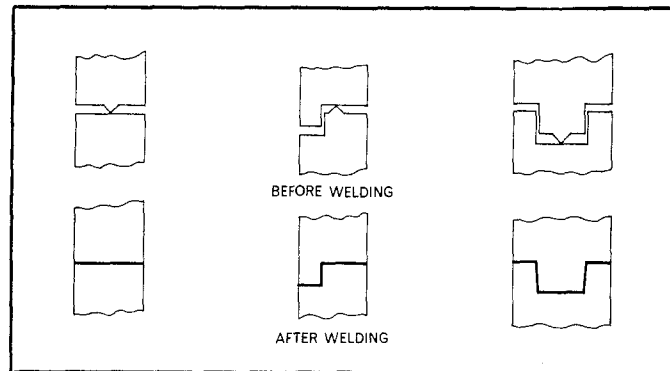


Fig 5. Some simple examples of good joint design.

A more recent development in ultrasonics techniques on plastics materials is the ultrasonic sewing machine from Branson Sonic Power. This has been developed to make welded seams in thermoplastics fibre cloth with up to 35 per cent natural fibre content. The principle of welding is the same except that a rotating wheel beneath the cloth allows both top and bottom cloths to move freely beneath the work horn. The periphery of the wheel is shaped to form the desired design of stitch, or a continuous seam as required. This sewing machine is, of course, too sophisticated and too expensive for the small-time user. It is intended for commercial users on a large scale.

Staking plastics "rivets" over other materials is another technique used frequently in assembly of plastics parts or metal parts inside plastics components. In this case the horn comes into direct control with the rivet blank and has the mirror of the desired head form machined into its end face.

Insertion of tapped inserts into plastics components is another field of great interest. It is much quicker to put these inserts in the required position in ready-moulded wells than to load a number of inserts to the inside of the mould to be moulded in. Inserts designed for ultrasonic insertion have a waisted form on their body and a pair of opposing helix knurls. The waist prevents pull-out while the double helix prevents turning of the insert in its hole. Ultrasonic energy melts material as the inset is driven home, and this material flows into the waist and sets around the knurl form.

Large components can be welded as well as small ones. In Fig. 6 a double-skinner ice bucket body is being welded by the latest high power welder from Dawe. Because the horn is of large diameter it has to incorporate slits to prevent transverse vibrations building up and marking the product.

Miniature indicator lights are staked and then remotely welded at Thorn Bendix by a Kerry machine in Fig. 7.

Fig 6. Welding an ice bucket (Dawe).

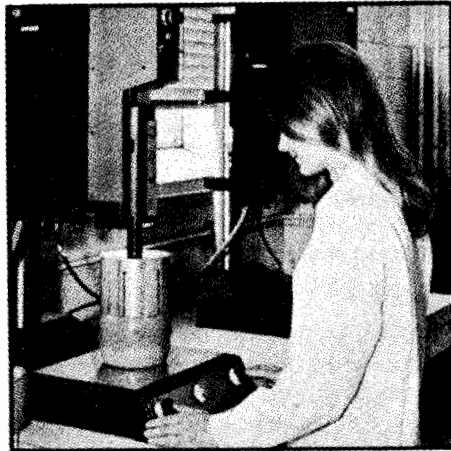
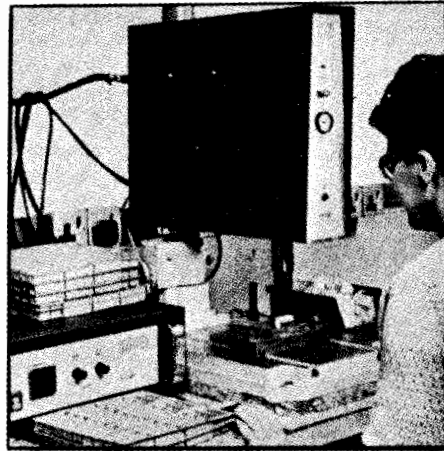


Fig 7. Welding and staking indicator lights (Kerry).



A rotary fixture on the intertherm machine, Fig. 8, allows the operator to load milometers while the ultrasonic head welds at another station. This cuts assembly time down still further.

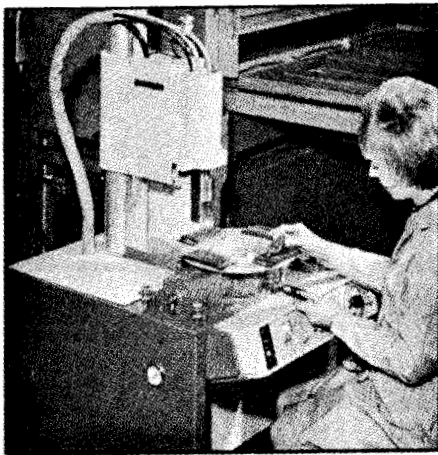


Fig 8. Milometer welding set up (Intertherm).

Often it is worth while for the moulder to install a machine at his own works so that he can offer a complete moulding and assembly service to his customers. John Dale Ltd. has done just this, and cosmetic bowls are assembled there for the customer on Radyne equipment.

Ultrasonic welding is growing in popularity and application at an unprecedented rate. Further increases in precision moulding of thermoplastics - that are bound to come - can only be a healthy sign for the ultrasonic welding industry.

COMPARISON OF PROCESSES FOR
SOLID CONCENTRIC SHAPES

PROCESS	COMMENTS	SIZE RANGE	GENERAL TOL. INS.
Sand Casting	Usually requires machining.	Under 11lb up to foundry capacity	1/16 - 1/8
Die Casting	For intricate shapes non-ferrous alloys	Under 1 oz. to 30lb.	.002 to .010
Centrifugal Casting	For long or large regular hollow shapes	2 1/Dia. x $\frac{1}{4}$ wall to 1000lb weight	1/16 - 1/8
Shell Moulding	Excellent finish	Under 11lb up to 150lb.	.005 to .015
Investment Casting	For intricate shapes	Up to 10 - 15 lb.	.003 to .005
Die Forging	Increase steel strength for high stress parts.	Under 11lb to 1000 lb.	.008 to 1/8
Sintering	Best for parts under 4 in. dia.	Under 11lb.	.001 to .005
Impact extrusion	For aluminium, zinc, copper & some steel parts	Up to 5lb.	.0005 to .002
Hot upsetting	For complex small parts	Up to 4lb.	.003 to 1/32
Cold heading	High production rate improves metal strength	.020 to 1 in. dia. up to 9 in. long	.002 to .005

COMPARISON OF DIECASTING - SINTERING -
INJECTION MOULDING

	Type of Component		
	Die Casting	Sintering	Injection Moulding
Initial tooling & equipment	High to very high dependent upon number of cavities & casting temp. Dies may be required for flash removal.	Very high. Coining may be required for high quality & low tolerances.	High. Dependent on cavities required.
Tool Maintenance	High depending on alloy, surface finish requirements etc.	Low unless a high density part is required.	Very low except when high pressures are required to fill heavy sections.
Tool life	Limited. Usually over 1 million parts for zinc but 10,000 to 250,000 for high temp. alloys.	Indefinite	Indefinite, unless high temp. & pressures are used.
Materials	Generally low cost per pound.	May be high for stainless parts or parts having a high copper content but generally low.	Generally low but can be much higher if certain qualities are required.
Direct production labour	Generally low cost depending on degree of automation.	Low cost - no skilled labour required.	Low cost depending on degree of automation.
Production Speed	High to very high depending on alloy & part size 150/hour	Very high. 120/hour.	High depending on part size. 60/hour.
Economic quantities	10,000/annum	20,000/annum	10,000/annum

	Gravity Sand Castings	Permanent Mould Gravity Castings	Shell Mould Castings	Die Castings	Investment Castings
Raw Materials Cost	Low to medium, depending upon metal.	Medium - nonferrous alloys used primarily.	Medium - nonferrous alloys only.	Medium - mostly zinc, aluminium and magnesium.	High - process best suited to special, costly alloys.
Tool and Die Costs	Low as compared to dies and moulds.	Moderate - higher than other casting methods except die casting.	Medium - between permanent mould and castings.	High, more than for other casting methods - £200 to £3000 or more.	Low to moderate depending upon a model being available.
Optimum Sized Lots	Wide range from a few pieces to 10,000.	Large - requirements in thousands best.	Small - 100 to 2,000 best range.	Large, 1,000 to hundreds of thousands.	Wide, although best for less than 1,000 pieces.
Direct Labour Costs	High - men needed to mould, melt, clean, snag, etc.	Medium	High - many skilled operators necessary.	Low to medium.	High - many hand operations required.
Finishing Costs	High - require machining, cleaning and snagging.	Low to moderate - less machining than sand casting.	Low - little machining needed.	Low - little if any machining, only a simple trim.	Low - machine not generally necessary.
Scrap Loss	Moderate - foundry scrap can be remelted.	Low - most scrap can be re-used.	Low - most is foundry scrap which can be re-used	Low - gates sprues, etc. can be remelted.	Low - most scrap can be remelted.
Choice of Materials	Wide - ferrous, nonferrous, light and heavy alloys.	Wide - nonferrous alloys and gray iron.	Narrow - limited to brass, bronze and aluminium.	Narrow, zinc, aluminium, magnesium and brass.	Wide - include materials hard to machine or forge.
Complexity of Parts	Considerable - holes, bosses, locating pads, complex shapes.	Limited - mould cannot be highly complex.	Great - mould destroyed after casting.	Great - limited only to die, which can be complex.	Great - mould destroyed after casting.
Maximum Size	High - as large or larger as any other method.	Moderate - 50lb is practical limit in aluminium.	Moderate - up to 15lb in most materials.	Moderate - about 35lb for zinc, less for light metals.	Moderate - large sizes possible, but under 2lb best.
Minimum Size	1/8th in. is the smallest practical section thickness.	Small - 1 oz. sections as thin as 0.1 in. often cast; some smaller.	Small - down to 1/32nd in. section possible.	Tiny - from fractions of an ounce down to 0.012 in. sections.	Small - sections down to 0.030 in.
Mechanical Properties	Fair to high, depending upon the material.	Fair - good in centrifugal castings.	Fair	Fair to good	Good.
Precision and Tolerances	Low - $\pm 1/16$ th in. per in. of casting except for shell moulding.	Low to moderate - $\pm 1/64$ th in. per in. in aluminium, better in brass.	Good - ± 0.010 to ± 0.005 in.	High - ± 0.001 to ± 0.003 in. common.	Good - to ± 0.005 in. per in. general.
Special Structural Characteristics	Good bearing structure.	Centrifugal castings have high strength and density.	None	Inserts of other metals can be cast in.	None.
Surface Smoothness	Poor	Good, often obviate finishing	Good	Good, often obviate finishing	Excellent.
Surface Detail	Fair	Good	Good	Good	Excellent
Getting into Production	Moderate - 3 to 5 days for pattern to be made.	Moderate - several days to several weeks.	Moderate - several days to a few weeks.	Moderate to slow - from a week to several weeks.	Fast - sometimes in a few hours.
Rate of Output	25 to 600 or more pieces per hour by using modern methods.	Moderate - up to 100 per hour easy, often more.	High - up to 1,000 per hour depending upon size.	High - usual range from 100 to 1,000 per hour, up to 3,500.	Slow - up to 100 per hour.
Remarks	Most sand castings require some machining.	Fall between sand castings and die castings as far as most production factors are concerned.	Over-all costs less than for sand castings.	Among the most economical metal forms for larger quantities.	Used best on parts too complicated for other casting methods or where machining is difficult.

COST, DESIGN AND PRODUCTION FACTORS IN SELECTING MANUFACTURING METHODS

SECTION 3 Table 3

	Drop Forgings	Press Forgings	Upset Forgings	Cold Headed Parts	Stamped and Formed Parts
Raw Materials Cost	Low to moderate - steels up to high alloys.	Low to moderate - compare with drop forgings.	Low to moderate, as with other forgings.	Low to moderate - steel wire chiefly.	Low to moderate, ranging from carbon steel to stainless.
Tool and Die Costs	High, great care needed in dies - £100 to £1,000 or more.	High, but usually less than drop forgings.	High - often because of number of impressions or difficult design.	Medium	High
Optimum Sized Lots	Large, 10,000 or more best, although used on smaller quantities.	Medium to high production lots.	Medium to high lot production best.	Large - not suited to small quantities.	Large - over 10,000 best.
Direct Labour Costs	Medium - skilled labour needed for heating and hammer work.	Medium - but less than drop forgings.	Medium - lowest of forging processes.	Low - almost entirely automatic.	Medium - depending on size and shape.
Finishing Costs	Medium - ferrous need more than nonferrous due to scaling.	Medium - same conditions as with drop forgings.	Medium - often less than other forgings.	Low - thread grinding or rolling sometimes necessary.	Low - cleaning and trimming most frequent.
Scrap Loss	Medium - depending on size, shape and machining needed.	Medium - usually less than drop forgings.	Medium - often less than other forging processes.	Low - practically no scrap loss.	Low to moderate - some scrap in blanks can be re-used.
Choice of materials	Medium - many alloys are forgeable.	Medium - best for non-ferrous alloys.	Medium - many ferrous and nonferrous materials.	Narrow - confined to steel and highly ductile metals.	Wide - includes all workable sheet metals; plastics
Complexity of Parts	Moderate - limited by die restrictions.	Limited - but better than drop forgings.	Limited to cylindrical shapes and certain dimensional limitations.	Limited - less flexibility than forging.	Limited - many restricted design rules.
Maximum Size	Large, largest require steam hammers.	Moderate - 25-30lb a practical maximum.	Medium - 9 in. bar about largest size; weights may be high.	Small - 7 in. long by $\frac{1}{2}$ in. dia. usual maximum.	Large - can be used on very large parts.
Minimum Size	Small - to fractions of an ounce on board hammers.	Small - to fractions of an ounce, better than drop forgings.	Moderate - not comparable to casting processes.	Small - $\frac{1}{8}$ th in. dia. parts can be made.	Small - sections as thin as 0.003 to 0.005 in. possible.
Mechanical Properties	High	High	High	High	Fair to High
Precision and Tolerances	Medium - \pm 0.010 to \pm 0.030 without coining.	Medium - somewhat better than drop forgings.	Medium - similar to press forgings.	Medium - \pm 0.002 in. possible; \pm 0.010 in. common.	High - \pm 0.001 in common, closer on small parts.
Special Structural Characteristics	Grain flow provides toughness.	Hot worked structure a mechanical advantage.	Grain flow provides toughness.	Grain flow adds to toughness.	None.
Surface Smoothness	Fair	Fair	Medium	High	High
Surface Detail	Fair	Fair	Medium	Fair	Fair
Getting into Production	Slow - one to several weeks to make dies.	Slow, possibly somewhat faster than drop forgings.	Slow - similar to drop forgings.	Fair - dies are relatively simple.	Slow - dies may require several weeks.
Rate of Output	Medium - 120 per hour for small parts, less on large.	Medium - slower than drop forgings.	Medium - equal to or better than drop forgings.	High - 4,800 per hour common; higher possible.	High - up to several thousand pieces per hour.
Remarks	Used when high strength and high production are required. Preferred for large pieces	Somewhat closer tolerances than drop forgings; permit greater design intricacy.	Best suited to relatively small parts. Uses: bar stock.	Method is competitive with screw machining on fasteners and simple flanged or headed parts.	Usually the cheapest when quantities are high enough; best for thin sections.

COST, DESIGN AND PRODUCTION FACTORS IN SELECTING MANUFACTURING METHODS

	Impact Extrusions	Machined Extruded Shapes	Powder Metal Parts	Spun Shapes	Screw Machine Parts
Raw Materials Cost	Moderate - usually zinc, lead and aluminium.	Medium - in soft metals High - in harder metals	Medium to high	Low to moderate.	Low to medium - seldom used on high cost alloys.
Tool and Die Costs	Medium - some dies less than £100.	Low - cutting done with simple tools.	Medium - range from £100 to £1,500.	Low - forms cost from £10 to £100.	Medium - from £20 to £100 common.
Optimum Sized Lots	Wide range - from thousands to millions.	Wide range - useful for large and small lots.	Large lots best (10,000), but small runs might be necessary.	Low - quantities under 1,000.	Large - the larger the better, over 1,000.
Direct Labour Costs	Low - little skilled labour needed.	Low - skilled labour not required.	Moderate - some skilled labour needed for certain stops.	High - skilled craftsmen needed.	Low - one operator can handle several machines.
Finishing Costs	Low - possibly no finishing.	Low - tumbling or deburring might be needed.	Low - machining seldom needed.	Low - cleaning and trimming.	Low - cleaning and deburring.
Scrap Loss	Low - most loss in blanking scrap.	Low - waste removal at extruding mills.	Low - practically no scrap.	Moderate - comes in cutting blanks.	High - large quantities of chips generated.
Choice of materials	Narrow - best on soft metals, lead, copper, aluminium, zinc.	Narrow - copper and light metals, but steel processes being developed; plastics.	Narrow - iron brass and combinations; plastics combinations.	Wide - many sheet metals are spinnable.	Wide - although highly machinable materials best, including plastics.
Complexity of Parts	Limited to shell-like shapes usually.	Limited - can be complex in cross-section only.	Limited - powders flow poorly and do not transmit pressures.	Limited - cylindrical or concentric shapes.	Limited to rotational shapes.
Maximum Size	Medium - 4 in. dia. by 12 in. length.	Medium - 8 or 10 in. dia. is usual maximum.	Low - parts below 4 in. sq. are best; larger are made	Large - can be several feet in diameter; max. gauges 1/8th to 1/4 in.	Medium - most machines use stock up to 2 1/2 in. dia. and 6 in. long.
Minimum Size	Small - fractions of an ounce; walls as thin as 0.003 in.	Small - 0.050 in. sections possible in aluminium and magnesium.	Small - parts smaller than 1/16th in. dia. can be made.	Moderate - 1/4 in. dia. in gauges less than 0.040 in. are made.	Small - often under 1/16th in. dia. and weighing fractions of an ounce.
Mechanical Properties	High - Metals cold worked.	Good - light metals can be heat treated; strong copper alloys used.	Fair to good - impact values low, wear resistance high.	Good	High
Precision and Tolerances	High - tolerances closer than 0.001 in. are common	Fair - ± 0.005 in. to 0.020 in. common	High - ± 0.005 in. through sizing; ± 0.001 to 0.005 in. common.	Fair - ± 0.015 to 0.060 in. common; ± 0.005 in. can be had.	High - ± 0.005 to 0.001 in. possible; ± 0.001 to 0.003 in. common.
Special Structural Characteristics	Grain flow improves properties somewhat.	Grain flow improves properties somewhat.	Many possible structures; controlled porosity, complex materials.	Grain flow and cold work improve properties.	None.
Surface Smoothness	Good	Good	Fair - depends upon porosity.	Good - often better than other methods.	Excellent.
Getting into Production	Fair - dies can be had in a few days.	Fast - when shapes are in stock.	Medium - dies must be carefully designed and made.	Fast - forms can be made quickly.	Moderately fast - tooling and set-up may take several days.
Rate of Output	High - small parts can be produced at rates over 2,000 per hour.	High - 1,000 small parts per hour; possible on automatic saws.	High - 1,800 per hour is not uncommon; can be higher.	Slow - 12 to 30 per hour common.	High - 3,000 to 4,000 per hour on small parts.
Remarks	Method now being used on mechanical parts as well as containers.	Sometimes used as blanks for forging.	Can use materials not formable by other methods.	Over-all costs on large pieces less than by other methods.	When shape and materials agree, process is fastest cheapest & most accurate.

COST, DESIGN AND PRODUCTION FACTORS IN SELECTING MANUFACTURING METHODS

COST, DESIGN AND PRODUCTION FACTORS IN
SELECTING MANUFACTURING METHODS

	Electroformed Parts	Sectioned Tubing	Welded and Brazed Parts	Moulded Plastics	Moulded Nonmetallics
Raw Materials Cost	Low to high - iron to chromium.	Moderate to high.	Low to moderate	Medium to high - on a per lb. basis.	Moderate to high.
Tool and Die Costs	High - mould lasts, but must be perfect.	Low - cutting done with simple tools.	Low to moderate - jigs often used.	Medium to high.	Medium - most dies and moulds of simple shape.
Optimum Sized Lots	Small - best when few pieces are needed.	Wide range - good for small and large quantities	Small, but brazing can handle large lots.	Large - over 5,000 best	Wide - from low to high. Special properties are guide.
Direct Labour Costs	Medium to high - both skilled and unskilled labour needed.	Low - skilled labour not required.	Medium to high - skilled labour required.	Low - most operations automatic.	Moderate - processes not automatic.
Finishing Costs	Low - no subsequent finishing.	Low - generally.	Medium - joints must be cleaned.	Low - fins and flash removed by tumbling.	Low except where low tolerances are involved.
Scrap Loss	Low - little if any scrap.	Low - practically no scrap	Low - practically no scrap	Medium to low - Thermoplastics are reusable.	Low - most scrap re-used.
Choice of Materials	Narrow, iron, copper, nickel, chromium.	Wide - all ductile metals and plastics.	Wide - dissimilar metals can be joined.	Wide range of plastics with many characteristics.	Narrow, ceramics, rubbers, carbon, graphite.
Complexity of Parts	Great - extreme complexity possible.	Limited by sectional shapes of available tubing.	Complex and intricate forms can be produced.	Limited by die, but some coring is possible.	Limited by dies and moulds.
Maximum Size	Limited - by plating equipment, sections up to $\frac{1}{2}$ in. possible.	Usually 4 to 6 in. O.D. some materials up to 22 in. in welded tube.	Unlimited.	Moderate - under 2 lb best in some materials; larger possible.	Small best - including cylinders up to 6 in. I.D.
Minimum Size	Small - 0.005 in. or less possible.	Moderate - $\frac{1}{4}$ O.D. in. most, although speciality tubing as small as 0.012 in.	Moderate - usually not small - thin and thick sections can be joined.	Small $\frac{1}{32}$ nd in. thick is common minimum.	Fairly small, depends upon material being formed.
Mechanical Properties.	Fair - lower than wrought forms.	Good - cold working adds to properties.	Depends upon components.	Low as compared to metals	Low as compared to metals
Precision and Tolerances	High - \pm 0.002 to 0.0002 in. met regularly.	Good - small sizes to \pm 0.002 in.; larger to \pm 0.004 to 0.025 in.	Medium - joints seldom closer than \pm 0.070 in.	High - \pm 0.005 in. common; can be closer	Moderate - close dimensions obtained by extra operations.
Special Structural Characteristics	Extremely dense structures; laminated metals possible	Grain flow improves properties.	Special property parts can be combined.	Inserts can be moulded in.	None
Surface Smoothness	Excellent, high finish attained.	Good	Depends upon components	Excellent	Fair, depends upon material
Surface Detail	Excellent - minute detail and intricate patterns reproduced.	None	None in joining process.	Good	Fair to Poor
Getting into Production	Slow - master or die might take several weeks to prepare.	Fast - shapes often available from stock.	Fair - when components have been decided upon.	Slow - moulds require considerable time.	Fair - dies and mould fairly simple.
Rate of Output	Slow - time usually in hours or days.	High - automatic machines often used.	Varies - brazing can be fast as can resistance welding.	Moderate - 20 to 300 shots per hour.	Slow - parts require baking or curing after forming.
Remarks	Best when parts are complex and surface accuracy is important.	Costs can be reduced considerably through lower scrap losses.	Often the only way to meet design requirements.	Can serve as alternates for metal parts at lower cost.	All materials have special characteristics which dictate their choice.

SECTION 4

VALUE ENGINEERING CASE STUDIES

Introduction

Case Studies are useful to illustrate some of the points made in the Project Workbook and in this Reference Manual. They can often trigger ideas for improving other designs.

They are not given as unique cases but are important only insofar as they assist in the understanding and use of the Value Engineering approach.

There are two main groups of case studies, those from outside the Plessey Company and those from within.

The case studies cited from outside the Company (Section 4.1) are extracted from various sources including extracts from a thesis on Value Engineering by a Graduate Student.

The case studies from within the Plessey Company (Section 4.2) are drawn from various Businesses, and are the result of team studies often initiated at a training seminar.

They include both mechanical and electronic circuit studies. It is often thought that Value Engineering can only be applied to mechanical designs and assemblies or layouts of electrical components. This is not so. The discipline can be effectively applied to basic electronic circuits.

Because of the time limitation in preparing this Manual, the Plessey section is far from complete and will be augmented by examples to be issued later.

CASE STUDIES TAKEN FROM OUTSIDE THE COMPANY

It is a wrong impression that Value Engineering or Analysis is made necessary only by poor original engineering. There are many factors which result in a design that may be improved later. Not the least of these is the fact that a design engineering department cannot do 100-percent value engineering at the same time it does design engineering. This is because the design group normally does not have the time to do both simultaneously. The "pick and shovel" part of Value Engineering is performed by a team working on high cost areas of a particular product. No design engineer needs to be ashamed that Value Engineering can make cost improvements.

Another aspect that leaves room for design improvement is the particularly high specialisation in all fields.

A look at the following case histories will illustrate much of what has been said in the previous paragraphs.

CASE HISTORY NO. 1

In the drawing office of an electric clock factory, the word "crystal" was always used to designate clock faces, as a matter of habit. They were called clock crystals. This meant that drawings delineating the exact shape and dimensions of clock faces always specified these as crystals.

In general auditing of freight bills, it became accepted practice to expect the crystals to require a very high freight rate. However, when the time came for making a special audit of freight rates, the question arose, "How does a clock factory use so much crystal?". The investigation which followed disclosed that the clock faces were indeed window glass, warmed and sagged. The investigation also brought forth the information that the transportation of crystal, a very expensive grade of glass, is extremely costly, while window glass, in any form, travels at a much lower rate.

Crystal shipped "less than carload" costs 1.25 times the first-class freight rate, while "bent window glass", which correctly described the product being shipped, travels at only 0.85 times the first-class freight rate.

The result was that the name was changed on the drawings, in the specifications, on the orders, and on the bills of lading so that, instead of being wrongly called crystal, the material was correctly called bent window glass. The freight rate was cut by 32 per cent.

From this case we can see that the "historical", but erroneous terminology for clock faces appeared on drawings, specifications, etc. Moreover, because of this the people had become fairly conditioned to high cost. At first look some would say, "You don't need Value Engineering to find this type of improvement". This is true. However, it is also true that the application of Value Analysis will find these types of hidden costs - and find them quickly.

CASE HISTORY NO. 2

..... case of an electrical control. It worked very well indeed, but its cost was too high. Sales had dropped off. The makers brought the control in for value engineering with a statement which said, "We give you this with tongue in cheek; we don't think another penny can be taken out of the cost, but we're desperate".

In applying the value engineering approach to the device, one of the first parts to come up for review was a wire clip which held the cover on. It was made of phosphor bronze and cost \$7,000 a year. The value specialist asked, "What is the function? Now does the phosphor bronze contribute to that function? It is a material that is commonly used when a part has to flex millions of times. But this clip is flexed only when the cover is removed for servicing an average of six times in the life of the product". By changing to spring brass, the same job could be done for \$3,000 a year, that is, for less than half.

The cover itself cost 4 cents, an expenditure of \$40,000 a year. Its function was to keep extraneous material out of the small mechanism. The entire control was mounted inside another enclosure. Using a plain piece of laminated plastic reduced the cost from 4 cents to 1.5 cents each, and out went \$25,000. Many similar findings were made as the Engineering of the complete device proceeded.

This case illustrates where selection of the subject was unnecessary because the makers brought the product in for study. In addition, it should be noted that the philosophy of no further cost reduction being possible was held by the makers.

CASE HISTORY NO. 3

A manufacturer produced a piece of hardware - the primary function of this piece was to guide bolts. It cost \$1.63 to make each piece. Cost reduction methods (changing the handling and tooling methods) reduced this to \$0.81. Value control came up with a

total of \$0.08, and still provided the essential function (guide bolts).

CASE HISTORY NO. 4

..... in the carrier programme, it was found that the guard rail for hatches required by the working plans was composed of wire rope 3/8 in. diameter cut to length and special stainless steel fittings put on each end. The wire rope is preserved with paint wrapped with muslin and served with marline cord. This in turn is again wrapped with muslin and the whole length covered with hand-stitched canvas. Each end of the canvas is served with copper wire and soldered. One end is fastened to the hatch cover by means of a short length of 1/4 in. close-link chain, the other to the deck or stanchion. This is an expensive item. There are approximately 344 hatches per carrier and the guard rail outlined cost \$16,438 per carrier. Its function ? To guard people. For this application, the substitution of 1/4 in. chain was recommended at a cost of \$1,233 per carrier. The acceptance of this recommendation saved approximately \$15,000 per ship!

This case illustrates the influence of tradition. Often a specification remains unchallenged after initial approval. In an age of daily breakthroughs of new materials, methods, techniques, etc., we cannot be satisfied until the applicability of all specifications have been thoroughly examined.

CASE HISTORY NO. 5

Value Engineering study was conducted on circuit board bracket. Original bracket consisted of 15 pieces plus rivets, cost \$10.25. Re-engineered bracket is produced as one piece, costs only £1.91.

CASE HISTORY NO. 6

A requirement existed for targets for rifle marksmanship training. These targets had to possess certain shock-transmitting characteristics so that a hit would be recorded. In addition, the target had to withstand the effects of weather for a stated period of time while maintaining required rigidity. A very suitable target of plastic-impregnated fibreglass was developed - cost in quantity, \$2. each.

This was a good product, soundly engineered. It served the function and was reliable, but, to the value engineer, we were paying far too much for the function. An exhaustive search in co-operation with designers, engineers, procurement specialists, and suppliers, revealed that a specially treated paper board would accomplish all required functions with the necessary degree of reliability, but in this case the price in quantity was only 24 cents each. These items are procured in quantity and the savings on the first order amounted to \$709,764.

A fundamental lesson in this case is the key role that Purchasing can play in cost reduction and Value Engineering. Procurement, when properly used, is an integral part of the business operation and not merely a group of clerks processing purchase requests. However, it requires communication and co-ordination between all departments. In this respect, Value Engineering provides the integrating function which can unify a company's operation.

CASE HISTORY NO. 7

..... we have the example wherein special aluminium alloys were substituted for the more expensive beryllium and titanium specified in the design of certain missile components. These modifications - prior to production - precluded costs estimated to be approximately \$3.8 million dollars over the currently planned programme for one missile system. Here again the question was raised : What else will do the job and what does that cost? Such questioning is typical of the Value Engineering approach.

This case highlights the fact that a small saving per unit results in substantial savings when a large quantity of units are produced.

CASE HISTORY NO. 8

For want of a better idea, the bore sight for the 106 mm. rifle had been designed as an aluminium casting requiring extensive machining. When Value Engineering found that it cost \$3.21 to perform the simple function of holding a peep sight on the axis of the rifle tube, a simple sheet-metal stamping was devised. At a production cost of only 36 cents, a reduction cost of 89 per cent was achieved.

This case is indicative of the advantages of two things : (1) the functional approach brings all elements of item cost under scrutiny, and (2) the team approach makes it possible to get expert information either from the team or through the team.

CASE HISTORY NO. 9

A striking example of the savings inherent in simple components of missile systems was a fuse holder used in ground-control vans. Carried over in essentially the same form from early ground-control systems, it consisted of a drilled stainless steel bracket on which 37 machined and threaded bolt, nut and washer assemblies were mounted. The sole function of the assembly was to hold spare fuses.

Although it was immediately obvious to the team that cost was out of proportion to the necessary function, confirmation was supplied during the information phase. The cost per holder was found to be \$195.

Brainstorming, a common Value Engineering technique, was employed in the speculative phase. A stenographer in the value engineering office asked: Why can't you drill holes in a metal sheet and put in rubber grommets to hold the fuses? A hand-built model was easily constructed and found to be suitable for the purpose. Production cost was estimated at less than \$1.50 - a 99 per cent reduction.

This is another example of "hidden" costs. A carry-over from some other application may become a standard item and remain unchallenged unless Value Engineering is applied. Many, many other items most likely passed examination without exciting savings. Each item like the fuse holder, however, rewards the Engineer with a feeling of accomplishment.

CASE HISTORY NO. 10

At an electronics company, a shop worker noticed the similarity between a \$1.35 "heat sink" clip (used to bleed off heat from a transistor during soldering of a connecting wire) and a 2 cent clip used by his wife in setting her hair. Changeover to the hair clip resulted in savings of \$1,330 a year.

Creative thinking and suggestions are available to all companies. Value Engineering can benefit greatly through the employee suggestion plan. However, the suggestion plan requires careful handling. This is particularly true where the suggestion is good but will not result in a cost saving because of such other factors as retrofit, etc. In all cases, the employee should be given an early and complete explanation and, perhaps, a suitable commendation or recognition for a good suggestion.

CASE HISTORY NO. 11

Often it is cheaper to buy a part from a speciality supplier than to make it yourself, particularly if the supplier's production is automated. One firm discovered that it could buy a small bracket from a supplier for a delivered cost of \$3 per thousand. The same kind of bracket had been costing this firm \$13 per thousand when made in its own shop.

Many large companies have a "Make-or-Buy" committee. A "fall-out" benefit from Value Engineering is a technical library on the costs of items, processes, materials, components, and other elements of cost. This information, provided by value studies, may be compiled by electronic data processing (EDP) to provide the Make-or-Buy Committee much greater effectiveness.

CASE HISTORY NO. 12

A simple, throwaway clip to hold four washers has knocked \$3,000 a year off a jet engine manufacturer's costs. Formerly cemented as a stack, the three washers and one flat washer were messy and difficult for Associated Spring Corporation to assemble and ship. ASC asked permission to run a V.E. study, suggested the clip, and costs dropped over 50%. In addition, there is no chance of cement getting on the washer faces.

One would hardly expect a cost improvement of \$3,000 from four washers. However, after experience in Value Engineering it is hard not to find cost savings hanging from every tree !

CASE HISTORY NO. 13

The case of the building wire involved a number of interesting aspects. A study showed the analysts that a less expensive, less heavily insulated building wire could perform the required function and meet all safety requirements in certain locations.

Plant engineers were willing enough to consider the change but said it would be more expensive to use since it would be more difficult to install than the wire then in use. The analysts then went to maintenance and asked if they could install the wire without additional labour cost. The answer was yes, and when engineering saw that it could be done - and at a material saving of \$15,000 - they readily agreed to the change.

This case also illustrates the integration roles played by Value Engineering departments together

CASE HISTORY NO. 14

The mechanical pencil case offers a good example of how different value techniques can be applied to a relatively simple item to produce unexpected savings. Burnette and Murray's original study showed that one plant had been distributing a 34 cent mechanical pencil to employees, while the other was using a 24 cent product that performed just as well. By standardising on the 24 cent pencil, UCC was able to save several hundred dollars.

The team didn't stop there, however. It analysed usage of the pencils and found that Institute was issuing one pencil per man in a given period, while South Charleston was issuing more. By changing to one standard of issue, the company was able to save another \$3,000.

Burnette & Murray went a little further. What was the function of the advertising imprinted on each pencil? How much did imprinting cost? The answer was, of course, that UCC was simply advertising itself to itself at a cost of $2\frac{1}{2}$ cents a pencil. The unnecessary advertising came off, and the total saving on the project zoomed close to \$4,000.

Value Engineering may be applied to any element of cost. In this case, the pencils are not a product. Any department could have explored this. However, the functional approach of Value Engineering even challenged the function of the advertising. Was it a primary function? Was it a secondary function?

CASE HISTORY NO. 15

We sat down one day to deliberately pick an item that you just could not cut any cost out of. We wanted to use it to prove a point at a meeting.

After concluding that a plain standard threaded pipe nipple was what we were looking for, we began to gather some data on it. We were shocked to discover a potential \$12,000 a year saving in it - we had been buying premium quality in a "standard" item where adequate quality was all we needed.

This short case illustrates that every element of cost should be subjected to Value Engineering.

CASE STUDY NO. 16

American Airlines drive for standardisation is the immediate responsibility of Value Engineer M.E. Malet, who recently saved \$110,000 by reducing the tremendous variety of clamps used by the airline. Malet, whose 25 years with American have given him a thorough knowledge of part functions, highlights the basic nature of any standards programme.

"All clamps do the same thing", he says, "they squeeze". We just started asking a few simple questions : How many different clamps do we have ? Do we really need so many different types ? Why do many apparently identical clamps have such a variety of part numbers and prices ? How many can we eliminate ? How much can we save ?

To recruit help in answering these questions, the purchase analysis group gathered a sample of every clamp carried in stock. Similar clamps were then displayed on large pegboards in the purchasing area.

"The boards were there as a challenge to everyone - mechanics, engineers and suppliers, as well as purchasing people - to suggest where we could standardise and tell us where we couldn't". Malet says. "The response was tremendous. Of course the project got plenty of useful information from EDP, technical drawings and catalogues. But it was only through the boards that we could determine quickly whether two apparently identical clamps really were the same, or whether they differed in some important respect, like chemical resistance, that an engineer would spot immediately".

Over a period of time, a variety of parts with a similar function will accumulate in most companies. One reason is that, as personnel turns over, there is an amalgamation of employees with experience from diverse companies. Each man is used to certain parts and design considerations and these show up in his specifications. In many cases, specifications are determined by individual draftsmen. These items slip by. To compound the problem, purchasing may be too busy with the large dollar orders to pay close attention to bolts, clamps, screws and other minor items. This carried over into the provisioning of operational spare parts and maintenance spare parts. Very soon we find a situation parallel to the clamp story.

CASE HISTORY NO. 17

A dust cap applied to numerous electrical fittings on the Minuteman missile was designed as a threaded metal fitting, with a chain attached. A change to a plastic clip cap reduced cost per cover from \$6 to 2 cents. This amounts to a saving of \$73,000 a year - and the idea will be extended to other weapons.

One cause of high cost in engineering design, for instance, is that many of the catalogues provided by suppliers do not list the prices. An engineer will research those catalogues his memory suggests and, very often, stop at the first item which meets his need. He will leave the details of procurement to the purchasing department. At the same time, purchasing figures the item selected by the engineer is exactly what is required. Value Engineering can make the engineers more aware of prices. Value Engineering can bring engineering and procurement closer together.

CASE HISTORY NO. 18

..... St. Louis' Emerson Electric Company, in a list of otherwise sophisticated Value Engineering results, tosses in this neat solution to a problem in the cost of a bathroom light fixture. The company was struggling with the design of a rectangular reflector, to be made of sheet metal. Finally, a Value Engineer noticed that the reflector looked a lot like a cake pan: now Emerson goes outside to buy actual cake pans, using them in the light fixture.

CASE HISTORY NO. 19

The roll-proof door holder was designed for an electronic cabinet on board ship. It cost \$65. Value Engineering of the part indicated that a strong version of a brace normally used on card tables would reliably perform the same function. Cost of the new part: \$0.57.

It is quite a leap from electronic cabinets to card tables. It is also quite a drop from \$65 to \$0.57. The engineering mind has a tendency to reinvent the wheel. At the same time, however, designing a card table brace is hardly a matter of the electronic discipline.

CASE STUDY NO. 20

A welded part cost \$100.59. It was designed as a fabricated part because in the past a similar cast part had failed in service. A redesigned casting of equal strength to the welded one is now used. It costs \$4.50.

This case is quite significant in highlighting the extreme cost penalty of a failure without follow-up to improve the part. Value Engineering provides companies and employees a better cost picture of the various processes and materials. Until a dollar comparison is made, few people will be aware of the cost difference between welding and casting. The benefits of Value Engineering are cumulative. In some companies, the accounting department provides the engineering department with "broad gauge" cost units. Value Engineering is in a position to provide engineering maintenance, procurement, and other departments with detailed information on various costs that are accumulated as a by-product of Value Engineering projects.

CASE HISTORY NO. 21

One of the first items to be value engineered was the automatic cold control of a refrigerator. This part, an expensive one, had gone through cost-reduction studies, and the department manager told us "If you can take another nickel out of it, I'll eat my hat!" Presumably he ate it, because the records show that value engineering in 1947-48 eliminated \$500,000 a year from the cost of that one refrigerator part.

A savings of \$500,000 is a sizeable amount. But when this amount is saved after cost reduction has already been applied, it becomes even more impressive.

CASE HISTORY NO. 22

..... attended a seminar for executives of oil well service firms conducted recently by William G. McMurry, Value Control Administrator for the Military Electronics Division of Motorola, in Scottsdale, Arizona. For study, McMurry is given a cigar-shaped aluminium tube with slots in the side. The oilmen tell him that it's called a "bull plug".

What does it do, he asks. It protects detonators sent down oil wells to perforate the pipe and let in oil.

What does it cost ? Seventy-nine cents.

How else could you possibly convey and protect a detonator? Various suggestions are made. One student suggests: place it in a paper bag. Ridiculous? Yet that is the suggestion which, with a slight refinement, was actually adopted. Tests showed that a cylinder of heavy, impregnated paper would do the job just as well as the aluminium tube. The paper tube costs 7 cents, a reduction of more than 90 per cent - and it is now a standard item in the oil well servicing industry, which uses bull plugs by the thousands.

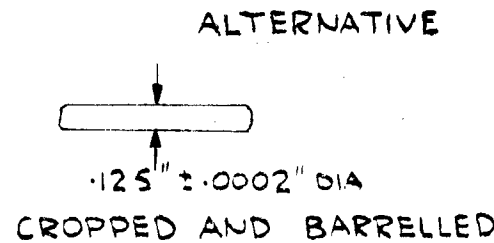
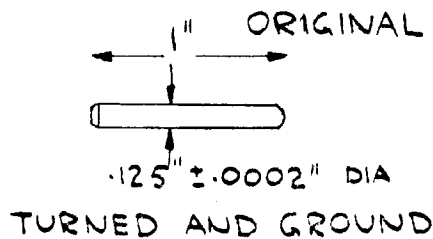
This brings to mind the story of not being able to see the wood for the trees. A 79 cent cost seemed negligible enough to go unchallenged. But an aggressive attitude and proper philosophy toward cost will not accept any cost as valid.

SAVINGS BY USING COLD FORMED WIRE

Below are given some typical case studies of savings made by changing from turned to wire formed parts.

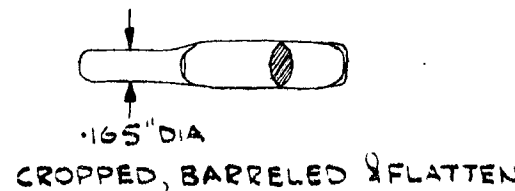
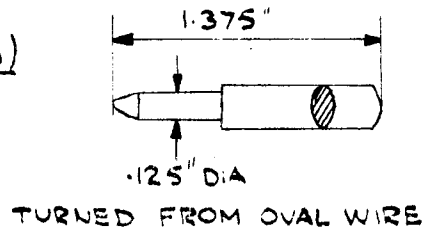
DOWEL PIN

COST SAVING
 10,000 = 89%
 100,000 = 89%



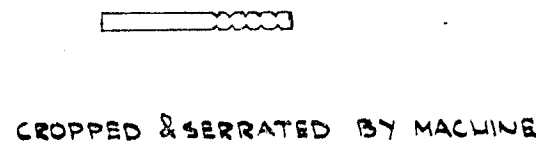
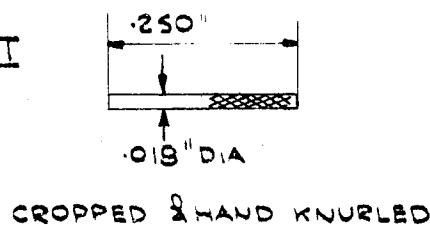
"BAT PIN" (PIANO'S)

COST SAVING
 10,000 = 25%
 100,000 = 48%



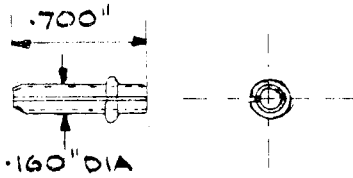
MOULDING INSERT

COST SAVING
 10,000 = 54%
 100,000 = 82%

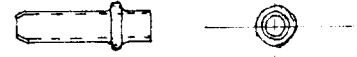


PLUG PIN

COST SAVING
 10,000 = 90%
 100,000 = 33%



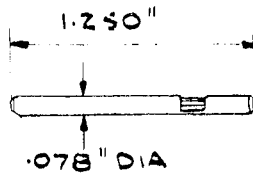
PROGRESSION PRESS TOOL
 FROM STRIP



HAND FORMED FROM TUBE

SPINDLE FOR
 MOULDED GEAR

COST SAVING
 10,000 = 18%
 100,000 = 38%



AUTO TURNED & KNURLED



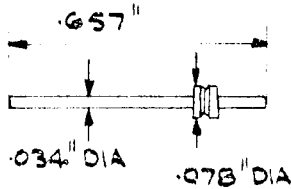
AUTO ECCENTRIC TURNED



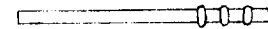
SECTION A-A

MOULDING INSERT

COST SAVING
 10,000 = 57%
 100,000 = 71%



AUTO TURNED



CROPPED & FLATTENED BY MACHINE

CASE STUDIES FROM WITHIN THE PLESSEY COMPANY

Introduction

A few case studies follow which are typical of the results of team studies within the Company.

Further examples will be circulated as they become available. One of the difficulties is the natural desire of Businesses in many cases to keep confidential the savings that they have achieved, both with regard to their competitors and customers, so that they are careful in selecting case studies which they agree to being included in this manual.

For this reason and because of the time limit of going into print with the new manual, the examples cited so far are fewer than intended.

Also, because this is intended to be a live document and provision has been made for the addition of case studies from time to time, Mechanical and Electronic examples are not segregated.

CASE STUDY No. 1

<u>Business</u>	Plessey Numerical Controls Ltd.	
<u>Unit Studied</u>	NC.22 Air Cooling System	
<u>Production Rate</u>	60 single 20 double per annum	
<u>Works Cost</u> (Before Study)		£
	Fan	35.20
	Fan Mounting	5.00
	Filter	1.87
	Securing Studs & Assembly	<u>0.31</u>
		<u>£42.38</u>

Date of Study April - May 1972

Background The NC.22 originated from an American Company, Allen-Bradley, and the equipment was anglicised and made under licence by Plessey Numerical Controls Ltd. The design had been in production for three years and other value engineering savings had been incorporated.

The air cooling system consisted of an electrically operated fan that passed ambient air through the cabinet to extract heat from the internal components. Air filters were used on both the inlet and outlet apertures and the fan was mounted in the lower part of the cabinet.

Two types of equipment were available, a single and a double cabinet, and the existing fan was large enough to accommodate the cooling requirements of the larger cabinet. The proposed change had a fan that met the cooling requirements of an existing single cabinet and an extra identical fan was used for the double cabinet.

Details of Study The cost of a fan for a particular system depended to a large extent on the back pressure of the complete system and the airflow requirements. If the back pressure could be reduced the fan costs to achieve the same airflow would be considerably reduced. The centrifugal fan used on the existing system was one of the most expensive types whereas if an axial or tangential fan were used the cost would be less.

To reduce the back pressure it was proposed that the outflow air filter would be dispensed with as the air only passed from inside the cabinet to the outside and the filter was not serving a useful purpose. One reason

Gross Saving/Year
£2,127

Implementation
£120

DOUBLE CABINET

Single cabinet saving £35.45 less second Fan and
Mounting £6.93 = £28.52

Gross Saving/Year
£570

Implementation
£100

Additional
Benefits

1. The number of filters changed in the field would be cut by 50%
2. Only one filter to install instead of two.
3. The smaller fan and the less airflow allows the system to operate with less audible noise.

CASE STUDY No. 2

<u>Business</u>	Plessey Numerical Control Limited	
<u>Unit Studied</u>	N.C. 1100 Module Rack	
<u>Production Rate</u>	100 per annum	
<u>Works Cost</u> (Before Study)	P.C.B. Connector Gold Plate (9)	£ 29.43
	Interface connectors on panel and harness	9.63
	Labour Wiring	15.06
	Wire, Screws etc.	2.00
	Assembly	7.23
	Inspection	5.04
		<hr/>
		68.39
		<hr/> <hr/>
<u>Date of Study</u>	December 1971 - March 1972	
<u>Background</u>	<p>The N.C. 1100 was designed by Plessey Numerical Control Ltd., as a low cost machine tool control system.</p> <p>Value Engineering and cost reduction exercises had been carried out and this work was continuing in an effort to maintain or reduce the works cost of the basic system.</p> <p>This equipment had recently been introduced into production and an initial batch of 10 units was almost complete and was to be followed by a further 50 units, after which full production of a 100 plus units per annum was envisaged.</p> <p>The actual number of modules used in the N.C. 1100 depended upon the number of axes and the type of option. The basic two axes system had six modules and nine was used as an average figure of modules for early production runs. The maximum number of modules possible eventually was 22. The nine module system consisted of the following equipment :</p>	
	<ul style="list-style-type: none"> 9 modules 250 wires 7 PCB connectors 1 x 47-way interface connectors 1 x 23-way interface connectors 2 x 41-way interface connectors 2 x 17-way interface connectors 	

Details of Study The use of a semi-automatic wire wrap machine was investigated for assistance with the system wiring instead of using the hand method as on the earlier units. This machine automatically located the terminal required and then found the next location when signalled by the operator.

With this system the number of wires completed (two ends) per hour increased from 41 to 110 and the inspection and test times were reduced considerably. This system required a more precise location of the terminations than previously necessary.

The existing P.C.B. 80-way Pye Ether connector contacts were gold plated and cost £3.27 each and by using the same connector with gold flash contacts the cost would be £1.40 each resulting in a saving of £1.87 per module.

The interface connector requirements were discussed with various suppliers, including Varalco who supply the present connectors. Connectors with long wire wrap termination were required to enable the wire wrap machine to be used. McMurdo connectors met these requirements and were supplied completely assembled, ready for use, with male and female connectors at £0.01 each way. The cost of the Varalco connectors used on the panel was £6.63 and the mating part on the harness £3.00, a total of £9.63. The McMurdo equivalent cost only £2.00 complete; a saving of £7.63 should result from each equipment.

Summary

Old Works Cost = £68.39

New Works Cost :

	£
P.C.B. Connector Gold Flash 9	12.60
Interface connectors, on Panel and Harness	2.00
Labour wiring	5.67
Wire, Screws etc.	1.50
Assembly	2.00
Inspection	1.53
	<u>£25.30</u>

Gross Saving/Year

Implementation

Additional
Benefits

1. Amendments to wiring can be incorporated in less time
2. A standard wire wrap termination is used.
3. More reliable electrical terminations.
4. Reduction of operator wiring errors.

CASE STUDY NO. 3

<u>Business</u>	Aerospace
<u>Unit Studied</u>	P.D.U. 100 Planet Gear Assembly
<u>Production Rate</u>	Initial order 50 per annum Potential order 130 per annum
<u>Works Cost</u> (Before Study)	Material £24.35 Labour & Overheads £33.68 <hr/> TOTAL £58.03 each <hr/>
<u>Date of Study</u>	December 1972
<u>Background</u>	<p>The Planet Gear Assembly had just completed development testing and was about to enter a limited production phase.</p> <p>The study was undertaken because the assembly had a long production cycle and was a potential holding item on the complete gearbox assembly.</p> <p>This was mainly due to bearing tracks which were ground and balls and cages assembled by a specialist supplier.</p>
<u>Details of Study</u>	<p>During the information phase it was found that as part of a previous gearbox re-design the speed of the Planet Gear Assembly had been significantly reduced, this enabled other bearing arrangements of a low load carrying capacity to be used.</p> <p>The gear cluster on the existing unit had been designed in two parts so that the bearing balls and cages could be assembled, but now these had been eliminated a one piece gear could be used. This made three dowels redundant as "transmit torque" function between gears was not required.</p> <p>The information phase highlighted the high cost of the shaft. This was attributed to the counter weight support arm. During the investigating phase it was found that by re-designing the counter weight the function "support counter weight" could be eliminated.</p>

<u>Summary</u>	<u>Old</u> (See Sketch)	Cost:	£58.03
	<u>New</u> (See Sketch)	Cost :	£21.35
		Saving/unit :	£36.67

Gross Saving/year : £4,760

Implementation cost : £1,050

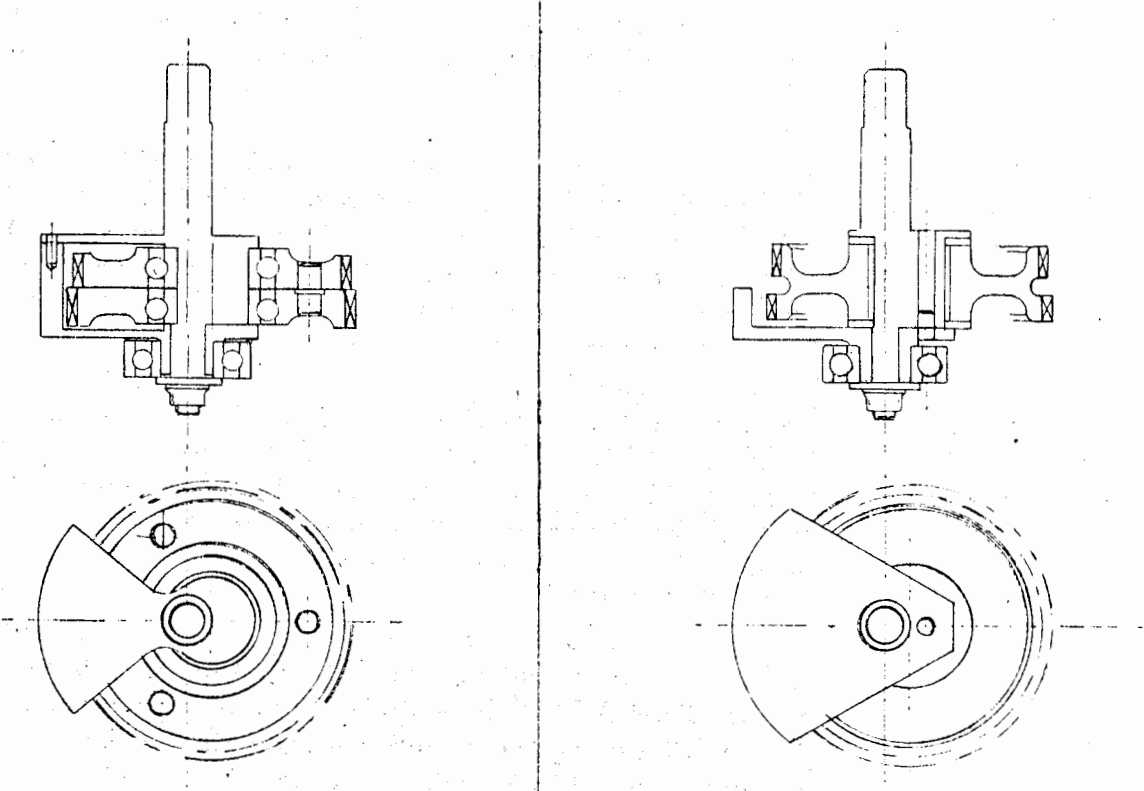
Additional Benefits

- 1. Specialist sub-contract work eliminated.
- 2. Gear tooth concentricity improved.
- 3. Lighter unit.

PLANET GEAR ASSEMBLY

OLD

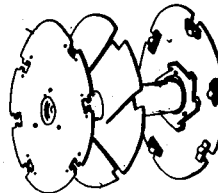
NEW



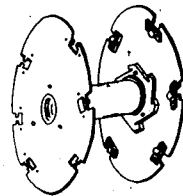
CASE STUDY NO. 4

<u>Business</u>	Plessey Avionics
<u>Units</u>	Tuning Unit. Turret Rotor Cheek Assembly.
<u>Production Quantity</u>	6,000 per annum
<u>Works Cost (Before Study)</u>	£10.77 each
<u>Date of Study</u>	July 1971
<u>Background</u>	The turret rotor assembly was the core of the tuner unit for a manpack radio.

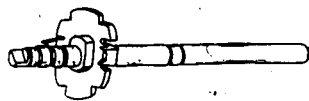
It consisted of four cheeks which formed guides into which two sets of six miniature printed circuit boards were mounted being held in place by screws located in tapped holes on the cheeks. (An additional cheek was used to form a screen). The cheeks were soldered to a mounting tube, and the tube was mounted on a coaxial shaft which carried a boss for connection to the drive.



ROTOR DT. CT.
ASSY



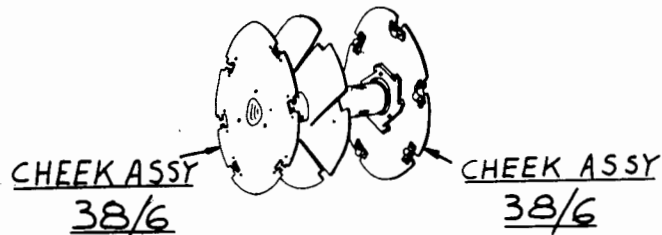
ROTOR OSC.
ASSY



SHAFT ASSY

Details of Study Each of the four cheek sub-assemblies cost 38/6d. (£1.93) and the four cheeks thus represented 80% of the cost of the overall assemblies.

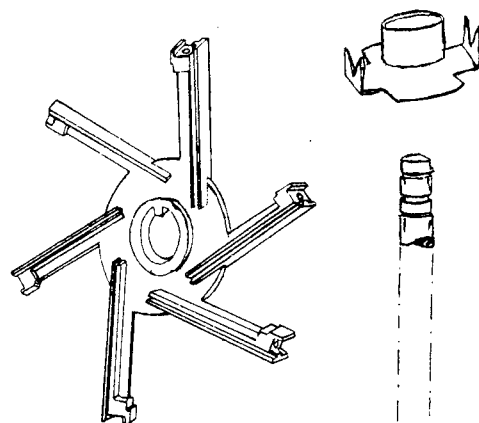
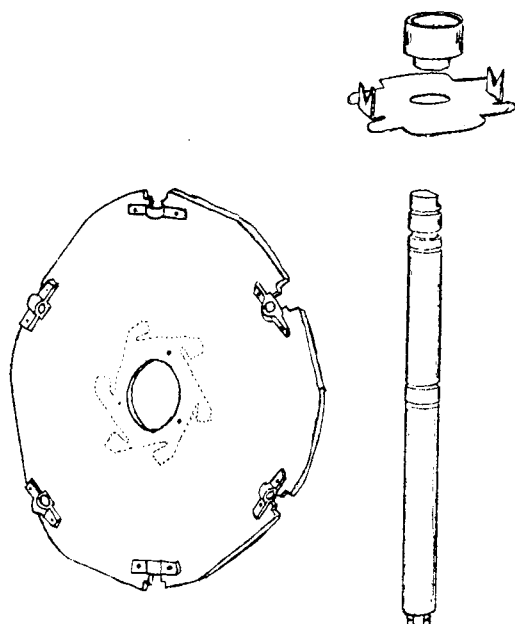
The cheeks were studied first and were each found to comprise 23 parts (plate, 6 special nuts, 15 rivets and one nylon moulding to form the inner guides for the P.C. boards near the centre.



It was found that a single mazak die casting could replace each cheek assembly, or an investment casting. Surprisingly the tooling for a die casting was estimated to be less expensive than the jigs and tools needed to manufacture and assemble the 23 components. Obviously reliability would be improved because of the elimination of assembly errors (loosening rivets etc.) and inspection, parts supply etc. were all improved.

A further saving was made because the die casting could include a more satisfactory central boss. This enabled the new cheek to be attached by a Loctite adhesive instead of soldering.

Similarly, on the shaft assembly an appreciable saving could be made by making a one piece die casting in place of the two part assembly of a turned part and pressed part, with the added advantage of the stop plate and boss being in one piece and needing less inspection.

OLDNEW

Cheek Assembly	£1.925 (23 part)	£0.095 (1 part)
<u>DT CT Rotor Assembly</u> (2 cheeks, tube, screen)	£ 5.29	£0.878
Osc. Rotor Assembly (2 cheeks & tube)	£ 4.53	£1.488
£		£
Shaft .33		.05 (New supplier)
Stop Plate .27 (Assy)		.01 (Die Casting)
Assy. .38		.38
Total Shaft Assy	£ 0.98	£0.44
TOTAL	£ 10.80	£2.796
Total for 6,000	£64,800	£16,776
ESTIMATED GROSS SAVING	£48,000	
Tooling	£2,882 (A)	£ 2,062
		Redrawing etc. £ 1,250
		£3,312 (B)

Net Implementation Cost (B - A) £430

EST. NET SAVING £47,500 on first 6,000

NOTE: Subsequent to the proposal above, there was further study in the light of reduced quantities. The casting was changed to an investment casting, raising the unit cost but reducing the tooling cost. Also the design detail was varied to stiffen the 'spokes' of the casting. The savings per unit will be only slightly reduced by this change and the basic concept remains unaltered.

CASE STUDY No. 5

Business Plessey Telecommunications (Australia)

Unit Studied 8501 Telephone Plinth Supply Circuit

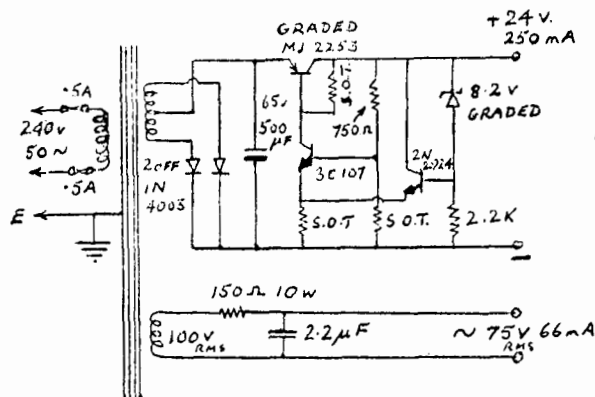
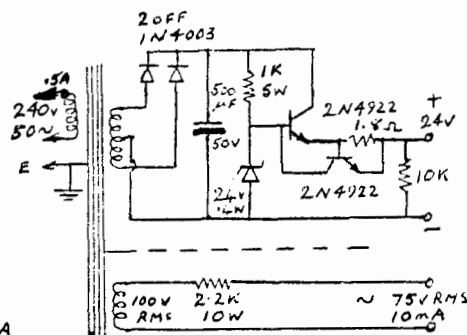
Production Rate 10,000 per year

Works Cost before Study \$A 8.27 (including assembly)

Date of Study April 1971

Background This equipment had been designed for the Australian Post Office. It had to meet their requirements which included short circuit protection.

Details of Study Only the circuit was studied at this stage. It was found that a simpler circuit could be expected to perform the same function. This involved changing from a series to a shunt regulator with active short circuit protection. One transistor was changed from PNP to a cheaper NPN and one was deleted.

OLD CIRCUIT (17 comps)NEW CIRCUIT (12 comps)Summary

Est. Cost of present Unit	\$A 8.27
Est. Cost of New Unit	\$A 5.91
Est. Savings per unit	\$A 2.36

Total savings on 10,000	\$A 23,600
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Implementation Costs :

Engineering, A.P.O. Correspondence	
Prototype test, Drawings etc.	\$A 1,000

Total Est. Net Saving 1st year	\$A 22,600
--------------------------------	------------

Additional
Advantages

- i) Positive Protection.
- ii) Components reduced from 17 to 12
- iii) Easier replacement of components
- iv) Less Maintenance
- v) No grading of components needed
- vi) No selection on Test of resistors
- vii) Labour content reduced.

CASE STUDY No. 6

<u>Business</u>	Hydraulics		
<u>Unit Studied</u>	Lift Pump		
<u>Production Rate</u>	12,000 per annum		
<u>Works Cost</u> (Before Study)	Material	.....	£3.10
	Labour	.....	£0.65
	Overheads	.....	£2.33
	TOTAL		<u>£6.08</u>

Date of Study June 1971

Background This unit has been in production for approximately three years. In this period it has undergone two team studies, and numerous lesser cost investigations. Some proposals have been incorporated and others are still awaiting implementation.

Details of Study During an investigation into the costs of the pump components the gears were taken as the initial items for examination. In order to find the purchase price of the forgings being used it was necessary to establish the relevant forging part numbers. It was found, however, that for the part numbers quoted on machining drawing there were no price records. From discussions with various people the forgings actually used were found. These forgings were in fact much larger than those quoted on the drawing. It was found that the "large forgings" had been used when this pump had started production as at that time the production programme was not sufficient to warrant laying down tooling. The production programme had in the meantime increased to reasonably reverse this decision but had been overlooked during normal day to day routine.

Quotations received by Purchasing established that substantial savings could be made in both the material cost and the machining cost, and because the quantity was high there was no charge for forging dies.

<u>Summary</u>	<u>OLD</u>	<u>NEW</u>
Cost of Forging	£0.76	£0.35
Cost of Machining	£1.18	£1.14
TOTAL	<u>£1.94</u>	<u>£1.49</u>

Savings	£0.44 each pump
<u>Gross Savings per year</u>	<u>Implementation Cost</u>
£5,280	Nil.

NOTE: This is a good example of a study which shows up a design which is perpetuated because of temporary reasons that no longer apply.

CASE STUDY No. 7

<u>Business</u>	Hydraulics	
<u>Unit Studied</u>	Gear Pump with Tank	
<u>Production Rate</u>	Variable currently 15,000/annum.	
<u>Works Cost</u> (Before Study)	Material	£2.86
	Labour	£0.65
	Overheads	£2.99
	TOTAL	<u>£6.50</u> each

Date of Study February 1972

Background The gear pump had been in production for some years, but had recently undergone design changes at the request of the customer. These design changes had created a situation where the complete unit could not be tested in the original manner. It had been decided to test the unit without the tank, assembling finally after test. This meant a reduction in test rate to half the previous value, i.e. the cost of testing had doubled.

Value Engineering was notified of the situation. The study was undertaken because :

1. The increase in test cost would seriously affect the profitability of the unit.
2. Emergency action was required as units were awaiting test.

Details of Study.

The study was carried out informally by the Value Engineer, Engineering Manager, Planning Engineer and the Assembly/Test Foreman. The basic facts were established as follows :-

1. The redesign of the tank had included an "Ever Open" breather.
2. This breather would point downwards during test.
3. The angular position of the vent valve when assembled to the test rig could not be changed as this would affect the position of the Relief Valve, causing difficulties for "intest" adjustment.

It was decided that to overcome the difficulties a cap should be held over the vent valve by a strap. This could easily be passed over the tank. The test rate was thus returned to the pre-modification level. During this investigation it was found that a torque requirement on the screwing in of the central stud retaining the tank was creating difficulties in assembling the stud to the cover. It was agreed that there was no real requirement for the torque tightening which was then deleted. Loctiting of the stud thread was incorporated to ensure the stud did not disassemble due to vibration.

Summary

OLD

Test Rate 2 per hour : Cost : = £1.12

NEW

Test Rate $3\frac{1}{2}$ per hour : Cost : = £0.64

Thus saving per unit : = £0.48

Gross Savings per year

£7,155

Implementation Cost

£105

CASE STUDY NO. 8

Business Hydraulics
Unit Studied Tandem Gear Pump
Production Rate Variable currently 20,000/annum

<u>Works Cost</u> (Before Study)	Material	£2.48
	Labour	£1.60
	Overheads	£6.00
	TOTAL	£10.08

Date of Study September 1970

Background This unit has been in production for about 4½ years. During this time it has been uprated due to new customer requirements. Further, a continuous Value Engineering surveillance has been maintained in addition to specific team studies. Numerous proposals have been accepted and some have already been incorporated.

Details of Study During the follow up to a team study the Foundry Manager was consulted on matters raised during the study. It was whilst in discussion with him that he made the suggestion to change the body material from LM.11 to LM.22. At the time of using LM.11 a considerable scrap rate was being incurred during machining of the body due to porosity in the casting. The change from LM.11 to LM.22 was expected not only to reduce the price of the casting but also to reduce the scrap rate on machining.

Summary

OLD

Casting Cost	=	£841.3 per 1,000
Scrap Cost @ 25%	=	£241.1 per 1,000
TOTAL	=	£1,082.4 per 1,000

NEW

Casting Cost	=	£758.8 per 1,000
Scrap Cost @ 10%	=	£ 96.4 per 1,000
TOTAL	=	£855.2 per 1,000
Saving	=	£227.2 per 1,000

Gross Savings per year

Implementation Cost

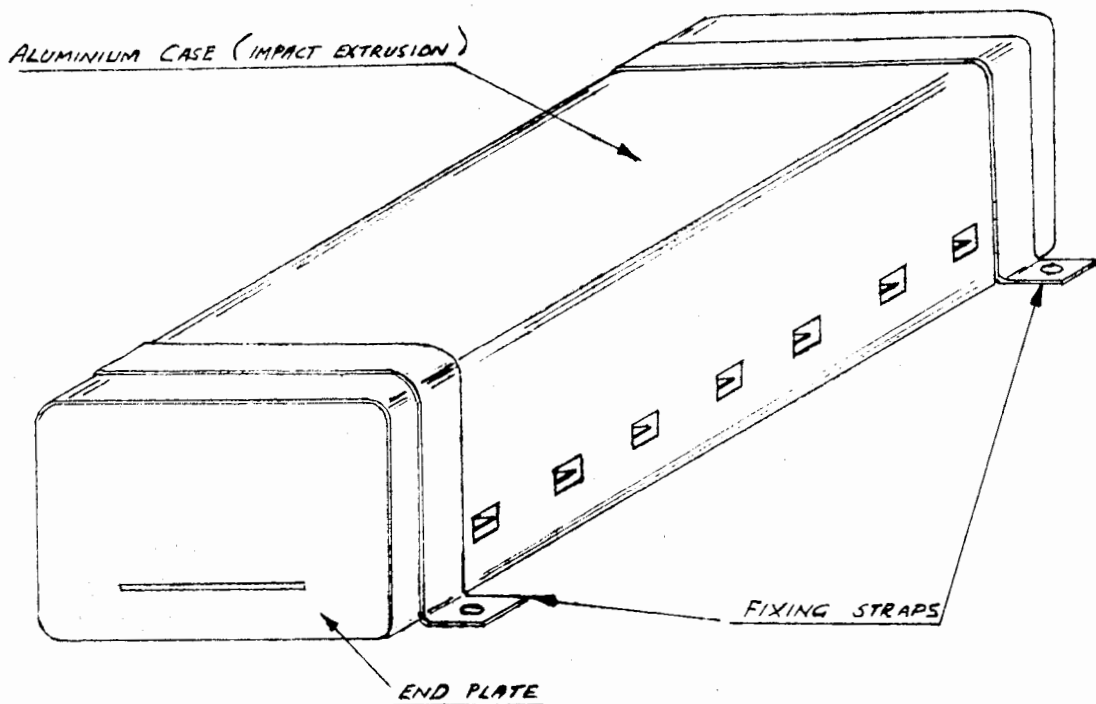
CASE STUDY NO. 9

<u>Business</u>	Wound Components Division, Titchfield
<u>Unit Studied</u>	Battery Operated 5 Point Gas Ignition Unit (Case only)
<u>Production Rate</u>	30,000 per year
<u>Date of Study</u>	October 1969
<u>Works Cost</u> (Before Study)	1/9d. (9p)
<u>Background</u>	<p>Original design conception, a printed circuit board and component assembly to be housed in a "Metal Can" (deep drawing and metal and plate) which would be attached to a cooker by fixing straps, "Metal Can" would need insulation (internal). By investigating other materials and methods an extruded P.V.C. section was designed providing a case into which the P.C.B. assembly was slid and trapped in position by two common end mouldings which also facilitated fixing to cooker.</p> <p>Separate insulation was no longer required. Fixing straps were no longer required.</p> <p>By varying the length of the extrusion it would be possible to cover 6 and 8 units without additional tooling costs.</p> <p>Best quotation for "Metal Can", made by impact extrusion technique, was 1/8d. (8½p) each - end plate 1d. (½p). each.</p> <p>Price of extruded case and end mouldings 1/3d. (6p) per set. In addition, by using bulk packaging and well designed assembly fixtures further costs would be avoided of at least 5d. (2p) per unit.</p> <p><u>Estimated Total Cost Avoidance</u> = <u>£13,500 p.a.</u></p>
<u>Additional Advantages</u>	<ul style="list-style-type: none"> i) Separate insulation no longer required. ii) Fixing straps no longer required. iii) Reduced Weight iv) Improved appearance.

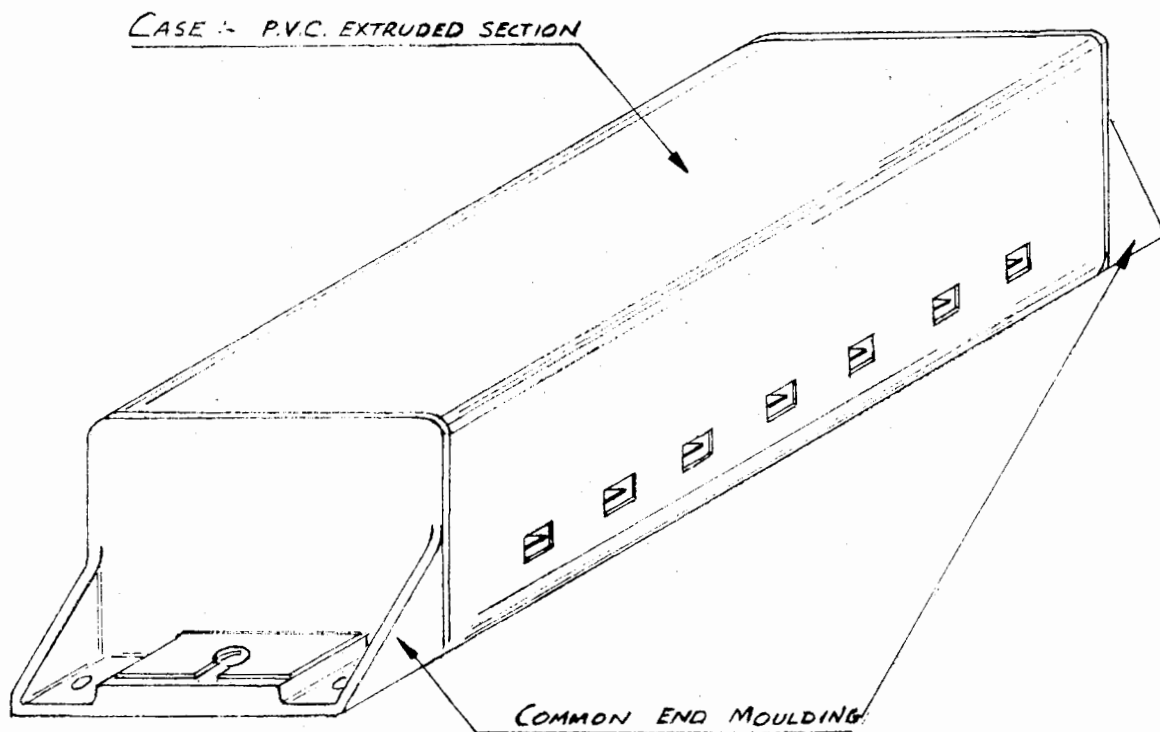
See Old and New Sketches on following page.

BATTERY OPERATED 5 POINT GAS IGNITION UNIT

OLD DESIGN



NEW DESIGN



CASE STUDY NO. 10

Business Interconnect (Resistors)

Unit Studied Switch Assembly

Production Rate 100,000 per year

Works Cost 4.21p.
(Before Study)

Date of Study June 1968

Background The assembly was basically a 2 amp., 2 pole, rotary action, on-off mains switch for panel mounting on TV receivers. The unit had been in production for 12 months at the time of the study and performance in the field was satisfactory.

Details of Study The Information Phase showed that there were three readily identifiable cost areas within the assembly: the switch, the bush and bracket and the spindle and stop plate. The switch accounted for 40% of the cost and the other two sub-assemblies 20% each.

Although it represented the highest cost area, the switch was not studied because its design had been approved to European Standards.

The bush and bracket were turned and pressed parts respectively in brass and steel which were rivetted together. Analysis of the functions of these parts showed that they did not need to be separate or necessarily in brass or steel. Attention was therefore given to producing these parts as a single piece bearing in mind that an electrical function "conduct current" was required in addition to the mechanical ones. This ruled out plastic mouldings, but discussion with a pressure die caster produced a component in Mazak in which only the thickness of the bracket needed to be increased to meet the mechanical requirements.

The cost of the casting was 0.55p. compared with 2.08p. and the tooling cost £370.

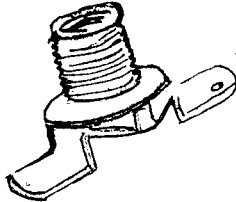
Similarly the spindle and stop plate were produced as separate steel parts and then rivetted. In this case a single plastic moulding was found to be capable of providing all the functions required and in addition provided a desirable insulating function as well. A Delvin moulding was obtained 0.74p. against 2.13p. with a tooling cost of £400.

Summary

OLD

1. Bush & Bracket Assy.

Turned and pressed parts
rivetted together.



2.08p.

2. Spindle & Stop Plate Assy.

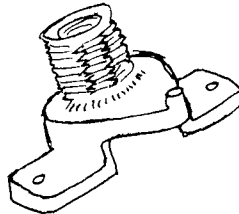
Turned and pressed parts
rivetted together

2.13p.

TOTAL COST 4.21p.

NEW

Single diecasting in
MAZAK



0.55p.

Single plastic moulding in
Delvin

0.74p.

TOTAL COST 1.29p.

SAVING/UNIT 2.92p.

Gross Savings/Year

£2,920

Implementation Cost

£770

Additional
Benefits

1. The new insulated spindle conformed to BS.415 (Safety Requirements for Mains Operated Equipment) and thereby increased the market potential.

CASE STUDY NO. 11

<u>Business</u>	Garrard	
<u>Unit Studied</u>	Zero 100 C/Balance Weight. 606/1/75138	
<u>Production Rate</u>	120,000 Units/annum	<u>£/1,000</u>
<u>Works Cost</u>	Material	156.08
	Labour	14.69
	Overhead	34.91
	TOTAL	<u>205.68</u>

Date of Study January 1972

Background The study was initiated by a request from Marketing to improve the design of the counterbalance weight by the following :

- i) To eliminate sagging of the weight in position on its P.U. arm.
- ii) To improve squareness of assembly.
- iii) To improve accuracy of setting.
- iv) To maintain or improve the performance.

Detail of Study The main area for improvement was the type of mounting used. The physical weight and styling requirement must remain unchanged. The costs showed that the mounting represented 2.89p of the 20.5 p of the total system.

Many alternatives were considered and models produced and performance checked. An improved system was derived that satisfied all functional requirements at 1.8p.

The lead weight, currently costing 7.8p, was circulated on enquiry and one quotation received was for 4.6p.

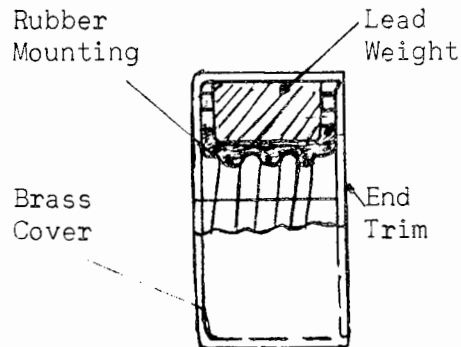
The brass cover purchased as a pressing and brushed grained and lacquered within Garrard was also circulated on enquiry. Quotations were received from a manufacturer of appliance control knobs for 3.9p. compared with the Garrard cost of 5.85p.

Similar reductions were obtained for the end trim.

Summary

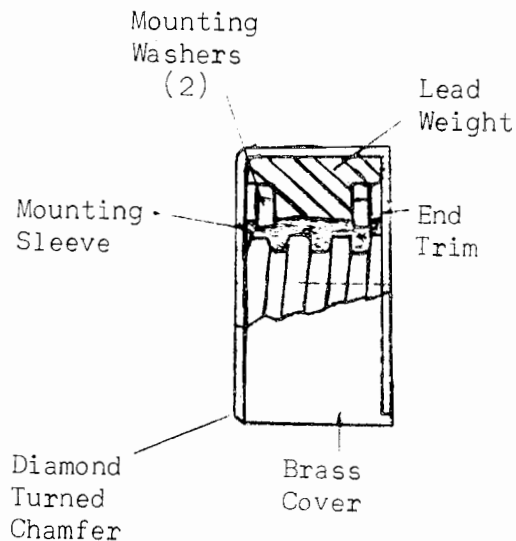
OLD

£/1,000



Lead Weight	78.30
Mounting	28.83
Cover	58.58
End Trim	27.24
Assembly	12.66
	<hr/>
	205.61
	<hr/> <hr/>

NEW



Lead Weight	40.60
Mounting	
Washers	12.10
Mounting Sleeve	6.00
Cover	39.00
End Trim	19.00
Assembly	16.88
	<hr/>
	133.58
	<hr/> <hr/>

ESTIMATED
WORKS COST £72.105/1000
SAVINGS

GROSS SAVINGS/YEAR

IMPLEMENTATION COST

£8,650

£2,545

Additional Benefits

- i) The improved design satisfied the requirements.
- ii) The overall appearance was improved by the diamond turned finish and chamfer.
- iii) The cost reductions shown were additional to the terms of reference.

CASE STUDY No. 12

Business Garrard

Unit Studied Zero 100 Control Paddles

Production Rate 120,000 Units per annum
3 Paddles per set.

<u>Works Cost</u>		£/1000 sets
Material	.....	55,55
Labour	.....	64.28
Overhead	.....	<u>163.78</u>
TOTAL		<u><u>283.61</u></u>

Date of Study December 1971

Background The 2100 unit is a recent introduction to the Garrard range of Record Players, occupying the top price position in the range. The main appearance styling is brass and aluminium.

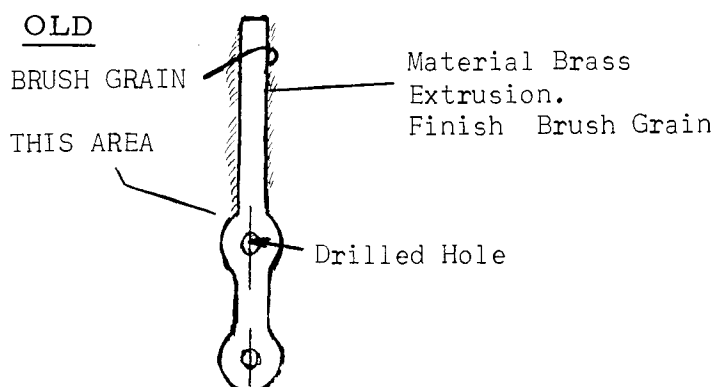
The paddles were produced from extruded brass in order to match the other brass features of the unit.

The brass paddles were milled from lengths of brass extrusion, drilled, brushed grained and lacquered. Damage rate was high during the machining operations and costly brush graining was necessary for salvage.

Details of Study It was quite evident that the Cost/Worth ratio was excessive by the fact that other units used moulded A.B.S. paddles costing £54.91/1000. Work carried out during the original design had shown that Brass colour, anodised aluminium paddles failed to colour match the brass components on the unit.

On consultation with suppliers a name plate manufacturer claimed that any shade of Gold Anodising could be done with their plant and produced samples to match the brass components costing £165.93/1000 sets. This permitted the deletion of all the brushing operations.

Summary



E.W.C.
1/1000

£283.60

NEW

Material	-	Aluminium	
Finish	-	Gold Anodise	
		No Brushing	£165.93

	SAVING/UNIT	<u>£117.67</u>
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GROSS SAVINGS/YEAR

£14,000

Additional Benefits

- i) Removal of Production of bottleneck caused by brush graining.
- ii) Reduced extrusion die wear.
- iii) Improved scratch resistant product.

N.B. Further consultation with the supplier resulted in the supplier offering to produce the following design complete:



Material Aluminium
Fully extruded
No drilling

E.W.C.
£/1000

111.77

ADDITIONAL PROPOSED SAVINGS	<u>£54.17</u>
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GROSS PROPOSED SAVINGS/YEAR

£6,500

<u>TOTAL SAVING BOTH PROPOSALS</u>	<u>£20,500/annum</u>
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CASE STUDY NO. 13

<u>Business</u>	Garrard	
<u>Unit Studied</u>	Voltage Changeover Facility	
<u>Production Rate</u>	589,000 Looms/annum	
<u>Est. Works Cost</u>		£/1000
	Material	95.58
	Labour	22.64
	Overhead	56.61
	TOTAL	<u>174.83</u>

Date of Study March 1970

Background The voltage change facility provides means of wiring to dual range motors for use at either :

- i) 100/130V. 60 H Z
- ii) 200/250V. 50 H Z

The changeover facility in the form of a changeover block permitting selection of voltage range by connecting links being positioned on pins connecting the coils of the motor in either series or parallel.

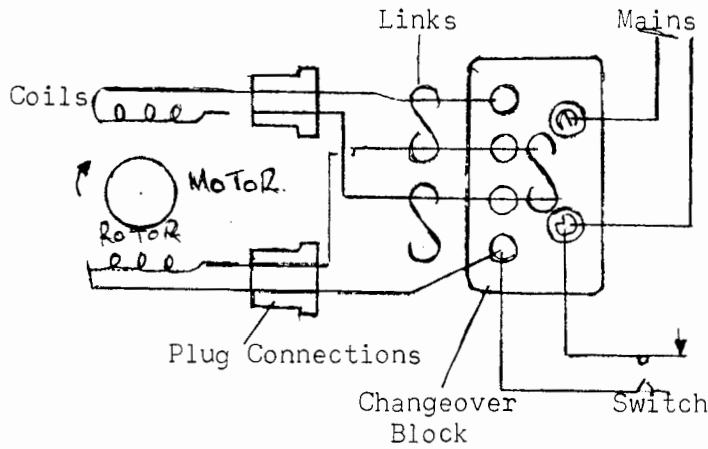
The changeover block used was a high cost area, using three stage hand soldered assembly operation.

Detail of Study The study was carried out at a V.E. training seminar.

It was noted that connection to the motor was by small 2 way plugs that were attached to the motor bobbins on the final record player assembly lines.

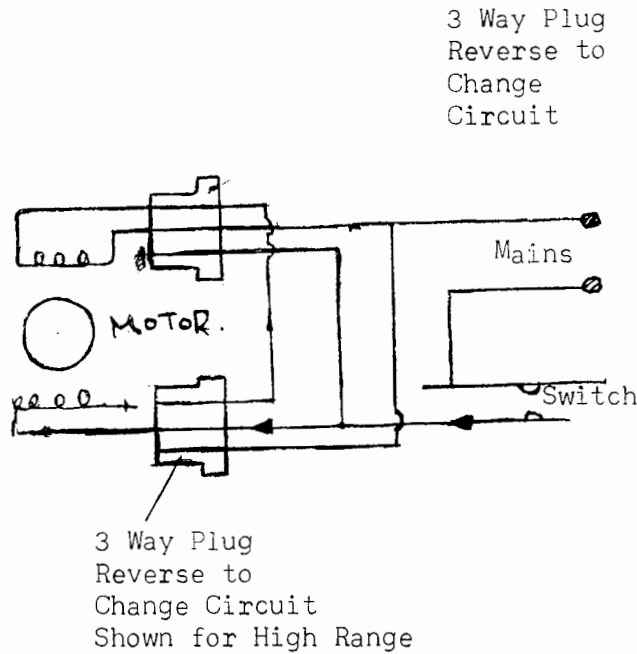
On consultation with vendors the manufacturer of the two way plug suggested using a three way system. This was taken up by the team and a simple plug in system completely dispensed with the changeover block.

OLD



	£/1000
Mains Material	95.58
Labour	24.47
Overhead	60.53
	<hr/>
	180.58
	<hr/>

NEW



3 Way Plug
Reverse to
Change
Circuit

	£/1000
Material	61.39
Labour	3.07
Overhead	6.62
	<hr/>
	71.08
	<hr/>

SAVINGS/
UNIT £109.48/1000

Gross Savings/Year

£64.400

Implementation Cost

£7,850

SECTION FIVE

SOURCES OF INFORMATION

One of the first hurdles to overcome in trying to improve the value of a design is to find a good source of information applicable to the particular subject in question.

Usually when an engineer sets out to achieve a function, mechanical (including pneumatic, hydraulic etc) he has a fair idea of ways in which to achieve it. On the other hand he may only know of one way based on past experience.

Information being sought in Value Engineering is therefore generally of two kinds, namely -

- 1) Specific information in a broadly defined field.
- 2) Information in an ill defined field on finding general solutions to a functional problem.

Specific Information in a Broadly Defined Field

1. Contact Specialists
 - a) Within Plessey .

Firstly there are specialists in numerous fields within the Plessey Company. Not only can they be found in our various Research Establishments such as those at Caswell, Roke Manor, Taplow Court etc. but also in the development laboratories attached to most of our businesses.

On a new project it is always worth discussing with another specialist on ways of achieving a solution to a functional problem, even if the engineer seeking the solution considers himself to be a specialist. It is surprising how often engineers do not know of the existence of particular specialists within the Company or if they do, how to find them.

There are several ways of finding out -

- i) In one's own business or in another Business on the site. Do not be afraid to ask the technical manager or chief engineer of the Business on site who else is working on a similar project in his area. There are numerous cases to illustrate this but one could be cited of a problem to which the solution was eventually to use electron beam welding. The Engineer concerned, and those associated with him, did not know that there was an electron beam welder being used on the same site, but in another Business, and that there was a lot of specialist information available, built up over four years.

ii) In other Businesses within the Company.
 Make use of either the old Plessey Product Directory (now out of print but available in many Business Stationery Stores) or the new one titled "Plessey - What we make and where we are". (Publication 2022/6/1) to find an area in which work is being carried out in the problems of interest. A phone call to the Secretary of the Technical Manager of the business or administrative manager of the Research Laboratory will lead to the specialist who may be able to help, either directly or by passing the call on to someone more directly concerned.

b) Outside the Company

There is a fund of information, most of it freely available from specialists in Trade Associations and Suppliers and from Journals, Journals which give condensed extracts from Journals etc.

In trade associations one could cite the various metal development associations (Zinc D.A., Aluminium D.A. etc) P.E.R.A. and numerous others.

For specialists among suppliers one can scan the few references given in this manual, consult the Business Purchasing staff or the Value Engineer in the Business. Similarly for advice on Journals one could go to the Librarian, or the Value Engineer. In this field one should not forget the journals of the professional institutions.

2. Search publications

As mentioned above, search journals. If it is a new subject seek advice from a central 'specialist' source of information.

Information on an Ill Defined Field

If seeking alternative ways of attacking a broad functional problem a similar approach is adopted as for specific information but it may be harder to define the specialist whom one is seeking or the journal in which to search.

Nevertheless, a discussion with a specialist in a similar field is nearly always helpful in leading to other new ones in the same field who can suggest fundamentally different approaches to the problem using a different area of technology.

Also it is always most creative, if a major project is concerned, to hold a discussion with a number of specialists from different fields.

In this area again the value engineer can often be useful in leading the way to people likely to be helpful. Because you can see only one possible way to approach the problem is all the more reason for finding an alternative.

Find out how competitors tackle the problem. The Japanese are generally expert at this. They do not copy, as they used to, but select the best ideas, combine, modify and add their ideas to produce a better solution in many products. We could learn much from this technique in many areas, even in some of those in which we consider ourselves to be leaders.

The main thing is, do not be afraid to ask. No one can be a specialist in all fields and even another specialist in the same field will have new approaches and new ideas.

Apart from the above suggestions, this section of the Reference Manual is largely a do-it-yourself section. A few pages follow in which you yourself can enter useful names, addresses and telephone numbers of specialists likely to be helpful to you.

NOTES

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