The Design of Light Duty Electrical Contacts

ECONOMICS OF MANUFACTURING AND ASSEMBLY METHODS

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The performance of any type of electrical equipment can be greatly affected by the care given to the specification and design of the contacts. Many metals and alloys are available, together with an increasing number and variety of methods of contact manufacture and assembly, but economic factors as well as metallurgical and mechanical considerations must naturally be taken into account in arriving at the optimum design.

This article is concerned only with the range of electrical contacts broadly described as operating on light duty. Concise definition of this type of loading is not a simple matter, but in general it may be taken to cover contacts handling currents measured in milliamperes rather than amperes, at voltages ranging up to 250. Such conditions obtain, of course, in a wide variety of relays, signalling devices and electrical instruments in which operation is sensitive and possibly infrequent, but reliability is of first importance. In designing such contacts—particularly for loads at the lower end of the range—the principal requirement is the maintenance of a low and stable contact resistance. Generally speaking, the extent to which the contacts have to withstand electrical or mechanical wear is of secondary importance (although in some cases of very high frequency of operation the wear problem does arise) while the low power to be handled makes electrical or thermal conductivity of little significance. It is in this field that the platinium metals and certain of their alloys, together with some alloys of gold, comprise the only suitable contact materials for efficient operation on account of their freedom from the type of oxide or sulphide films which, if present, would lead to high values of contact resistance. (It must be understood, however, that slight surface films may still be present even on the most corrosion-resistant of the platinum metals, these films consisting generally of adsorbed gases or of dust or organic matter.)

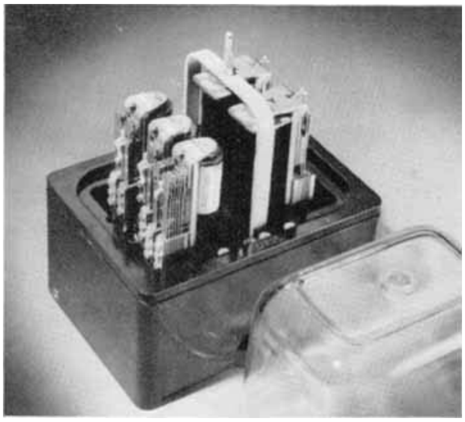
The Platinum Metals as Contact Materials

Apart from rhodium, which is only used as an electrodeposit—and then mainly for sliding rather than for make-and-break contacts—the two platinum metals used either unalloyed or as bases for alloys with other metals are platinum and palladium.

Platinum is tarnish-free at all temperatures up to its melting point. In the form normally used for contacts its hardness of 65 VPN (annealed) compares favourably with silver which is widely used for contacts, particularly in the medium duty range. It is ductile and malleable and lends itself to the manufacture of practically all of the required contact forms.

Palladium, which has a hardness of 40 VPN (annealed), may be considered as tarnish-free at temperatures up to 400°C; at this temperature it starts to form a brown oxide, which later dissociates at about 800°C. This is seldom of consequence from the point of view of contact behaviour, although it must be taken into account if the method of manufacture or assembly of the contacts demands a brazing operation. Apart from this, palladium lends itself to manufacture of contact

Electrical contacts that are required to control small currents at low voltages—as for example in many small relays, sensitive switches and measuring instruments—must generally be designed in one of the platinum metals or their alloys in order to ensure the maintenance of a low and stable contact resistance. This article discusses the design of such contacts to give optimum performance while ensuring that the costs of the assembly are kept as low as possible.



parts as readily as platinum. However, under corrosive conditions it behaves less satisfactorily than platinum and there is some evidence of its tarnishing in the presence of high concentrations of sulphur compounds. Its lower price (roughly one-fifth that of platinum for a given volume) is still a positive incentive towards its use, but because of the risk of slight tarnish it is generally avoided in very sensitive applications.

The hardness of platinum can be increased by alloying—for example with iridium, ruthenium or nickel. The iridium-platinum alloys remain tarnish-free at high temperatures; the 4 per cent ruthenium-platinum alloy is tarnish-free, although the 10 per cent ruthenium-platinum and the 8 per cent nickel-platinum alloys oxidise at higher temperatures.

Copper, silver and ruthenium are used as alloying metals with palladium. The 40 per cent copper-palladium alloy has a hardness (annealed) of 145 VPN, while 40 per cent silver-palladium has a hardness of 95 VPN. These additions—which considerably reduce cost—do not materially affect the tarnish-resistance of palladium in normal atmospheric conditions, although they reduce its resistance to attack under corrosive conditions. Less common is 10 per cent ruthenium-palladium with a hardness of 160 VPN.

The properties of the principal light duty contact materials, together with details of the forms in which they are available, are set out in the table on page 44.

It is not, however, the purpose of this article to discuss the selection of one of these materials to meet a particular set of electrical conditions; this aspect of contact specification has been dealt with in a number of papers and articles (see, for example, Hunt, *Platinum Metals Review*, 1957, **1**, (3), 74–81). The present article seeks rather to draw attention to the factors involved in the design of electrical contacts for economical manufacture, and to give some little guidance in arriving at the optimum combination of material and assembly method for large-scale production.

The Design of Contacts

One characteristic of contacts in the light duty range is that the mechanical force available between the contacts is usually small, while the limited overall size of the apparatus usually makes it practically impossible to introduce much wiping action on closure of the contacts. Thus mechanical breakdown of any surface films present is generally not possible. The choice of the correct configuration of contact head can, however, often help to overcome this problem. For light duty

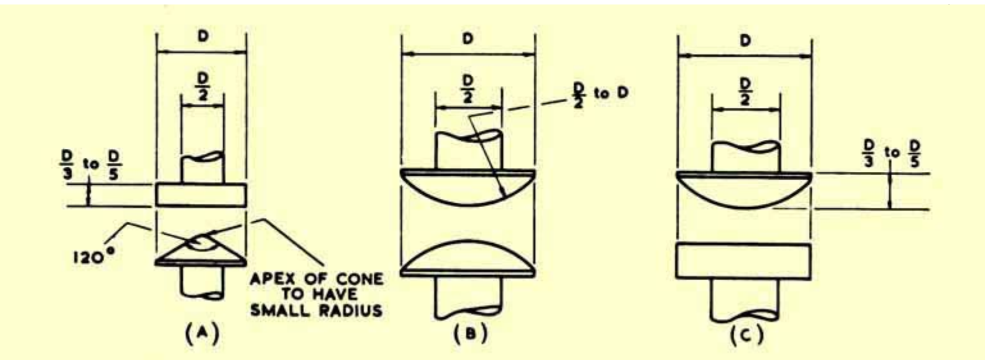
Properties and Availability of Light Duty Contact Materials

Material	Specific gravity	Vickers hardness (annealed)	Electrical conductivity per cent IACS	FORMS IN WHICH MATERIAL CAN BE MANUFACTURED: Headed rivets	Turned rivets	Composite contacts or screws	Contact bi-metal	Electro-deposits
Platinum	21.3	65	15	x	x	x	x	x
10% Iridium-platinum	21.6	120	7	x	x	x	x	
20% Iridium-platinum	21.7	200	5.7		x	x		
25% Iridium-platinum	21.7	240	5.4		x	x		
4% Ruthenium-platinum	20.8	130	5.7	x	x	x		
8% Nickel-platinum	19.3	175	6.4	x	x	x		
Iridium-ruthenium-platinum	20.8	310	4.4			x		
Palladium	11.9	40	16	x	x	x	x	x
40% Copper-palladium	10.4	145	4.9	x	x	x	x	
40% Silver-palladium	11.0	95	4.0	x	x	x	x	
10% Ruthenium-palladium	12.0	160	4.8	x	x	x		

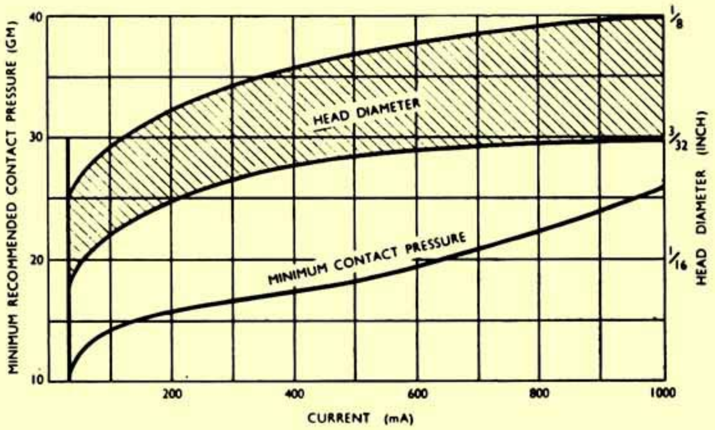
contacts the three combinations of contact shape shown below are recommended.

The conical/flat combination (A) is recommended when the available contact force is particularly low, since the extremely small area of contact ensures the highest possible contact pressure. Attention should be paid to the radius at the apex of the cone, and the included angle of the cone should be at least 120 degrees. The current-carrying capacity of such contacts is severely limited to a few milliamps only.

Where contact force is not so limited, the choice lies between the hemispherical/hemispherical and the hemispherical/flat combinations, (B) and (C). In either case the radius of spherical curvature is extremely important and experience shows that this should be between half and one times the head diameter, as shown below. Of the two, the



Recommended head configurations and proportions for light duty contacts



Recommended head diameter and minimum contact force for hemispherical/hemispherical or hemispherical/flat combinations (note false axis)

hemispherical/hemispherical combination is to be preferred since it provides the highest contact pressure. If the overall design does not permit sufficiently accurate contact alignment in the closed position, it is better to employ the hemispherical/flat combination. On no account should two flat contacts be used together.

The use of two hemispherical contacts has commercial advantages; stock-keeping is simplified and larger numbers in one type can be ordered.

Head Diameter

Where available contact force is so small that it is necessary to employ the conical/flat combination, a head diameter between 0.040 inch and 0.062 inch will be adequate. Where the hemispherical/hemispherical combination or the hemispherical/flat combination is employed the head diameter should be within the hatched area of the diagram above – that is between 0.062 inch and 0.125 inch in diameter according to the current handled. A larger diameter can of course be employed, but this may lead to unnecessary usage of noble metal.

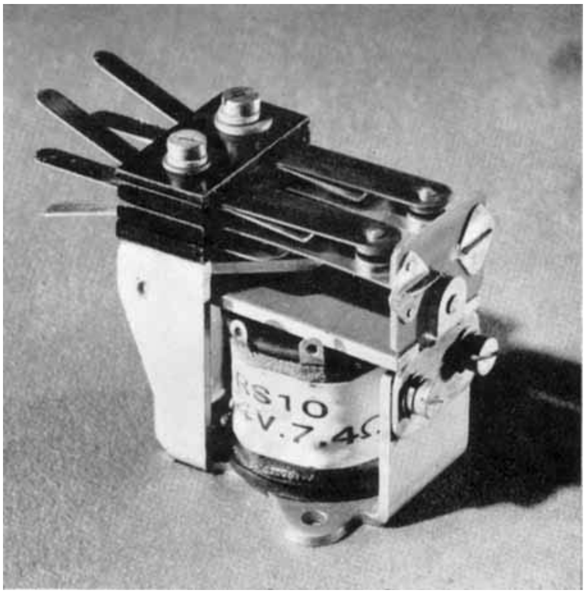
Contact Force

For any pair of contacts with a film-free surface, the effect of increasing the contact force, within certain limits, is to reduce the contact resistance and so increase the current that can be carried for a given IR drop. There is therefore a broad relationship between the current carried and the minimum contact force required.

Where it is necessary to use the conical/flat combination the device can seldom be designed to give a specified contact force; rather advantage must be taken of whatever limited contact force is available and the rating of the contacts decided accordingly—generally empirically. Where either the hemispherical/hemispherical or the hemispherical/flat combination is employed the contact force must be specified according to the required current-carrying capacity of the contacts. The minimum contact force for platinum metal contacts carrying up to one amp is also shown in the curve above. It is stressed that the values of contact force given by the curve represent minima. They can, with advantage in terms of reliability, be increased by a factor of two or three. Excessive force must be avoided since this will cause undue mechanical wear and so curtail the life of the contacts.

Forms of Contact and Contact Assembly

The small contact rivet which is the most widely used form of light duty contact is most economically manufactured by heading or cold forging on high-speed machines. In this process a short length of wire of the required shank diameter is cropped off and one end of



An example of the use of 40 per cent silver-palladium rivets is found in this light duty relay by Waymouth Gauges & Instruments Ltd

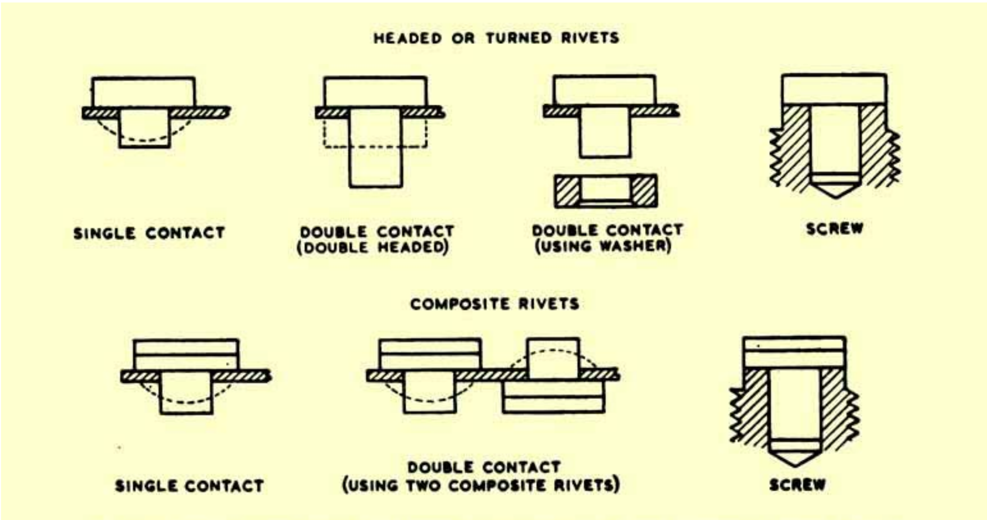
the cropped wire is then cold forged into the contact head. Rivets made this way have a hard head and a comparatively soft shank, which is an ideal combination from the point of view of long life and ease of riveting.

As can be seen from the table, the majority of the platinum and palladium alloys in general use as contact materials are suitable for heading, although it is essential to keep the proportions of the rivet within certain limits, depending to a large extent on the metallurgical properties of the contact material specified.

Rivets having the proportions shown on page 44 are ideal for heading and can be produced from all the contact materials shown as headable in the table. These recommended proportions also offer a good compromise between the sometimes conflicting requirements of economy of noble metal, electrical efficiency and mechanical strength.

Heading offers two economic advantages: not only is the heading process fast but it produces no scrap. Manufacturers of contacts generally offer standard ranges of headed contacts from stock; where non-standard contacts are required it is usually necessary to order a minimum number (typically 5,000) if they are to be made by heading.

If smaller numbers of non-standard rivets are required, or if the proportions of the con-



Types of riveted and force-fitted assemblies using solid and composite contact rivets

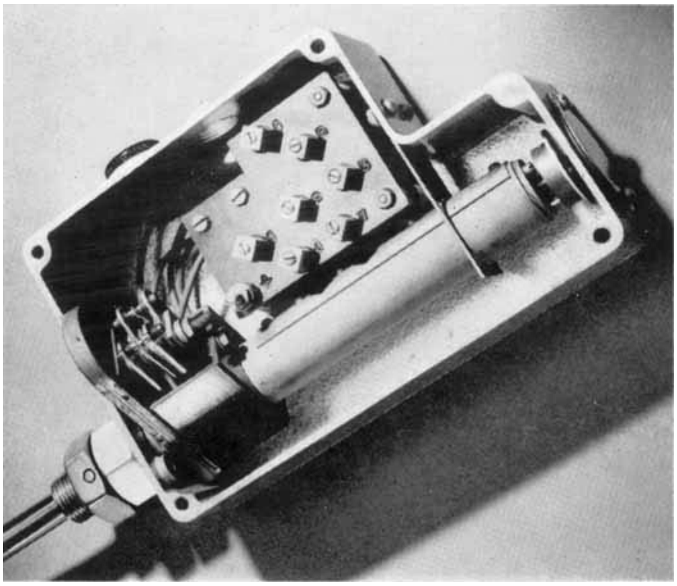
tact material rule out heading, the rivets must be produced by turning. In comparison with heading, turning is slow and produces swarf which must be returned for refining. Moreover, unlike the headed contact, the hardness of the head of a turned rivet is the same as that of the shank.

The use of composite rivets, in which a disc of noble metal is brazed to a base metal backing, is not always justified economically for contacts of 0.125 inch diameter and below, unless a very long shank is required. This is particularly true with palladium and palladium alloys because of their lower intrinsic cost. Such construction is, however, essential if the contact material is too hard to be riveted, as for example with more complex alloys such as iridium-ruthenium-platinum, or is of very high cost. The backing material employed for composite rivets is normally copper, and the backing should preferably be designed for production by heading. Here again contact manufacturers often have available a standard range of composite rivets with platinum and palladium alloy heads. Turned backings will of course be necessary for special shapes, but will result in an increase in cost.

Contact screws are required for certain applications, particularly where linear adjustment of position of one contact is necessary. They comprise a base metal screw carrying the noble metal contact at one end. Such contact screws can be designed for manufacture by force fitting (of rivets or cropped wires), by welding or by brazing. An electrodeposit of silver is sometimes specified on the body of the screw to improve *its* contact with the assembly into which it is fitted. The manufacture of contact screws generally demands a high order of precision which is reflected in their cost.

Welded and Brazed Assemblies

Many of the platinum metals lend themselves to direct resistance welding on to contact supports. A variety of techniques is employed: for example, discs of platinum or iridium-platinum can be resistance welded on to certain steels by forming a projection either on the reverse side of the disc or on the support. In another technique, employed by some large-scale manufacturers of telephone relays, platinum wire is taken from its reel, butt-welded on to the contact support and cropped, leaving the support with a small cylinder of platinum attached to it at 90 degrees. A second operation in a hand



In this regulator thermostat, manufactured by the Rheostatic Company Limited and used in relating the water temperature of central heating systems to the outside air temperature, double rivets of 10 per cent iridium-platinum move between two base metal screws fitted with contact discs in the same alloy press forms the wire into a contact head.

Discs of contact material can also be attached to the contact support by low temperature brazing, using a silver brazing alloy such as Easy-flo (BS 1845 Type 3) which has a melting range of 620 to 630°C. Unfortunately, this brazing temperature softens the support so that if a material is used which will not respond to heat treatment (for example, nickel silver or phosphor bronze) the designer must expect the support materials to be in the soft condition. With heat-treatable support materials such as beryllium-copper it is possible to harden the support after the brazing operation, provided that care has been taken during brazing to prevent irreparable metallurgical damage to the spring alloy.

Assembly Techniques

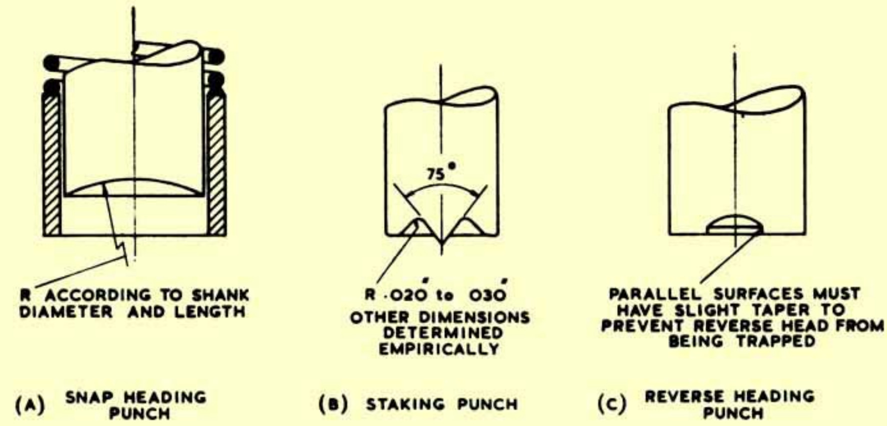
A number of different methods are available for attaching contacts to their supports. Suitable techniques for riveting, force fitting and brazing are briefly outlined below, but in practice these may be varied extensively to meet special requirements.

Riveting

By far the most widely used and the cheapest method of assembly is the riveting of a contact to its blade. Despite its simplicity considerable care should be taken in this operation as poor riveting can lead to premature failure, either electrical or mechanical, of the assembly. The hole into which the contact is to be riveted should be given a diameter 0.004 inch larger than the nominal diameter of the shank, and should be burr-free on the side against which the contact head is to fit, since the presence of a burr can prevent the back of the head from making contact with the support. A slight countersink on the same side may also be provided. If the rivet is to be double-headed, that is, if a second head is to be formed from the shank on the reverse side of the support, both sides must of course be burr-free.

During the riveting operation the head should be supported in a die which must be recessed to match accurately the profile of the head. Failure to take this step will cause indentations in the head after assembly.

A variety of forms of riveting punch can be used, some of which are shown below. If the head is required on only one side of the blade the snap-heading punch or the staking punch can be employed, the staking punch being of advantage when the length of shank available for riveting is short. A spring-loaded sleeve, shown in sketch A, is strongly recommended with either type of punch in order to press the blade firmly against the rivet



Forms of punch for the riveting of light duty contact rivets before closing and to correct errors in the angle of presentation of the blade to the punch.

A toggle press is generally used for this type of work. A spin/hammer riveter is recommended with thin supports if the fixing hole is near the edge of the blade, because of the stress set up in the material by conventional riveting.

If a double head is required, a reverse-heading punch, shown in sketch C, must be used, having a recess with the precise head form required for the reverse side. A slight taper must be provided on any parallel surfaces to prevent the newly-formed head from sticking in the punch. With thin blades a spin/hammer riveter or some similar machine is essential, although orthodox press techniques can generally by employed with thicker blades.

It is essential that the shank of the rivet swells in the hole during riveting and so grips the support firmly; it is not sufficient to rely on the "formed over" metal on the riveted side. With the shank correctly swollen there is no risk of lateral movement of the rivet in operation and sound electrical connection with the support is ensured.

The length of shank is important. For single heading the recommended shank lengths for blades of various thicknesses are given in the table. For double heading, the length of shank must be calculated from the volume of the required head. In practice a shank slightly longer than the theoretical length is normally required to allow for the metal used to fill the hole as the rivet swells.

Force Fitting

Contact screws can be produced by force-fitting a rivet into a suitable hole in a copper or brass screw. For economy and reliability in this type of assembly the drilled holes that are to receive the contact shank should be held within $+0-0.0005$ inch of the nominal diameter and should be not less in depth than $1\frac{1}{2}$ times the shank diameter plus about 0.030 inch. A slight lead-in at the mouth of the hole is desirable, and the face of the screw

Recommended Shank Lengths for Single Headed Assemblies

Thickness of contact support (inches)	Recommended shank length (inches)
Up to 0.008	0.025
0.009–0.013	0.035
0.014–0.018	0.040
0.019–0.023	0.050
0.024–0.033	0.060
0.034–0.038	0.070
0.039–0.048	0.080

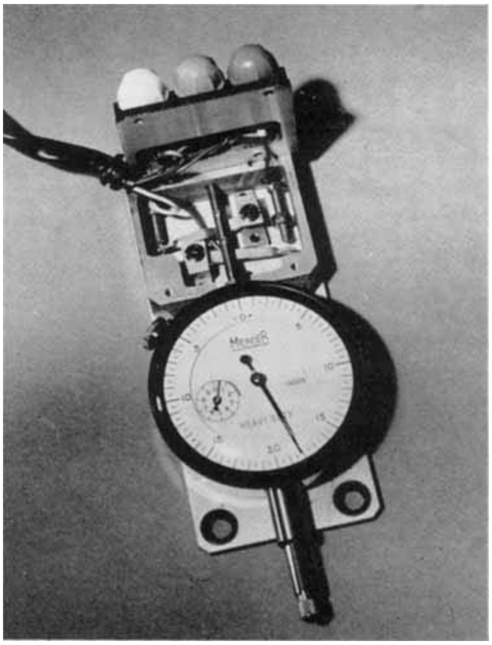
against which the underside of the contact head is to rest should be free from machining burrs. A punch designed to match the contours of the rivet head should be used, with a conventional toggle press.

An important point arises in the manufacture of screws to be force-fitted with headed rivets. If the overall length is subject to a wide tolerance, it becomes impossible to employ a toggle press working on a set stroke. Instead a hydraulic press or a toggle press with a spring-loaded attachment must be used. Either method leads to an increase in the cost of assembly.

Brazing

A widely used technique for making composite contact assemblies, such as fitted screws, is the low temperature brazing of a disc of contact material to its base metal backing. For mild steel, brass or copper, Easy-flo silver brazing alloy is normally recommended, with a conventional low temperature brazing flux.

The surface of the support to which the contact facing is to be attached must be free from burrs and turning pips, but too high a finish must be avoided. For small runs torch brazing is generally used, with a billet of brazing alloy whose volume is such as to produce a joint thickness after assembly of



The 10 per cent iridium-platinum alloy is used in this electric dial gauge by Thomas Mercer (Air Gauges) Limited. The moving contacts consist of rivets fitted into brass arms: the fixed contacts comprise fitted screws

about 0.002 inch. For larger runs the assemblies can be furnace brazed with pre-placed discs of solder, generally 0.003 inch thick and having the same diameter as the contact discs, which must be located on the support during the brazing operation by means of graphite jigs. Induction brazing can also be used, but with light duty contacts it demands special techniques because of the small component size.

Machining of brazed assemblies of this type may be necessary if the overall tolerances on the assembly are close because of the possibility of slight eccentricity or tilt of the disc in relation to the screw.

Economics of Contact Design

The platinum metals are costly, so also are certain of the techniques for manufacturing contacts from them, particularly those that produce scrap which must be refined. If, therefore, the cost of a light duty contact assembly is to be kept as low as possible, attention should be paid to the following points:

(*a*) The material chosen should be the lowest in intrinsic value that will operate satisfactorily under the specified conditions. In comparing costs, account must be taken of density as well as of price per unit weight.

(*b*) The contact should not be larger than is necessary for the specified electrical and mechanical conditions, and unnecessary thickness of contact material should be avoided.

(*c*) Where rivets are required, "headable" materials should always be specified in preference to "unheadable" materials, and the proportions of the rivet should be such as to permit easy heading.

(*d*) Tolerances on contact dimensions should not be so close as to demand special manufacturing techniques, but on the other hand the tolerance on backings should not be so wide as to reduce the speed of assembly or to demand special assembly techniques.

(*e*) The use of two hemispherical contacts in each pair is to be preferred on grounds of economy to one hemispherical and one flat. Not only are hemispherical contacts slightly cheaper than equivalent flat contacts but larger numbers in one size can be ordered, thus additionally reducing the cost per contact. Where relatively small numbers are required the use of one type of contact instead of two may make it economic to manufacture the contacts by heading instead of by turning.

(*f*) In many cases more than one method of assembly should be considered. When comparing two or more such methods consideration should be given not only to the cost of making prototype quantities but to the economics of production quantities. The cheapest method of making prototypes is sometimes the most expensive method of making large numbers of components.