Electrical Contact Materials for Light Duty Applications

EFFECTS OF OXIDE FILMS ON PERFORMANCE

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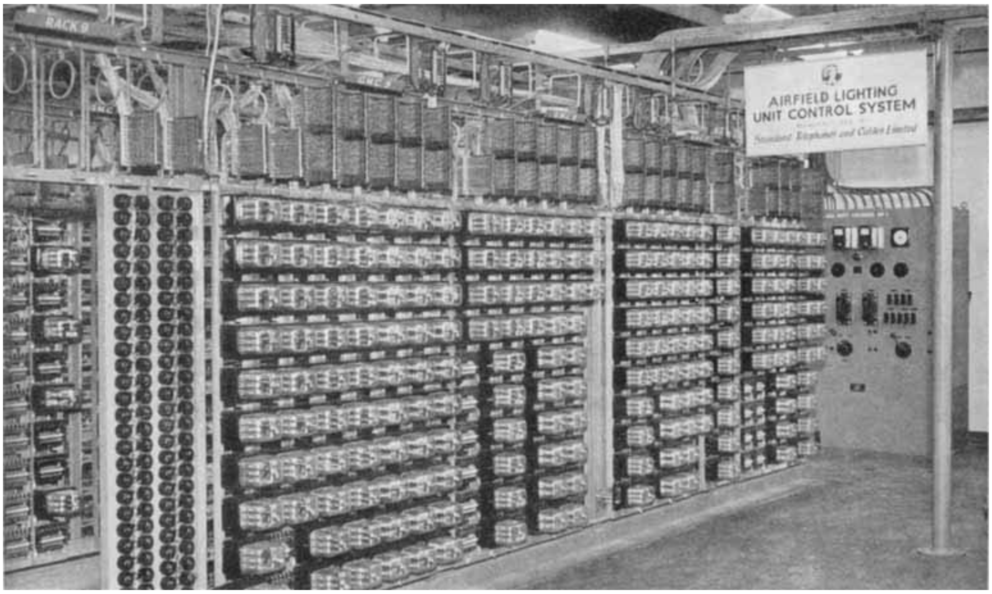
The successful operation of practically every type of electrical apparatus involves the opening and closing of a circuit by means of contacts. The duties imposed on the contacts may vary widely, but in almost every case the essential requirements can be reduced to three simple functions: the contacts must successfully close the circuit, must carry the current for the required period without overheating, and must interrupt the circuit without undue deterioration, repeating this cycle for the required number of operations.

The performance of these functions, even under light electrical loading, may bring into play exceptionally high electrical stresses, as well as excessive temperatures and complex chemical reactions at very localised points on or between the contacts, and much work remains to be done before a full understanding of contact phenomena is achieved. Certain generalisations have, however, been established, while practical experience with a number of metals and alloys commonly employed as contact materials has permitted working theories to be developed and has enabled broad recommendations to be made to meet a given set of conditions.

As is well known, when certain critical values of voltages and current are exceeded,



Part of the Ground Movement Control Installation at London Airport, installed by Standard Telephones and Cables Limited. Platinum is used as the contact material in many of the enclosed relays a stable arc is formed when the circuit is interrupted. These "critical values" are much less definite than is often supposed, and are much affected by the humidity of the atmosphere and by the presence of oxide or other films on the contact surfaces, as well as by the nature of the contact material. Moreover, it is often the case that while a stable arc cannot be maintained in a particular set of conditions, a transient or short-duration arc may be formed on interruption. Concise definition of "light duty" contacts is thus difficult, but in general it may be considered that the description can be applied to contacts handling currents measured in milliamperes rather than amperes at voltages ranging up to 250, or, of course, to those handling a few amperes only at lower voltages, provided that a load of the order of 50 volt-amp. is not exceeded.

In these conditions in DC circuits a phenomenon known as "fine transfer" or sometimes as "bridge erosion" may occur in which particles of the positive contact material become transferred to the negative. This effect, which will be referred to again later, is generally more pronounced at current and voltage values just below those necessary for arcing to occur, and may have serious consequences when contacts are employed at high operating rates for long periods.

This is of course quite a different phenomenon from the "coarse transfer" of metal associated with arcing when material from the negative contact is removed by vaporisation or sputtering and is deposited, at least in part, on the positive contact. The mass of material transferred in this direction usually considerably exceeds that due to "fine transfer" in the opposite direction. In AC circuits either type of erosion naturally becomes apparent as a general wearing away of both contacts.

It is in the light duty group of contacts that the platinum metals and certain of their alloys, together with some alloys of gold, comprise the only suitable type of contact materials for efficient operation on account of their freedom from the type of oxide or sulphide films which, if present, could lead to high values of contact resistance. (For medium to heavy duties the use of silver and silver alloy contacts is general practice, as the film of sulphide formed is fairly readily punctured and decomposed by the arc, while higher contact pressures are of course employed.)

This sensitive moving coil relay, made by Sangamo Weston Limited, is fitted with iridium-platinum alloy contacts. The contact rating is 0.5 watt maximum at 250 volts maximum

Light duty contacts may themselves range from those in which the currents handled are extremely small (in these cases the maintenance of a low and stable contact resistance is essential, contact pressure is often low, operation is sensitive and possibly infrequent, but reliability is of paramount importance) to those handling currents not greatly below the critical values, in which case "fine transfer" can be expected when interrupting DC circuits if the number of operations extends to many hundreds of thousands.

The Physics of Contact Operation

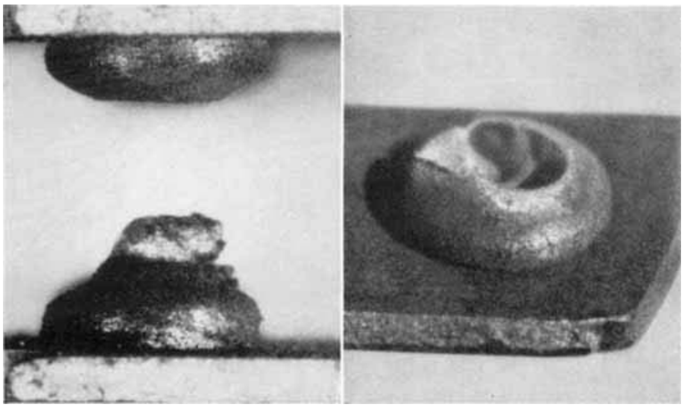
It is well known that when contact is first made it actually occurs at only a few microscopic points, and that current first flows only through minute areas or constrictions. The contact pressure applied will naturally give rise to both elastic and plastic deformation of the two surfaces until the very high local pressures have fallen sufficiently for further deformation to cease. In the course of this operation the current density will be very high and may cause local melting, while any thin poorly conducting oxide or tarnish films on the surfaces may be broken through by the pressure exerted. Depending on their nature and thickness, therefore, such films will govern the extent to which localised metal-to-metal connections can exist between the two contacts.

A fairly extensive literature exists on the physical phenomena occurring during the actual operation of electrical contacts. It is not possible here to give an adequate summary of this work, but the researches of Holm (1), Betteridge and Laird (2), Pearson (3), Curtis (4), Pfann (5), Fairweather (6), Llewellyn Jones (7) and others have established the fundamental facts that as a circuit is broken contact is ultimately confined to a minute area, that a molten metallic bridge then forms between the opening contacts, and that this bridge is then ruptured at its hottest point. This point of rupture is normally not found to be in the centre of the bridge, but to be displaced towards the positive contact (probably due to the Thomson effect), with the result that a minute amount of material is left on the negative contact. It is then a reasonable assumption that, once such an excrescence has been formed, subsequent operations of the contacts will cause contact to be made at the same spot, so that further bridge formation will result in the well-known pip-and-crater formation after a sufficient length of time.

Similarly, on closing a pair of contacts, the formation of a minute region of molten metal which solidifies before separation begins may cause sticking or welding of the contacts if the available force to open the contacts is not sufficient to tear the weld. This phenomenon probably occurs in the great majority of contact operations; in most cases the welds are readily fractured on opening, but in certain types of equipment welding may constitute a major cause of failure. It should be borne in mind that in practice contacts will rarely if ever close in one clear-cut operation; some "bounce" must occur, or the contacts may separate and re-close several times, often forming and breaking a weld before static contact is established.

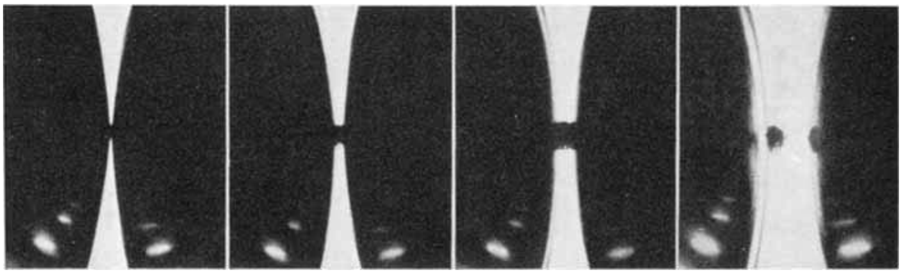
The Importance of Surface Films

The foregoing rather over-simplified account of the physical happenings during contact operation has assumed that perfectly clean metallic surfaces are involved. In fact this condition can never apply, with the possible exception of specially prepared and cleaned contacts working in a high vacuum,



A typical example of "fine transfer" in a telephone-type relay after several hundred thousand operations. The pip formed on the negative contact can be seen in the left-hand photograph, while the corresponding crater in the positive contact is shown in the right-hand photograph

The Formation and Rupture of a Metallic Bridge



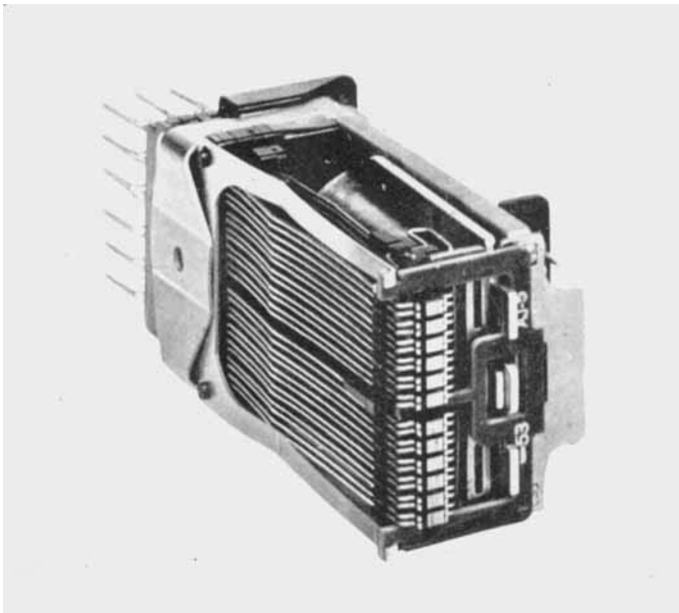
A sequence of photographs (magnification × 65) showing stages in the separation of a pair of contacts—platinum cathode to the left and iron anode to the right. (1) The contacts have just separated, showing a small glowing bridge. (2) Further separation increases the size of the bridge. (3) Current has been interrupted by the rupture of the bridge inside a cavity in the anode. (4) Further separation shows the complete frozen bridge left on the cathode; its reflection can be seen on the anode.

These photographs were taken by Mr. R. Hill Jones at the Department of Physics, University College, Swansea, and are reproduced by courtesy of Professor F. Llewellyn Jones

and in all practical cases the surfaces are to a greater or lesser extent contaminated with thin films of adsorbed gases, of oxidation or corrosion products, or of dust and organic matter. Such films, as already mentioned, may have an appreciable effect on contact resistance; they may also increase the likelihood of arc formation at voltages and currents below the accepted critical values, and they can have a pronounced effect on the formation of molten bridges and on the tendency of contacts to weld. To take an extreme example, it is found that tungsten—which readily forms a substantial and tenacious oxide film—will not maintain a molten metallic bridge on opening and does not exhibit appreciable fine transfer, while its relative freedom from welding is well known. On the other hand, of course, tungsten contacts develop, for the same reason, a high contact resistance which makes them quite unsuitable for operation in sensitive conditions.

Contact performance is thus very much bound up with the chemical behaviour of the contact surface in its ambient atmosphere and at the high temperatures prevailing at localised points. In this connection there is an accumulation of evidence to show that, in some light duty applications other than those of a very sensitive nature, there is an advantage in a certain degree of oxidation of the contact surfaces provided that contact resistances are not thereby appreciably increased. Here the rather unusual behaviour of some of the platinum metals is of considerable interest and some practical value. While platinum and iridium are completely free from oxidation at all temperatures up to their melting points, palladium and ruthenium both form oxide films which are thermally unstable. On palladium and its alloys an oxide film is formed on heating above about 400°C, but is decomposed at around 800°C. Similarly, an oxide of ruthenium forms at approximately 600°C, but decomposes at something over 1000°C.

It is known that the maintenance of a stable molten bridge is more difficult with palladium than with platinum. It is also established that some palladium alloys prone to the formation of oxide films are particularly free from fine transfer in difficult conditions,



The new type of general purpose telephone relay now in quantity production by the Bell Telephone System. Palladium is used for all contact surfaces and is found to give not only outstanding reliability but the best economic balance between manufacturing cost and service because of the reduced maintenance expense

while alloys of both platinum and palladium with additions of about 10 per cent of ruthenium have been found most successful in reducing transfer, as for example in automobile voltage regulators.

From what has been said earlier on the mechanism of both transfer and welding, the conclusion may be drawn that the formation of a slight or unstable oxide film at elevated temperatures may well have the effect of tending to prevent bridge formation. Obviously the permissible degree of oxidation is critical and will depend on the electrical and mechanical conditions of the circuit. The oxide film must be sufficiently thick to interfere with bridge formation and to protect the metallic surfaces from welding, but must not be so thick or so continuous as to bring about a serious increase in contact resistance.

The Selection of Contact Materials

To return now to the question of attempting to match the physical and chemical properties of one or other of the available materials to the electrical and mechanical factors of a particular piece of apparatus, it will be seen that the requirements for light duty contacts can be summarised as follows:

(1) Maintenance of a low and steady contact resistance

(2) Minimum tendency to fine transfer resulting from bridge formation

(3) Minimum tendency to sticking or welding.

Materials which satisfactorily meet the first of these requirements will not necessarily fulfil the second and third, while conversely those that fully meet the second and third requirements may well develop objectionably high contact resistances, and in selecting a contact material it is usually necessary to arrive at some kind of compromise solution or balance of properties. It is suggested that one of the important factors that must be taken into account is the extent, if any, to which an oxide film—unstable or stable—is likely to form on the contact surfaces during operation. In other words, one must attempt to decide to what extent oxide film formation can be tolerated in the interests of minimum tendency to transfer and welding, bearing in mind the required minimum values of contact resistance to be maintained.

The major physical properties of those platinum metals and alloys in general use as contact materials are set out in the accompanying table. This is divided into three parts in order to show clearly the distinction between those materials which are completely free from oxide formation at all temperatures, those which form thermally unstable oxide films at high temperatures, and those forming persistent oxide films of base metals.

Where both currents and mechanical pressures are extremely small, as for example in contacts operated by a delicate instrument mechanism and in similar very sensitive devices, the most important consideration is that of maintaining a low and stable contact resistance. In these cases the temperature at the contact surfaces never rises sufficiently to decompose any unstable oxide films, and a choice of material should be made from those given in the top part of the table.

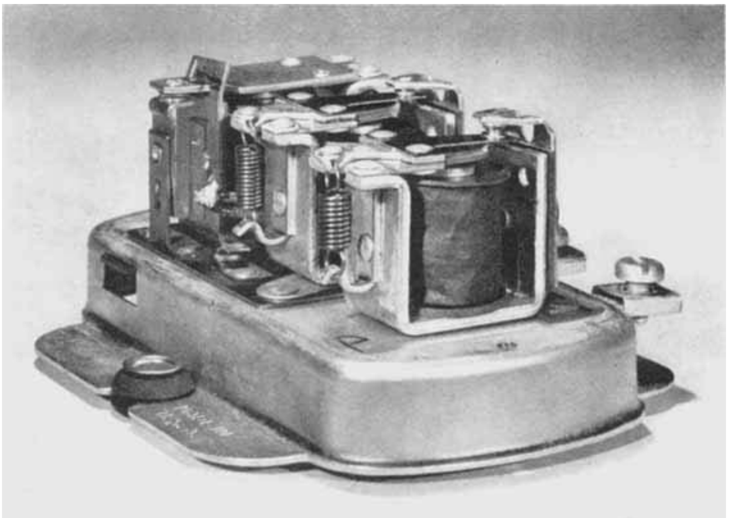
For some applications of this kind platinum contacts are employed, but a harder alloy of platinum is more often to be preferred. When contact pressures are measured only in milligrammes it is found that trouble may occur through particles of dust or dirt settling on the contact surfaces or becoming embedded. With a soft material this can cause imperfect contact or in extreme cases a condition of permanent open circuit. The 10 per cent iridium-platinum alloy is therefore to be recommended for its greater hardness, while the 4 per cent ruthenium-platinum alloy provides almost identical characteristics of hardness and complete freedom from oxidation. Where still greater hardness is required the iridium content can be increased to 20 per cent.

When contact pressures are of a different order of magnitude—that is, extending to say 10 to 50 grammes—platinum again becomes the most suitable choice for the majority of applications, such as in light duty relays handling currents up to about 1 ampere.

Platinum is of course very widely used in apparatus of this type, particularly in telephone relays, and in general where the relay must operate with certainty after long idle periods even in a corrosive atmosphere. In

Properties of Light Duty Contact Materials

		Specific gravity	Vickers hardness (annealed)	Melting point, °C. (solidus)	Specific resistance microhm-cm.	Electrical conductivity, per cent IACS
Free from oxide films at all temperatures	Platinum	21.3	65	1,769	11.6	15
	10% Iridium-platinum ..	21.6	120	1,780	24.5	7.0
	20% Iridium-platinum ..	21.7	200	1,815	30.0	5.7
	4% Ruthenium-platinum	20.8	130	1,775	30.0	5.7
Unstable oxide films formed at high temperatures	Palladium	11.9	40	1,552	10.7	16
	10% Ruthenium-platinum	19.9	200	1,780	42.2	4.1
	10% Ruthenium-palladium	12.0	160	1,580	36.0	4.8
	40% Silver-palladium ..	11.0	95	1,290	43.0	4.0
Stable oxide films formed	15% Copper-palladium ..	11.2	100	1,380	37.5	4.6
	40% Copper-palladium ..	10.4	145	1,200	35.0	4.9
	8% Nickel-platinum ..	19.3	175	1,660	27.0	6.4



An automobile voltage regulator produced by the Ideal Manufacturing Company, New York. This uses ruthenium-palladium alloy contacts operating against tungsten contacts

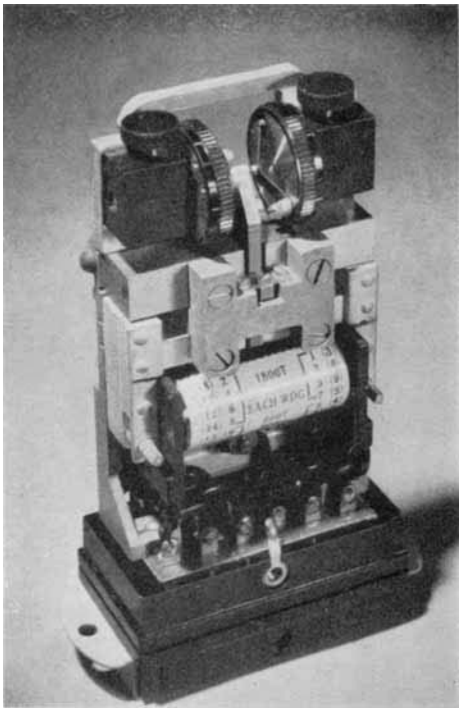
some conditions, however, considerable hammering of the contacts can occur at high rates of operation, and it is then preferable to use a material of greater hardness—either 10 per cent iridium-platinum or 4 per cent ruthenium-platinum.

With greater additions of ruthenium to platinum it has been established in a number of cases that fine transfer is reduced, as also is the tendency to welding, although some increase in contact resistance is also in evidence. It appears that a ruthenium content of 10 per cent provides about the optimum balance of comparative freedom from transfer and sticking without appreciable increase in contact resistance, while giving a material of equivalent hardness to 20 per cent iridium-platinum.

Palladium is softer even than platinum and experience shows that it is not suitable for very sensitive applications, but it is extensively and successfully employed in telephone type relays, more particularly in the United States. It has advantages in terms of lower intrinsic cost and lower density by comparison with platinum. Here again, the use of ruthenium-palladium alloys has been found, in certain experimental conditions, to reduce the extent of transfer over long periods and then to give a rounded, mound type of transfer rather than the much more objectionable pip formation. These results could quite possibly be explained by the higher temperature of decomposition associated with the oxide of ruthenium. There appears to be no advantage, in terms of transfer, in additions of ruthenium beyond 10 per cent, whereas contact resistances can begin to increase perceptibly when such a proportion is exceeded. The greater hardness of ruthenium-palladium also contributes to improved resistance to wear.

Other palladium alloys that are in current use were developed to economise in palladium and yet to provide essentially the same resistance to tarnish at normal temperatures characteristic of the parent metal. The 40 per cent silver-palladium alloy is used for relay contacts in conditions bordering on light and medium duty—that is where silver contacts are inadmissible on account of tarnish films but where both voltage and contact pressure are reasonably high.

The addition of copper to palladium yields several possible alloys having interesting characteristics. Clearly some copper oxide, in addition to palladium oxide, will be formed on the surfaces of such alloys at high temperatures, and although little or no experimental work seems to have been carried out on this point there is ample practical evidence that such alloys are particularly well-behaved in terms of transfer. For some applications a 15 per cent copper-palladium alloy is recommended, but the 40 per cent copper alloy undoubtedly exhibits the minimum of transfer in conditions of high-speed operation and where appreciable capacitance and inductance are present. Such factors are chiefly associated with telegraph relays, where a very small contact clearance must be maintained, and the 40 per cent copper-palladium contacts normally used in this type of apparatus are found to maintain a smooth surface when other materials are prone to develop sharp growths. Naturally such an alloy will develop a higher order of contact resistance than will alloys free from any base metal content, but this is not of first importance in telegraph circuits. When a similar relay is used as a " chopper " the extremely low values of voltage and current make it necessary to employ platinum for the contacts.



A Carpenter high-speed relay, by the Telephone Manufacturing Co. Limited, fitted with 40 per cent copper-palladium contacts

One other material of some importance, also prone to the formation of a slight permanent oxide film at high temperatures, is the 8 per cent nickel-platinum alloy. This was developed in Germany for applications where a material of considerable hardness was required but where minimum tendency to transfer was essential. Again, an appreciably higher contact resistance will be developed by comparison with the iridium-platinum alloys which it was designed to replace.

From this brief survey, it will be seen that the platinum metals and their alloys provide a reasonably wide scope in the selection of a contact material to fulfil a particular requirement. Other and more complex alloys are in use in special circumstances, but those listed in the table account for a large proportion of light duty contact applications.

It is possible to give only generalised recommendations on the selection of a material for a given set of conditions, and it is always necessary for practical tests to be carried out on a "short list" of alloys before a final decision can be taken. Some consideration given to the effects of oxide films—thermally unstable or more persistent—may, however, be of help in making a first selection.

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