Sliding Noble Metal Contacts

CONTACT RESISTANCE AND WEAR CHARACTERISTICS OF SOME NEW PALLADIUM ALLOY SLIDEWIRES

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When, as in many low torque potentiometers, contact pressures must not exceed a few grams the use of noble metals for both resistance wire and wiping contact becomes almost essential. As the factors that determine the electrical and mechanical behaviour of such low load sliding contacts have not yet been established, wiper/slidewire combinations are still selected on an empirical basis. This paper, based on a lecture recently delivered to the Fourth International Research Symposium on Electrical Contact Phenomena at Swansea, describes some results obtained on an apparatus in which the abrasion resistance and frictional characteristics of precision resistance alloys can be assessed in an objective manner at very low contact loads. Under such conditions metal is transferred from wiper to resistance alloy and the efficiency of this transfer process determines the electrical behaviour of these sliding contacts.

A general view of the apparatus employed is given in Fig. 1. As shown diagrammatically in Fig. 2, the wiping contact is in the form of a bent hairpin. Mounted as a cantilever, it is clamped below the bob of a compound pendulum and pressed against the contact track which has been prepared on the surface of an aluminium bobbin, closely wound with the resistance wire under test. This coil is reciprocated below the stationary wiper to establish the necessary sliding contact.

The wiper wire is approximately 0.010 inch in diameter and contact pressures, in the range from 0.1 to 10 grams, are adjusted by lowering the pendulum suspension until flexure of the cantilever produces the load required. After such adjustment the pendulum is rigidly clamped so that well defined wear tracks are obtained on the wire under test when the bobbin is reciprocated.

Coefficients of friction are determined by unclamping the pendulum and measuring the angular deflections which result when the coil of resistance wire is moved below the wiper. With the experimental arrangement employed a tangential force of 0.2 gram corresponds to a pendulum displacement of 1° and is therefore easily measured with the optical lever.

Current is led into the wiper through a separate current lead which constitutes one arm of the bifilar tape suspension. The potential lead, attached to the other side of the wiper hairpin, passes out through the other suspension. By this method contact resistances are accurately determined by the four-wire method.

The equipment employed is surrounded by a gas-tight metal and glass container in which organic materials are largely avoided. The chamber can if required be evacuated and back-filled with any desired atmosphere, and equipment is provided for varying the internal humidity. Being suspended from long, elastic, nylon ropes the equipment is effectively isolated from most vibrations.

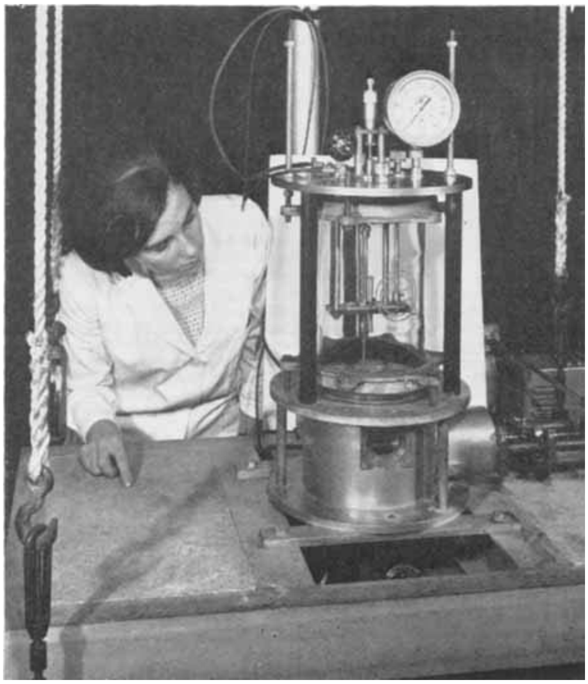

Fig. 1 General view of the apparatus used for wear and contact resistance measurements on noble metal slidewire materials

The solid solution alloy containing 40 per cent of silver and 60 per cent of palladium is very widely used for precision resistance purposes as it combines a moderately high resistivity with low contact resistance and a very low temperature coefficient of resistance. Silver-palladium has therefore been used as a standard of reference in this investigation, where its characteristics in the annealed and work-hardened condition have been compared with those of vanadium-palladium and molybdenum-palladium-gold alloys.

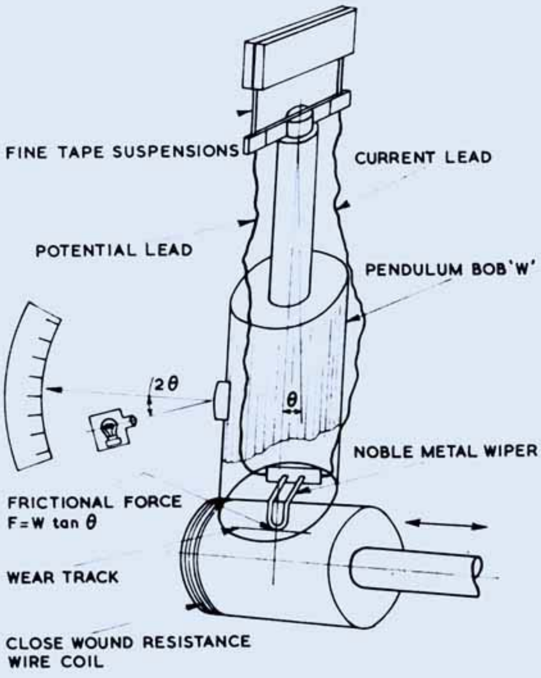

Fig. 2 Diagrammatic arrangement of contact resistance apparatus showing the pendulum used for friction coefficient measurements

In all the tests reported a gold-silver-copper alloy (625 alloy) was used for the wiping contact.

The composition and electrical characteristics of the various alloys investigated are summarised in the table overpage, which also defines the metallurgical condition in which these materials were actually tested.

Static Contact Resistance

These experiments were made in the normal laboratory atmosphere which was not dried before admission to the apparatus. The resistance alloys were tested in the form of a thin sheet which was wrapped round the drum normally used for testing wire. Apart from careful degreasing before test no attempt was made to improve on the high quality rolled finish of these sheets.

Physical Properties of the Alloys Investigated

Alloy	Specific Resistance		Temperature coefficient of resistance (0–100°C) per °C	U.T.S. and Hardness			
				Annealed		Hard	
	μΩ –cm	Ω/circ mil/ft		Kg/mm^2	Hv	Kg/mm^2	Hv
40 per cent Silver-palladium	42	252	0.00003	38	70	100	270
5 per cent Molybdenum–40 per cent palladium-gold	100	600	0.00012	68	150	110	310
9 per cent Vanadium-palladium	150	900	−0.00008	78	190	140	390
Fine silver	1.6	9.6	0.0041	14	24	—	—
62.5 per cent Au/Cu/Ag wiper alloy	14	84	—	—	—	70	220

Some of the effects of load and wiping on the static contact resistance of fully annealed specimens are shown in Fig. 3. These resistance measurements were made with a constant current of 50 milliamps, and the high resistance values determined at loads below one gram were found to decrease very rapidly as the contact load increased. With soft materials such as fine silver and silver-palladium the initial fall in contact resistance occurred very rapidly. Steady conditions were arrived at with loads of about five grams and little change in contact resistance occurred at higher pressures. The harder vanadium-palladium and molybdenum-palladium alloys did not arrive at steady conditions so rapidly, and as shown in Fig. 4 the resistance still fell significantly at contact loads of ten grams.

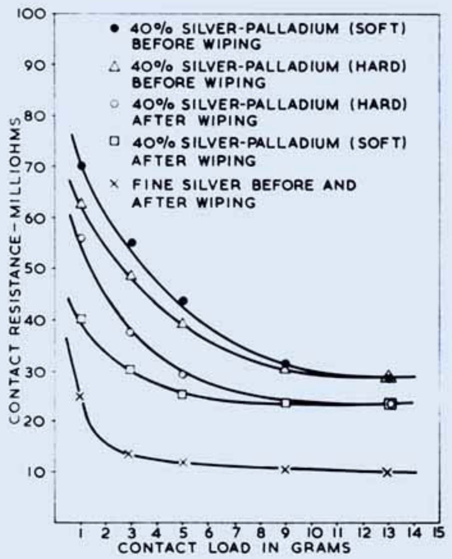

Fig. 3 Effect of load and wiping on the static contact resistance between the silver-palladium resistance alloy and a 625 alloy wiper

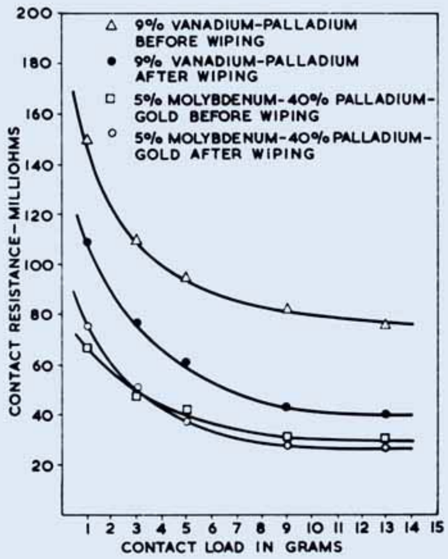

Fig. 4 Effect of load and wiping on the static contact resistance between vanadium-palladium and molybdenum-palladium-gold resistance alloys and a 625 alloy wiper

These well defined relationships between contact resistance and load for noble metal alloys are in complete contrast to the uncertain behaviour experienced with base metal resistance wires.

The experimental values plotted in these curves were obtained for increasing loads. Slight hysteresis effects occurred during unloading when the loads fell below three grams, although the effect was not pronounced and was barely detectable with the molybdenum-palladium and vanadium-palladium alloys.

Static contact resistances fell significantly after sliding had occurred. The behaviour of work hardened and annealed silver-palladium alloys is shown in Fig. 3, where the effects of wiping under a 7 gram load can be observed. Decrements in contact resistance of up to 50 per cent occurred simply as a result of relative movement between the two contacts. Steady conditions were arrived at after approximately one hundred wiping operations, and subsequent work showed that this effect was not greatly influenced by the magnitude of the wiping load. After wiping, the contact resistances of the silver-palladium and molybdenum-palladium-gold alloys became comparable in magnitude at loads above 5 grams.

Although it was originally felt that this reduction in contact resistance was due to the removal of adsorbed and combined surface films, detailed examination of the wear tracks obtained showed that rapid material transfer occurred during wiping and that a large proportion of the resistance decrement could be accounted for in this way. This subject is discussed later in the paper.

Sliding Contact Resistance

In the early stages of operation the sliding contact resistance is appreciably higher than the statically determined value, and as shown in Fig. 5 this difference is more pronounced with a soft material, such as fully annealed silver-palladium, than with a hard alloy such as molybdenum-palladium-gold.

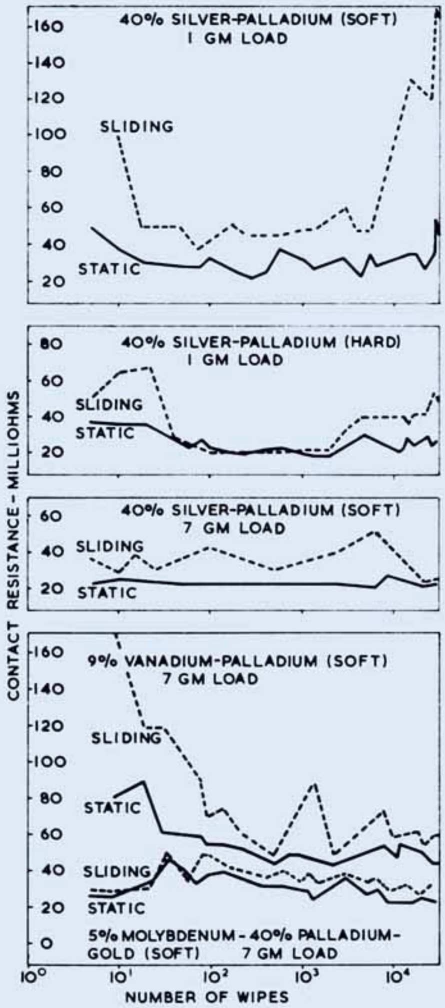

Fig. 5 Sliding and static contact resistances plotted as a function of the number of wiping operations

After about one hundred wiping operations, however, the dynamic and static values begin to converge and over the range 100 to 3,000 operations both values remain at a consistently low level, which for silver-palladium is almost independent of the wiper load imposed.

After approximately 3,000 wiping operations high dynamic contact resistances tend to develop on materials tested at loads below 3 grams. Fully annealed silver-palladium, run on a 1 gram load showed this effect to a high degree, although it behaved in a very satisfactory manner with a 7 gram load. Under low load conditions the work-hardened silver-palladium alloy performed better than the fully annealed material and discrepancies between the statically and dynamically determined contact resistances were very much less. Peak to peak noise, as indicated by the oscilloscope, showed the same general trends, and in the case of fully annealed silver-palladium working under a one gram load approached values equivalent to a resistance of 0.5 ohms during the latter stages of the test. At intermediate loads the molybdenum-palladium-gold alloy, with a specific resistance of 100 μΩ cm, was shown to be equal to silver-palladium in its contact performance. The vanadium-bearing alloy displayed some unusual characteristics; during the initial wiping period sliding contact resistances and noise levels rose steeply, the former reaching values of several ohms in some instances. After one hundred wipes with a 7 gram load, however, the sliding contact resistance and noise level dropped rapidly and approached closely the normal static values.

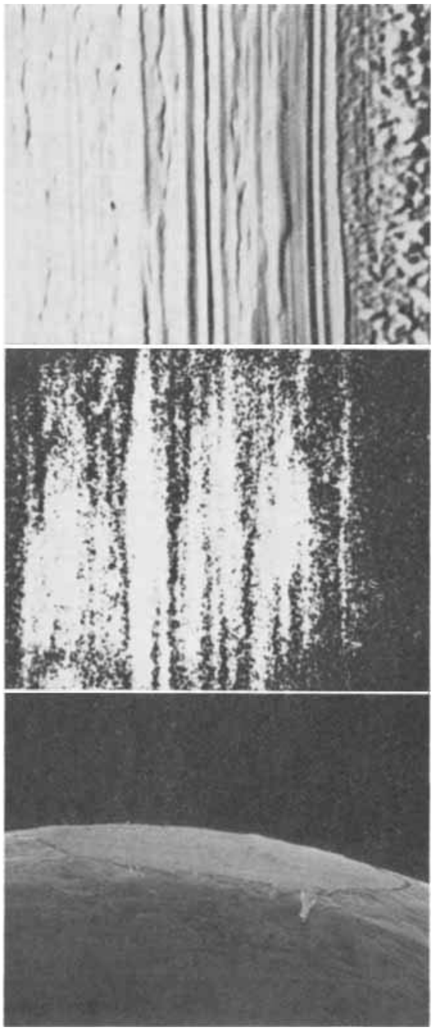

Fig. 6 Appearance and composition of worn surfaces. Fig. 6a (top) shows the visual appearance of the right hand side of the wear furrow on a work hardened silver-palladium specimen. (× 350). Fig. 6b (centre) shows at the same magnification the distribution of gold transferred to this surface from the wiper, while Fig. 6c (bottom) shows the worn surface of the 625 alloy wiper which produced this track. (× 150)

Wear and Metal Transfer

Microscopic examination of the wear tracks on the sheet specimens showed a fairly broad shallow furrow with a continuous row of wear fragments thrown out on each side of the track. Fig. 6a shows one side of such a track with its associated bank of debris. Microprobe analysis of this groove and many others in all the palladium alloys tested showed that smears of the transferred gold alloy existed over the complete abraded surface. On the silver-palladium alloys this film was virtually continuous as indicated by Fig. 6b which provides a gold Kα-ray image of the surface of the track shown in Fig. 6a. This track had been formed on a work-hardened silver-palladium specimen after 30,000 wipes with a 7 gram load. At lower loads, and on the resistance alloys containing base metal additions, this gold film was less uniformly distributed although still present. In all instances the gold/copper ratio in the transferred film was the same as that existing in the wiper alloy.

In Fig. 6c can be seen the worn area of the wiper which produced the wear track in

Fig. 6a. The foil-like metal fragments hanging from the periphery of the wear area are of the same composition as the wiper, and no evidence of palladium transfer from resistance alloy to wiper was detected in any of the experiments except those made on fully annealed silver-palladium. In such instances traces of silver-palladium were detected on the leading and trailing edges of the wiper but not on the worn area. Obvious "prows" of pure silver were also detected when wear tests were made on this pure metal.

Although the worn area of the wiper provided a rough indication of the quantity of metal removed, no correlation has yet been established between the rate of wiper wear and the hardness or composition of the resistance alloy against which it had been abraded.

Silver-palladium potentiometer windings that have been in service for many thousands of operations show wear tracks which closely resemble those referred to above. The track illustrated in Fig. 7 shows the extensive plastic deformation that occurs. Metal is moved over laterally in the direction of wiping and eventually begins to short circuit adjacent turns. For this reason serious wear in close-wound slidewire potentiometers is usually accompanied by a rapid fall in total resistance.

Fig. 7 Wear tracks on a potentiometer wound with silver-palladium wire ($\times$ 300)

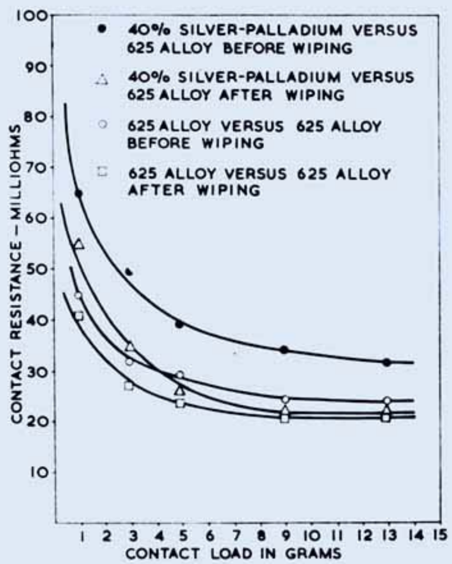

Fig. 8 Effect of load and wiping on the contact resistance set up between a 625 alloy wiper and a 625 alloy resistance wire. After 100 wiping operations the contact resistance of 625 alloy rubbed against itself coincides with that established between a 625 wiper and the silver palladium resistance alloy

Discussion and Conclusions

This report is based on what must be regarded as the preliminary results of a rather wider investigation and it would be unwise therefore to draw too many specific conclusions from the data presented. It has been established, however, that under rubbing loads of less than ten grams metal is transferred from the wiper to the resistance alloy and it appears that, after a brief period of sliding, electrical contact is established between the wiper and a thin film of the wiper alloy spread out on the resistance alloy surface.

The results of tests in which 625 alloy was used both as a wiper and as a resistance alloy supported this conclusion. Some of the contact resistance curves obtained are shown in Fig. 8. Before wiping, values of contact resistance were measured which, for a given load, closely resembled those of the 625 alloy/silver-palladium combination after wiping. Although subsequent sliding reduced slightly the contact resistance of the 625 alloy combination, significant decrements in resistance occurred only at very low loads and after 100 wiping operations the contact resistance curve became almost coincident with that of the wiped silver-palladium resistance alloy.

It seems evident therefore that the initial static contact resistance of wiper against resistance alloy does not provide a realistic indication of contact performance. After sliding under low load conditions, as in the present experiments, metal transfers from wiper to slidewire and because of this effect we are really testing the performance of this wiper alloy rubbed against itself. Viewed in this way it is easy to understand why all the palladium alloys tended, after a little rubbing, to develop similar contract resistances. This finding has an important bearing on resistance alloy development as it appears to suggest that within the same general range of composition new and improved resistance alloys could be selected on the basis of their bulk electrical resistivity and temperature coefficient, as contact resistances will be determined largely by the properties of the wiping alloy employed.

This generalisation applies, however, only when the noble metal resistance alloy contains low concentrations of base metals. When the alloying elements have a tendency to form stable oxides, metal transfer from the wiper is less efficient and higher contact resistances are encountered.

This effect becomes detectable with the vanadium-palladium alloy where electron probe examination showed that the transferred film of gold-based wiper alloy was rather less uniformly distributed than on the silver-palladium or molybdenum-palladium-gold alloys. Even so, the measured contact resistances were only marginally higher.

Noble metals from the wiper are not, however, effectively transferred to base metals such as nickel-chromium, and although beneficial results are undoubtedly obtained by the use of noble metal slidewires the contact resistances provided by such combinations are at low loads still many times higher than those available from noble metal wire.

The vanadium-palladium (1) alloy displayed a contact resistance which, although initially a little higher than that of silver-palladium, decreased rapidly on wiping and settled down at an acceptably low level. The molybdenum-palladium-gold alloy (2) is unique in combining a very high specific resistance with a contact resistance which, after one or two wiping operations is no higher than that of silver palladium. The success of this alloy as a slidewire material might well be attributable to its duplex microstructure, one phase of which contains a high proportion of gold.

Although no quantitative correlations have yet been established between the mechanical properties of the resistance alloys and their wear characteristics this subject obviously merits closer attention. None of the wear tracks examined were more than two microns deep, and it is certainly true to say that for any given condition of test the harder alloys showed rather shallower grooves than the fully annealed silver-palladium alloy. Although the wear tracks showed on their surface a parallel series of micro-furrows, no corresponding serrations occurred on the wiper and it appears very probable that, as suggested by Antler (3), the transferred metal does not adhere well to the smaller surface. Our results differ from those of Antler in that metal transfer was invariably from wiper to resistance alloy even when the wiper was considerably harder. Such differences are probably attributable to the low contact pressures employed in this work.

References

1 Johnson Matthey, Prov. Pat. 21853/67

2 Johnson Matthey, B.P. 861,646

3 M. Antler, Mechanisms of Solid Friction, Elsevier Pub. Co, London, 1964, pp. 181–203; *Platinum Metals Rev.*, 1966, **10**, 2