INVITED PAPER *Special Issue on Electromechanical Devices and Their Materials*

# Contact Fretting of Electronic Connectors*

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**SUMMARY** Connector contact resistance may become unstable if fretting occurs. Such motions result in the formation of insulating oxides on the surface of base metal contacts or organic polymers on contacts made of platinum group metals. These degradations are termed fretting corrosion and frictional polymerization, respectively. Motion may be caused by external vibration or fluctuating temperature. The lower the frequency of movement, the fewer the number of cycles to contact failure. Increasing the contact normal load or reducing the amplitude of movement may stabilize the connection. Tin and palladium and many of their alloys are especially prone to fretting failure. Tin mated to gold is worse than all-tin contacts. Gold and high gold-silver alloys that are softer when mated to palladium stabilize contact resistance since these metals transfer to the palladium during fretting; but flash gold coatings on palladium and palladium nickel offer marginal improvement for the gold often quickly wears out. Dissimilar metal contact pairs show behaviors like that of the metal which predominates on the surface by transfer. Contact lubricants can often prevent fretting failures and may even restore unlubricated failed contacts to satisfactory service.
***key words:*** *fretting corrosion, frictional polymerization, connectors, tin, gold, palladium, contact lubrication*

## 1. Introduction

Fretting is a significant contact failure process. These micromotions may range from a few to as much as 100 $\mu$m in electronic connectors [1] and are caused by external vibrations or changing temperature, for example, due to differences in the coefficients of thermal expansion of the elements to which mated contacts are mounted [2].

Fretting causes metal transfer and wear. Base metal contacts produce insulating oxide debris ("fretting corrosion") such as that shown in Fig. 1(a) from tin lead solder plate. Palladium and other platinum group metals catalyze the formation of insulating frictional organic polymers in the absence of significant metallic wear [3] (Fig. 1(b)). The result of these surface contaminating processes is variable contact resistance (electrical noise) during fretting and the attainment of an unacceptably high contact resistance even should such motions cease.

The objective of this review is to consider mechanisms of fretting degradations, to survey contact materials behavior and the effect of operational parameters on contact resistance, and to provide design guidelines for fretting control in electronic connectors.

## 2. Fretting Regimes

When a force is applied to a connection due to thermal excursions, vibrations, or other means, its magnitude must be sufficient to exceed the friction between the mating contacts for fretting to occur. However, many connector designs have considerable compliance, so that fretting is not a factor. For example, mated contacts (i.e., pin-socket) may "float" in their housing. A high normal force can minimize the possibility of motion. Contact springs can be designed to be very flexible.

Assuming that motion occurs, the resulting contact surface damage will depend on the magnitude of movement. This has been categorized [4], into these regimes: (1) *Stick.* Movement between the contact surfaces is accommodated by elastic deformation of the members in the near-surface regions. The asperities are joined, and there is no surface damage until the members are separated. The stick regime may occur for movements of about 1 $\mu$m depending on the material, contact geometry, and on other factors. (2) *Mixed stick-slip.* There is central stick area surrounded by an annular slip region where there may be crack formation, fretting fatigue, and wear debris. Movements are of the order 5 $\mu$m. (3) *Gross slip.* All asperity contacts are broken during each cycle. Asperities slide across several others of the opposing surface. Damage is extreme with delamination wear. Movements of 10–100 $\mu$m typically are involved.

## 3. Static versus Dynamic Contact Resistance

There are two aspects of electrical resistance degradation: (1) the "static" contact resistance of the system at rest, and (2) the variability of contact resistance which may reach high values during fretting for nanoseconds to much longer times depending on the velocity of movement, cycle rate, contact materials, and the physical properties and thickness of the insulating layer.

Manuscript received July 3, 1998.
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*This paper is abstracted from a chapter by the author, entitled "Tribology of Electronic Connectors: Contact Sliding Wear, Fretting, and Lubrication," which appears in the book, *Electrical Contacts: Principles and Applications*, edited by P. Slade, Marcel Dekker, N.Y., to be published.

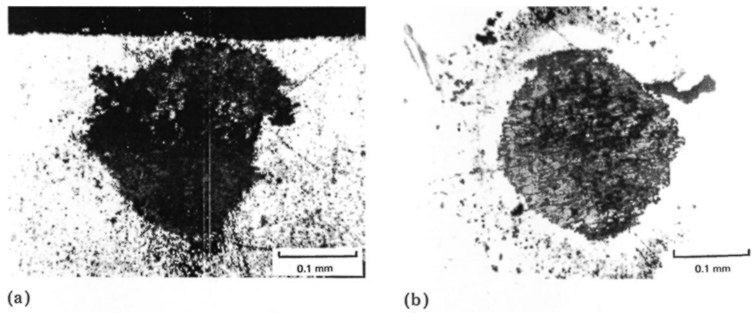


**Fig. 1** Contacts which acquire insulating films because of fretting: (a) tin lead plate (the black oxide covered surface and debris should be noted) (150 g; 20 $\mu$m wipe; $10^4$ cycles); (b) palladium contact covered with and surrounded by frictional polymers (50 g; 20 $\mu$m wipe; 8 Hz, $10^5$ cycles).

There has been considerable speculation about the physics of contact resistance change from fretting corrosion, and several models [5]–[8] have been proposed. For example, the *Asperity Model* postulates that there is a continuous reduction in real contact area as metallic asperities and wear debris are transformed into oxides. There also is a volume growth, from metal to oxides, which further tends to separate the contact surfaces. The reduction of contact area causes contact resistance to increase, and with motion eventually there is momentary loss of asperity contact followed by the reestablishment of contact with another array of asperities. Figure 2 is a representation of this process. It has been shown [9] that with the increase in static contact resistance from fretting, the frequency of short time resistance excursions increase as well.

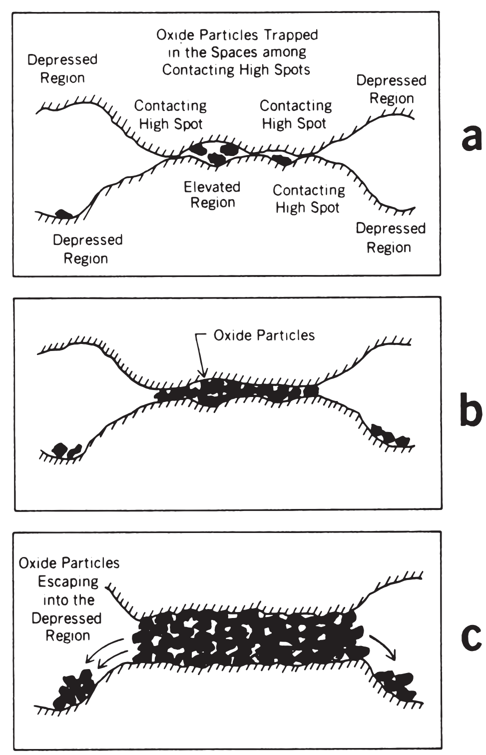


**Fig. 2** Schematic representation of formation and accumulation of fretting corrosion solids. (a) Accumulation of oxide particles in the spaces among the high spots. (b) Integration of a company of high spots into one single united area, after the space among the high spots is filled by oxides. (c) Spilling of oxide particles into the adjoining depressed regions. (After [46]).

## 4. Laboratory Testing Methodologies

### 4.1 Generation of Movement

Hardware studies are sometimes conducted by forcing displacements, as when a printed circuit board in a connector is rocked [10], [11], by using severe external vibrations [12], by thermal cycling [10], and by imposing a reversing force of constant magnitude to the samples.

### 4.2 Determination of Contact Resistance

One method involves measuring static contact resistance initially and then periodically during the course of the test [2], [12], [13]. A disadvantage of this approach is that little data are obtained, for contact resistance is monitored only intermittently; also, in static tests contact resistance is determined at a fortuitous rest point within the zone of fretting. It has been shown [1] that contact resistance may differ by orders of magnitude within the swept track.

Another approach is to measure transients during simulated operation. An event counter tabulates the transients for preset detection limits according to voltage drop and duration. Such apparatus has been designed [8] with less than 10 nsec sensitivity.

Contact resistance may be measured by dc or ac methods at low voltage and current so as to not cause heating or electrical breakdown of insulating films that may be present and with no current flowing except during the periodic resistance measurement. Alternately, the circuit may be continuously powered during fretting at levels consistent with the intended application. Static contact resistance changes due to fretting wear were found [9], [11] to be much less than the changes

**Table 1** Classification of contact resistance behaviors.

| | *Type I* (unstable) | *Type II* (intermediate) | *Type III* (stable) |
|---|---|---|---|
| Cycles to attain 10 mΩ | <5000 | >5000 | >$10^5$ |
| Contact resistance by $10^5$ cycles | >1 Ω | <1 Ω | <10mΩ |

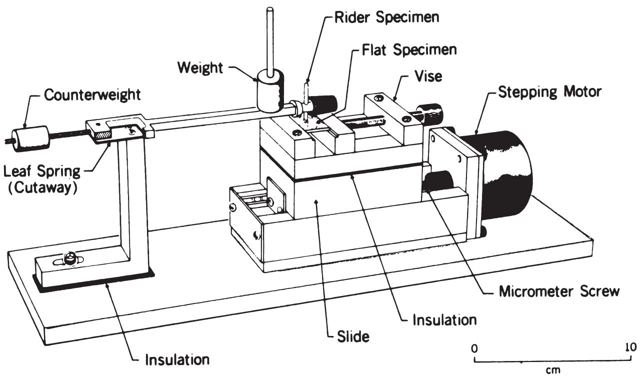


**Fig. 3** Fretting test apparatus.

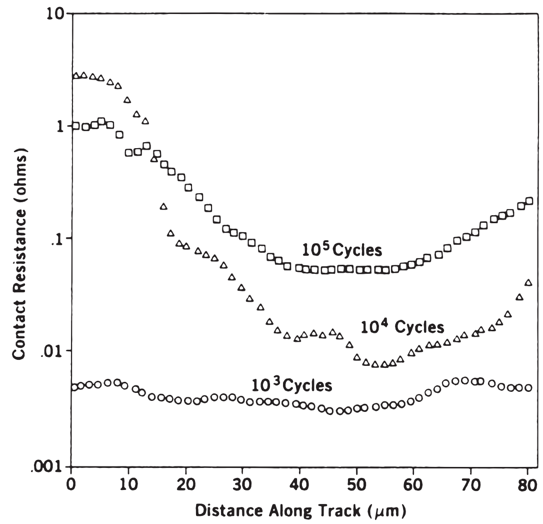


**Fig. 4** Variation of contact resistance along a track for increasing numbers of fretting cycles. Solid palladium rider vs. clad palladium flat fretted in air: 50 g, 80 μm wipe, 1 Hz.

observed during transient operation.

## 5. Materials Studies

Determination of contact resistance during the fretting of materials has been the subject of numerous studies. Many metals were systematically investigated by the author and his associates, and a review of this work forms the basis of the succeeding sections, supplemented by comments on important results from other investigations.

### 5.1 Apparatus

Figure 3 illustrates a forced displacement fretting apparatus which has proven versatile and convenient to use. The unique features of this equipment are its ability to fret small distances reproducibly and to measure contact resistance along the wear track. Details of the operation of this apparatus have been given previously [13]. All runs were with uncontrolled environment. The laboratory air ranged from 20 to 25°C and 20 to 50% relative humidity.

Contact resistance determinations are made using the dc four-wire dry circuit method with an open circuit voltage of 20 mV and with current limited to 100 mA. Current and voltage leads are clamped to the rider and flat. The circuit ordinarily is activated only for the cycle when contact resistance is being determined. A computer samples contact resistance at preprogrammed numbers of cycles. At these times, the table is stopped at the beginning of a wear track and the computer takes four measurements and stores them. The table then moves 1.6 μm and another four determinations are made. This procedure continues for the length of the track. Each set of measurements is averaged by the computer. A typical plot of contact resistance against distance along the track for a run with palladium contacts in which frictional polymers had formed is given in Fig. 4. Maximum contact resistance occurs at or near the ends of the track where insulating materials tend to accumulate. The maximum values are used in the subsequent analysis.

A useful categorization of contact resistance stability in comparing materials divides behaviors into three classes: *stable* (Type III), *unstable* (Type I), and *intermediate* (Type II). These behaviors are defined in Table 1 according to the numbers of cycles required to attain 10 mΩ and the contact resistance after $10^5$ cycles [14].

The materials studies which will be described are grouped according to their mix in a contact pair and whether film formation occurred. Wear out phenomena and the effect of material hardness are considered later. Freshly degreased specimens were flats mated to smooth hemispherically ended riders or crossed cylinders having a radius of curvature of 1.6 mm.

### 5.2 Metals Having Little or No Film-Forming Tendency

*Silver versus Silver.* Silver is low wearing, oxide free, and does not form frictional polymers [3]. It displays Type III (*stable*) behavior, as shown in Fig. 5.

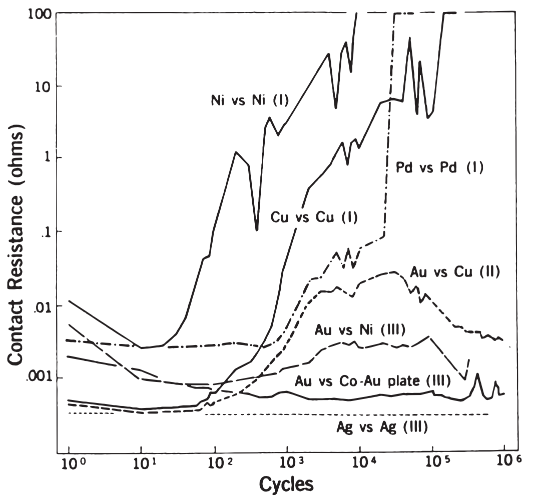


**Fig. 5** Contact resistance behaviors for various combination of materials fretted at 50 g with a 20 $\mu$m wipe at 4–8 Hz (contact resistance behavior according to Table 1). I (*unstable*): solid nickel vs. nickel plate 2.5 $\mu$m thick on copper; solid copper vs. solid copper; solid palladium vs. clad palladium 5 $\mu$m thick on nickel. II (*intermediate*): solid gold vs. solid copper. III (*stable*): solid gold vs. nickel plate 2.5 $\mu$m thick on copper; solid gold vs. 0.2% cobalt gold plate 0.6 $\mu$m thick on nickel underplate 2.5 $\mu$m thick on copper; solid silver vs. solid silver.

*Gold versus Gold.* Gold approaches silver in its stability. Although solid gold has been found to form a trace of polymer when fretted in benzene vapor [3] or immersed in an oil [1], this contaminant has no detectable effect on connector contact resistance. Figure 5 presents data for the fretting of solid gold against a 99.0% pure hard gold plate. Fretting gold versus gold contacts have Type III (*stable*) behavior [1].

Gold surfaces when scratched were found to catalyze the decomposition of adsorbed organic compounds [15]. These findings are in agreement with the small amounts of film observed in fretting and sliding studies. Copper reacted similarly to gold, but silver was much less active.

### 5.3 Non-noble Metals/Fretting Corrosion

*Nickel versus Nickel and Copper versus Copper.* Non-noble metals form fretting corrosion products which may have a significant effect on contact resistance after few cycles of operation. This is illustrated in Fig. 5 for nickel and copper contacts mated to themselves [1].

Electrodeposited *thick 60Sn40Pb* solder and tin versus themselves. The instability of contact resistance is illustrated in Fig. 6. Tin and tin lead have similar Type I (*unstable*) contact resistance and that of tin lead versus gold is even worse.

### 5.4 Frictional Polymer-Forming Metals

Polymer-forming materials include platinum, palladium, rhodium, and ruthenium, and many of their alloys [3].

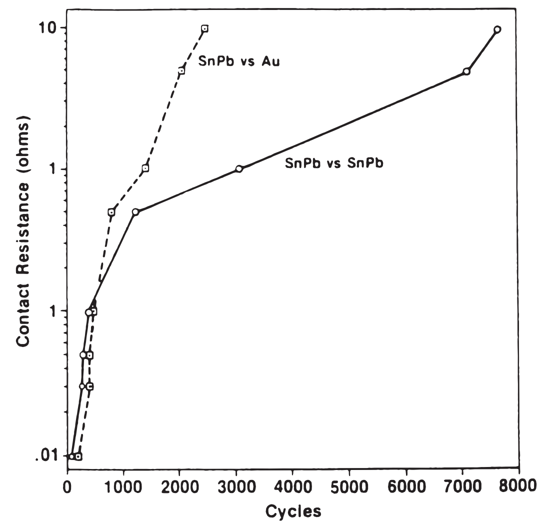


**Fig. 6** Contact resistance vs. number of fretting cycles for tin lead vs. tin lead compared with gold vs. tin lead-plated contacts (50 g, 8 Hz, 10 $\mu$m wipe).

*Palladium versus Palladium.* The contact resistance of palladium is Type I (*unstable*), as shown in Fig. 5.

*Palladium alloys mated to themselves.* Clad and electroplated Pd-Ag alloys and clad Pd-Au-Ag alloys are of interest as replacements for gold connector contacts. DG R-156, an inlay of 60Pd40Ag having a gold-rich surface with a diffusion gradient in the body of the alloy, is also used in connectors. The low polymer-forming tendency of materials from this group, especially DG R-156 and the Pd-Ag alloys from 70Pd30Ag to 30Pd70Ag, compared with that of palladium, is significant [16], [17]. Electroplated palladium nickel alloys containing 70–85% palladium are also widely used, but perform poorly in fretting [17], [44]. Flash gold overplatings can improve the performance of these metals until the gold is lost by wear.

*Mechanisms of frictional polymerization.* There has been much speculation on the mechanisms of frictional polymerization but the process is not well understood. The physical properties of frictional polymers, such as their adherence, depend on the contact metal [15], [18]. Poisons for conventional catalysis reactions are ineffective in stopping frictional polymerization, although the rate of reaction can be reduced when non-polymerizable low molecular weight compounds are present in the atmosphere or on the contact surfaces. Alloys of non-reactive elements with catalytic metals are less affected, and the particularly low activity of 60Pd40Ag [19] suggests that special influences can also occur.

More recently [20], [21] studies of relays indicate that palladium oxides can form on palladium-palladium contact surfaces operated is air in inactive (zero discharge) circuits when the level of organic pollutants is very low. Contact resistance increases due to the reaction product. Oxidation has been hypothesized to occur because of the mechanical energy involved in contact closure, hence the term, “mechanochemical reaction,” for the phenomenon.

### 5.5 Dissimilar Metals on Mating Contacts

Cold welding and transfer are likely to occur during fretting, particularly when the metals are noble, ductile or soft. Many practical systems involve contacts made of materials having different compositions, forms, or mechanical characteristics. Several important systems were studied with contact finishes of sufficient thickness so that wear out during test did not occur.

*Palladium versus Gold or Gold Alloys.* The gold and gold-silver versus palladium contact systems were early found to be satisfactory in practical applications, in contrast to all-palladium contacts which produce frictional polymers. This is because pure gold [13], high karat gold alloys [13] and gold-silver alloys [14] are softer than most forms of palladium. Consequently, transfer takes place primarily to the palladium surface, so that the system becomes all-gold or all-gold alloy. Type III (*stable*) contact behavior then occurs. On the other hand, if a metal which is significantly harder is mated to palladium, transfer will be from the palladium surface, thereby making the system all-palladium with resultant Type I (*unstable*) contact resistance. An example is 75Au25Cu (248 $kg/mm^2$ compared to palladium which is 196 $kg/mm^2$).

*Gold versus Nickel and Gold versus Copper.* The nickel-nickel and copper-copper systems have unstable contact resistance (Fig. 5) because of fretting corrosion [1], [22]. However, the contact resistance behavior improves dramatically when these metals are mated to pure gold [1]. In the case of electrodeposited nickel (450 $kg/mm^2$), which is considerably harder than gold, transfer occurs nearly entirely from gold to the nickel with Type III (*stable*) behavior, as shown in Fig. 5. When solid gold is coupled to solid copper (120 $kg/mm^2$) there is some contact resistance instability (Fig. 5), with Type II (*intermediate*) behavior.

*Gold versus SnPb Solder.* The gold versus electroplated 60Sn40Pb system has Type I (*unstable*) contact resistance [23] (Fig. 6), because of the transfer of tin lead to the gold, with resultant fretting corrosion of the base material on both surfaces. Gold transfer does not occur if the tin lead layer remains intact because of the large difference in the bulk hardness of the contact metals (electroplated gold containing 0.2% cobalt, 180 $kg/mm^2$; 60Sn40Pb, 12 $kg/mm^2$). Surprisingly, however, contact resistance begins to rise after fewer fretting cycles than in the all-tin lead contact pair. This result is consistent with hardware experience [12], [24]. This behavior has been postulated to originate in differences in the mechanics of disruption of surface films on the pairs of metals in contact [25].

## 6. Wear-Out Phenomena

Fretting wear may result in the penetration of a contact material having small thickness, as is often the case with electrodeposited and clad finishes. Contact resistance may change when this occurs, particularly if the substrate is subject to fretting corrosion or frictional polymerization.

### 6.1 Gold-Based Systems

Runs were made [1] with solid gold riders versus copper flats plated with golds containing about 0.2% cobalt as a hardener. Deposit thickness ranged from 0.05 to 0.6 $\mu$m. The contact resistance behavior was similar to that of solid gold versus unplated copper (Fig. 5), except that the maximum values after $10^4$–$10^5$ cycles varied from about 100 m$\Omega$ with the thinnest cobalt gold deposit, to 4 m$\Omega$ with the plating 0.6 $\mu$m thick. Contact resistances initially were less than 1 m$\Omega$ and remained relatively constant for several hundred up to 2000 cycles; then they rose gradually, followed by a slow fall and a leveling to a somewhat higher value than that obtained earlier. At equilibrium the surfaces of both contacts in a pair were a mixture of gold, copper and copper oxide, having a greater gold content the larger the thickness of gold originally plated on the copper substrates.

### 6.2 Palladium-Based Systems

Gold coatings 0.05–0.2 $\mu$m thick have been found [26]–[28] to be good metallic film lubricants for palladium and palladium alloys which, by themselves, have relatively poor adhesive wear on contact insertion. This has stimulated the use of palladium-based finishes that are less expensive than the equivalent thickness of plated hard golds.

However, gold plated (0.05 $\mu$m thick) on palladium, mated to itself, was found [28] to have Type I (*unstable*) contact resistance in fretting at 50 g with a 20 $\mu$m wipe. The thin gold layer was readily penetrated.

### 6.3 Tin Lead Alloy Systems

A scanning electron microscope–energy dispersive X-ray analysis [29] was made of contact surfaces for a system involving plated 60Sn40Pb mated to itself or to hard gold on nickel underplate. The substrates were brass. During extended fretting runs, contact resistance rose, then fell sharply, and finally increased again. Changing compositions of the surfaces due to wear was responsible for these results. An interesting finding was limited transfer of gold to the original tin lead oppos-

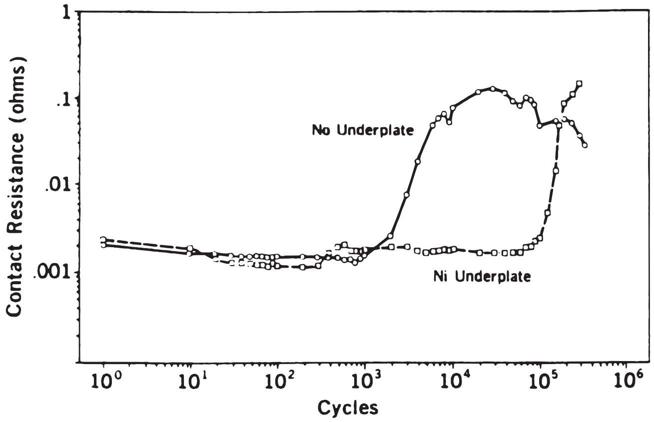


**Fig. 7** Contact resistance vs. the number of fretting cycles for solid 70Au30Ag alloy against cobalt gold-plated copper 0.05 $\mu$m thick with and without nickel underplate (2.5 $\mu$m). The contact resistance behavior is Type I (*unstable*) when cobalt gold-plated copper is used and Type III (*stable*) with the sample having a nickel underplate (50 g, 8 Hz, 20 $\mu$m wipe).

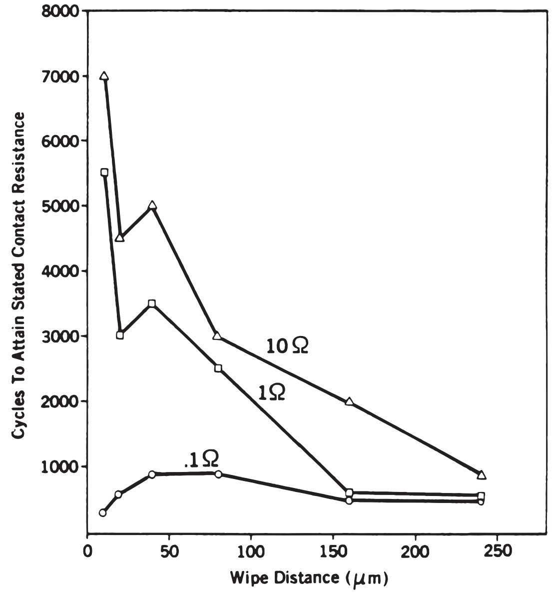


**Fig. 8** Number of fretting cycles vs. distance of wipe for 60Sn40Pb vs. 60Sn40Pb required to attain 0.1, 1, and 10 Ω: 50 g, 8 Hz.

ing contact. This was attributed to the much harder copper-tin intermetallics which spontaneously formed on that member on aging, and which become a contact surface after the tin lead layer had worn through.

### 6.4 Role of Underplate and Substrate

The durability of a thin plating when sliding over long tracks is affected by the composite hardness of the system. Thus, the incorporation of a nickel plating, which has a bulk hardness of about 450 kg/mm$^2$, between the gold deposit and a substrate that is considerably softer such as copper (about 120 kg/mm$^2$) is advantageous [30]. Figure 7 is an example [1] of the improvement in contact resistance for solid 70Au30Ag versus 0.05 $\mu$m cobalt gold plated copper with and without nickel underplate. Without underplate, wear-out of the gold occurs quickly and fretting corrosion ensues (Type I, *unstable* contact resistance).

It has been shown [1] that 70Au30Ag does not transfer to nickel as readily as does solid gold, and so following wear-out of the 0.05 $\mu$m cobalt gold layer beyond $10^5$ cycles, fretting corrosion of nickel was probably responsible for the insulating materials at the interface which caused the contact resistance to rise.

## 7. Parametric Studies

The same test conditions were used in all work described thus far: 50 g load, 20 $\mu$m wipe, and a cycle rate of 4 to 8 Hz. These studies were expanded by exploring a range of test conditions with typical contact materials that degrade by fretting corrosion or frictional polymerization [1].

### 7.1 Cycle Rate

Contact resistance changes due to fretting corrosion and frictional polymerization can be expected to be influenced by frequency because both involve rate-dependent surface chemical reactions. For example, with lower frequency, oxide thicknesses in fretting corrosion can grow larger between wipes. Hence, the numbers of cycles to attain a given rise of contact resistance becomes less.

### 7.2 Wipe Distance

The amplitude of wipe controls deterioration, for the amounts of insulating films which are produced depend on the distance that is swept.

Figure 8 shows typical results from tin lead fretting where the numbers of cycles required to attain stated levels of contact resistance are plotted against wipe length from 10 to 240 $\mu$m [23]. The longer the track, the fewer the cycles for contact resistance to degrade. Similar results were obtained [31], [32] in frictional polymerization studies with palladium-palladium contacts, both dry and lubricated, at the test conditions of Fig. 8.

### 7.3 Force

Increasing force enhances the penetration of fretting corrosion products or frictional polymers, and thereby lowers contact resistance. The effect of a given increase has been found to be less with tin lead than with palladium contacts, probably because fretting corrosion films are tougher than frictional polymers [23].

## 8. Environmental Effects

The frictional polymer-forming tendencies of organic vapors in palladium-palladium fretting were studied by various workers [3], [33]–[35].

It was earlier shown (Fig. 5) that solid silver does not degrade in air due to fretting. However, if the environment contains a high concentration of gaseous pollutants which can tarnish silver, such as hydrogen sulfide and chlorine at elevated relative humidity, then films may form so rapidly that fretting corrosion occurs. This was demonstrated in a laboratory test at a low cycle rate and relatively small contact normal load [36] using the Battelle Class III flowing mixed gas atmospheric test. At higher loads and fretting velocities, there was little or no effect from these pollutants [37].

## 9. Thermal

There is interest, particularly in the automotive sector, in thermal effects. For example, the numbers of cycles to failure [38] at particular test conditions for tin plated contacts was determined with test apparatus similar to Fig. 3. It was concluded that with rising temperature to about 60°C, an increase in the oxidation rate of tin was responsible for a reduction in cycles to failure. At still higher temperatures, to 110°C, the tin softens. This results in an enlargement of the contact area, with subsequent improvement in fretting corrosion behavior [39].

## 10. Contact Geometry

Contact geometry was found [40], [41] to affect the stability of contact resistance of fretting plated tin lead. Contacts having a 90° or 120° wedge shape were superior to domed contacts when mated to tin lead-plated flats. Motion was mechanically or thermally forced at right angles to the line of contact of the wedge.

## 11. Effect of Current

Current may affect surface films and thereby alter contact resistance. At relatively small levels of voltage and current, electrically insulating thin oxides or polymers may break down, or "frit." This would lower contact resistance compared to fretting without power. Such behavior was found in studies at 5 and 14 V with tin plate [42], and at 1 and 2 V with tin lead plated [43] contacts. There were, however, contrary results in limited studies with electrodeposited gold and gold flashed palladium nickel [44] contacts in which a small current, 100 mA, at 10.5 V degraded their performance.

When appreciable voltage and especially high currents are employed, however, as would be usual for power connections, there can be a profound effect on interfacial topography, film formation, and contact resistance due to fritting, resistance heating, and microarcing. Films can cause heating which accelerates oxidation and, depending on the circuit, leads to melting and loss of electrical continuity.

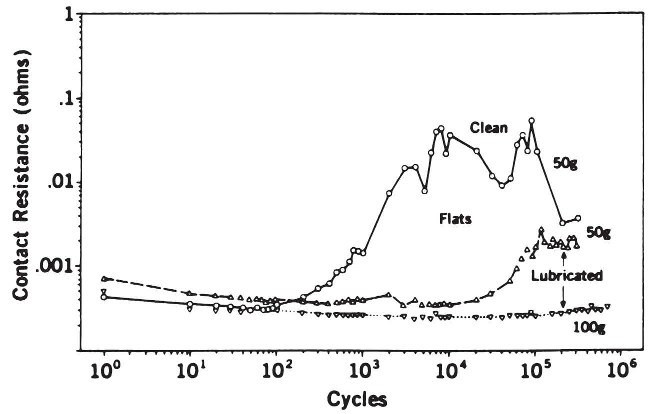


**Fig. 9** Contact resistance vs. fretting cycles for solid gold riders against 0.23 μm cobalt gold plated copper flats, with and without polyphenyl ether obtained by immersion and withdrawal from a 0.5% solution of the contact lubricant in a volatile solvent: 20 μm wipe.

## 12. Control of Fretting Degradations with Lubricants

Lubricants can significantly improve the contact resistance behavior of fretting electrical contacts. The amount of lubricant required depends on the contact metal and the mechanism by which it degrades. Also, only fluids and greases are useful; solid lubricants, such as microcrystalline wax, are of little value in fretting because they are quickly displaced from the contact.

*Reduction in Rate of Wear.*

Oxides which form during the fretting of base metals originate in loose wear debris. A lowering in wear rate will, therefore, tend to stabilize contact resistance. When the contact finish is gold, a reduction in its wear is beneficial, for the time until base underlying metal is exposed is extended. An example [1] is given in Fig. 9 which compares the contact resistance during fretting of gold plated copper with and without a lubricant.

*Effect on Frictional Polymerization.*

Lubricants are able to stabilize the contact resistance of metals which degrade by frictional polymerization, and effectiveness usually is strongly dependent on thickness of the lubricant.

An example is given in Fig. 10 with fretting palladium contacts having a gold flash where a 5-ring polyphenyl ether coating from a 0.5% solution in a volatile solvent was used. The maximum contact resistance was three orders of magnitude less with lubricant than without it, and the initiation of contact resistance rise was also significantly delayed. Probably the effectiveness of the lubricant was due to both reduction in the rate of wear of the gold flash and contact resistance

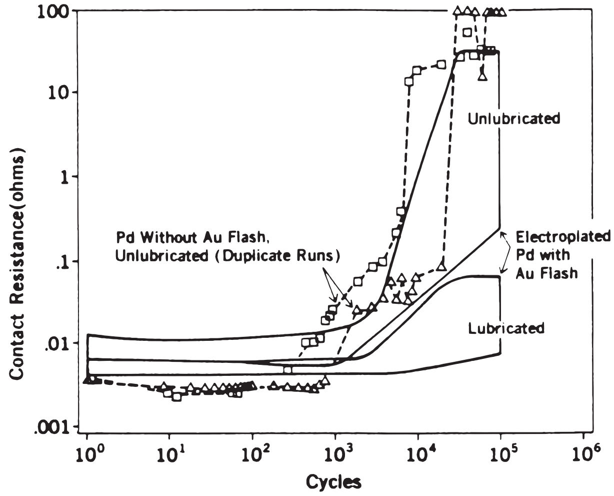


**Fig. 10** Contact resistance from fretting of samples with pure gold flash on 1.5 $\mu$m palladium having a 1.25 $\mu$m nickel subplate mated to itself, clean and lubricated with a polyphenyl ether obtained by immersion and withdrawal of both contacts from a 0.5% solution in a volatile solvent. All data from four replicate runs at each condition fall within their respective bands. Data for duplicate runs with unlubricated palladium without gold flash is indicated by dashed lines. The gold flash has limited durability at the test conditions. Contact resistance is more stable when lubrication is used: 50 g, 20 $\mu$m wipe.

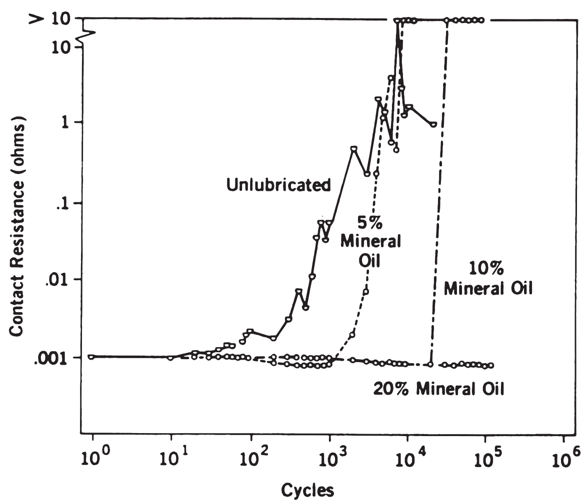


**Fig. 11** Contact resistance vs. fretting cycles for 60Sn40Pb vs. 60Sn40Pb plated contacts. Flats lubricated by immersion and withdrawal from 5, 10, and 20% solutions of U.S.P. mineral oil in a volatile solvent. The thicker the lubricant layer, the greater the stability of contact resistance: 50 g, 20 $\mu$m wipe.

stabilization once the gold had been worn away to underlying palladium.

Mechanisms: Frictional polymers can readily be dispersed by excess unreacted lubricant and contact resistance is little affected [19]. Polymers may also be less tough if fluid is incorporated in their matrix to produce a gelatinous solid [1].

*Effect on Fretting Corrosion.*

Both fluids and greases have long been recognized [2],

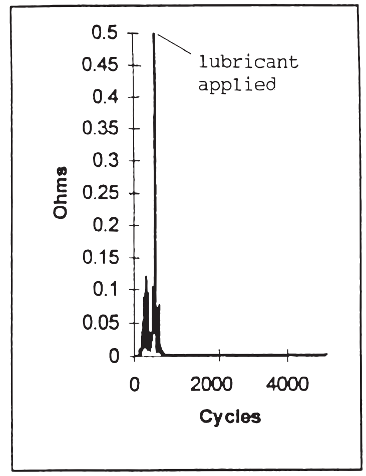


**Fig. 12** Tin lead vs. tin lead, dry. Fretted (50 g, 10 Hz, 40 $\mu$m wipe) until contact resistance increased by 0.5 Ω; lubricant applied, contacts reseated, and fretting resumed. Contact resistance fully recovered.

[45] to be effective in inhibiting the increase of contact resistance in fretting corrosion, and an example [23] is given in Fig. 11 for tin lead-tin lead contacts. Lubricants were of little value unless thick layers were used. The effectiveness of a lubricant appears to be more dependent on its quantity than on its composition. It is better to apply the lubricant to both contacts than to only one, for a thicker coating is obtained in the mated system.

Mechanisms: The mechanism by which lubricants stabilize contact resistance in fretting corrosion is by wear reduction, dispersing insulating solids, and by shielding the surface from air thereby retarding the rate of oxide formation.

*Recovery of Failed Contacts*

Unlubricated connections that have failed by fretting corrosion or frictional polymerization can often be returned to service by the application of lubricants. If a lubricant is applied to a failed contact which is them reseated, this action can disturb the insulting layer so as to reestablish a good connection. The process described above, by which the lubricant protects the contact from degradation, will then function to prolong the life of the connector. This was demonstrated in experiments involving various lubricants with tin lead and gold flashed 80Pd20Ni plated contacts mated to themselves and with tin lead mated to gold plated contacts [29]. Typical results are shown in Fig. 12 where tin lead-tin lead contacts were fretted at 10 Hz, 50 g, and 40 $\mu$m wipe. After several hundred cycles, the contact resistance increased by 0.5 Ω and was considered to be a failure. Fretting was stopped and the contacts were then lubricated with a drop of 20% of a water insoluble polyalkylene glycol in isopropyl alcohol. When the solvent evaporated, the contacts were slid together five times to simulate reseating, and fretting was resumed. After 120,000 cycles of movement there was no significant increase in contact resistance from the initial level.

## 13. Conclusions

Separable electronic connectors have serious reliability problems in many applications due to fretting. This results in the formation of insulating films, such as oxides and organic polymers, on the contact surface. The trend away from thick gold (about 1 $\mu$m) finishes, to thin golds, to platinum group metal, and to base metal contacts (such as tin and its alloys) has caused these difficulties. Numerous studies have identified the degradation mechanisms and the relation between fretting failures to contact materials compositions and properties and to connector/contact design parameters. Contact lubricants are often of value in minimizing fretting failures, and their application may be the most cost-effective solution to the problem.

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