Stationary Lubricants Increase Connector Reliability

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The most frequent cause of failure in portable systems such as cellular telephones, computers, instruments, etc. is not a defect in an active or passive component, nor the breaking of a component interconnect. Instead, the most common cause of failure is a defect at the metallic interface inside a connector. For example, when a cellular telephone connector fails, the user may hear static or intermittent feedback. Or he may find that the geographic range of the telephone has suddenly diminished, and that he cannot place a call from an accustomed location. If the failure is more serious, he may find that he has no reception at all.

The metallic interface inside a connector is typically tin or tin-lead, but may be plated with a very thin layer of a noble metal such as gold. Whether a pin is tin or gold, the failure mechanism begins with wear due to friction at the metallic interface. In cellular telephones, wear is usually the result of micromotion, which may involve displacement between the pin and the socket of only a few microns. Vibration from handling of the telephone is one cause of micromotion. Another less obvious cause of micromotion is temperature change. The base metals at the point of contact and the plastics used in the connector have different coefficients of thermal expansion, and a thermal change of only 10° C. can cause linear micromotion of 5 microns. Ordinary daily use exposes a cellular telephone to numerous sources of vibration and to numerous temperature changes. Therefore, micromotion between the pin and the socket is a very frequent phenomenon.

The wear from micromotion abrades (or it causes what is known as "fretting corrosion" on) the surface of the metallic interface. If the metallic surface is plated, the gold, which is generally only a fraction of a micron thick, may be removed; if the pin is not gold, the tin-lead surface is scored. But abrasion by itself does not generally cause an interconnection failure, primarily because a more powerful failure mechanism occurs first. Micromotion exposes less noble sublayers below the less corrosive tin or gold layers. These sublayers are quickly oxidized and are sensitive to contact with moisture and other airborne contaminants. The moisture and airborne contaminants (sulfuric acid, nitric acid, and many more) create electrolytic cells that begin the corrosion of the pin and promote rapid failure. Failure actually occurs when the corrosion products grow and eventually separate the metallic surfaces at the point of contact.

A very large number of airborne contaminants are present everywhere in the atmosphere. Over 150 common organic contaminants have been identified, and there are inorganic contaminants as well. Many exist in the atmosphere as suspended aerosols; some are fine particulate solids. They attack not only connectors but also plastic-packaged integrated circuits. In plastic ICs, contaminants and moisture may enter along the external leads, or they may settle on the package surface and then migrate as ions through the epoxy. Within 24 hours the entire volume of a plastic IC package will have reached equilibrium with the surrounding atmosphere. In cellular telephones, it appears likely that oxygen, moisture and contaminants may migrate into the plastic housing around a connector in similar fashion and, therefore, may eventually reach the metallic surfaces of the connector. But the primary route for contaminants is probably along the surface of the pin.

The connector's metallic interface can be protected from both abrasion and subsequent corrosion by a specialized class of lubricants called polyphenyl ethers. Polyphenyl ethers have little in common with other lubricants such as greases and oils. Once applied to a metallic surface such as a connector pin, polyphenyl ethers do not migrate from the point of contact, even if they are subjected to extensive temperature, motion and high pressure. Instead, they remain where they were applied. One important application for polyphenyl ethers - and the original reason for their development - is on the internal rotors of the jet engines in commercial aircraft. A growing application is on the metallic interface of connectors in microelectronic systems.

Why do polyphenyl ethers remain at the point of contact? Instead of forming a continuous sheet or film, as you might expect a lubricant to do, polyphenyl ethers form a field of tiny droplets between the two solid surfaces. Each droplet is in constant, localized motion similar to Brownian movement. Thus, even though each droplet moves, the field of droplets remains stationary. There are, of course, spaces between the droplets, but contaminants - moisture, sulfuric acid, and all the others - cannot reach the solid surfaces in these spaces.

The mechanism that prevents contaminants from reaching the surfaces is not yet completely understood. One theory is that the constant localized motion of the droplets enables them to capture the contaminants. A second theory relates to the squeezing down of the lubricant at the connector contact point (where there is an applied outside normal force) in addition to the forces inherent in the very high surface tension of the polyphenyl ether molecule. The combination of these forces is thought to be another reason for the stationary property and performance of the polyphenyl ether lubricants in connector applications.

Polyphenyl ethers have other desirable qualities as well. They are stable at temperatures higher than those commonly encountered in cellular phones or other electronic systems. The ambient temperature to which polyphenyl ethers are exposed in one jet engine is 316° C. Chemically, they are relatively inert, and when used on connector pins would not react with nearby metal and plastic elements even if they could migrate to them. They also have a very low vapor pressure. A very thin film of polyphenyl ether deposited onto a tin-lead connector pin will, at normal temperatures and pressures, evaporate only after 40 to 50 years.

The surface of a tin-lead pin is, microscopically, not really smooth, but consists of low points and high points. The high points are called asperities. On a tin-lead connector, the asperities are typically 15 to 20 microns high. If polyphenyl ether is applied in its undiluted state, it will form a coating about 250 microns thick - much more than is really needed. In production, the polyphenyl ether is first diluted in a solvent, and the pins are dipped into the solvent. After the solvent evaporates, a layer of polyphenyl ether about 10-20 microns thick remains. This layer (which is actually a field of tiny droplets) is high enough to provide lubrication between the asperities of the tin-metallic interface and to prevent wear that would expose the non-noble sublayers to corrosion.

One interesting test is to coat a connector pin that has already become corroded with a polyphenyl ether. The performance of the pin immediately improves, because the droplets of the lubricant have absorbed the corrosion products that were preventing contact between the pin and the socket.

The actual performance of a polyphenyl ether on a tin-lead surface was tested by using a fretting machine, which performs at an accelerated rate the type of micromotion that would be expected in a microelectronics system. The samples were rods of 60% tin and 40% lead, and were arranged at 90° to each other. One rod was held stationary, and the other rod moved back and forth over the pin at a constant pressure. The range of travel was 50 microns, and the moving rod was loaded with 50 grams of force.

The results of testing unlubricated rods are shown in Figure X [Fax page 9]. Ohms (y axis) measure friction and wear during the approximately 3600 cycles of this test. At the very beginning, resistance is very low. But after only a few hundred cycles, resistance increases rapidly. In part this resistance is the result of surface roughness that is being abraded; the two rods are beginning to cut into each other. But part of the resistance at this early stage is also caused by exposure of clean metallic surfaces, which oxidize quickly and from loose oxide particles.

After the initial high resistance, the two tin-lead surfaces are worn through to the copper base metal and resistance declines sharply - but not for long.

Shortly after 2000 cycles of 50-micron travel, the copper surface has a thick oxide layer. At the same time, particulate deposits have accumulated on the surface, and resistance begins to increase. Resistance increases rapidly and is soon followed by total failure at about 3600 cycles. This number of cycles is not unlike the number of cycles of micromotion that a cellular telephone or similar system traveling in a car or airplane would experience in a day.

Results of the same test using tin-lead rods coated with a polyphenyl ether are shown in Figure X [Fax page 10]. Instead of ending with failure after 3600 cycles, this test continued until it was arbitrarily terminated after 500,000 cycles. There are no spikes in the resistance, and there was no failure of the rods. The stationary, inert polyphenyl ether prevented both wear damage and corrosion throughout the 500,000 cycles.

Summary

No other lubricants have the characteristics of polyphenyl ethers: stability at high temperatures, very low vapor pressure, and above all their ability to remain at the contact point without migrating. They also provide, by an unusual mechanism that is not yet fully understood, a high degree of protection for connectors from atmospheric contaminants. Applied to connector pins in a very thin layer, polyphenyl ethers can extend the service life of connectors by a factor of 1,000 or more. Increasing the service life of connectors - the most frequent failure site in cellular telephones - greatly increases the reliability of the telephone.

Acknowledgements:

The assistance of Dr. Neil R. Aukland in editing of this paper, and helpful discussions with Dr. Roland S. Timsit, are appreciated. In addition, we appreciate the assistance of New Mexico State University for generating the fretting test data and certain figures used in this paper.

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Figure captions for Stationary Lubricants Increase Connector Reliability:

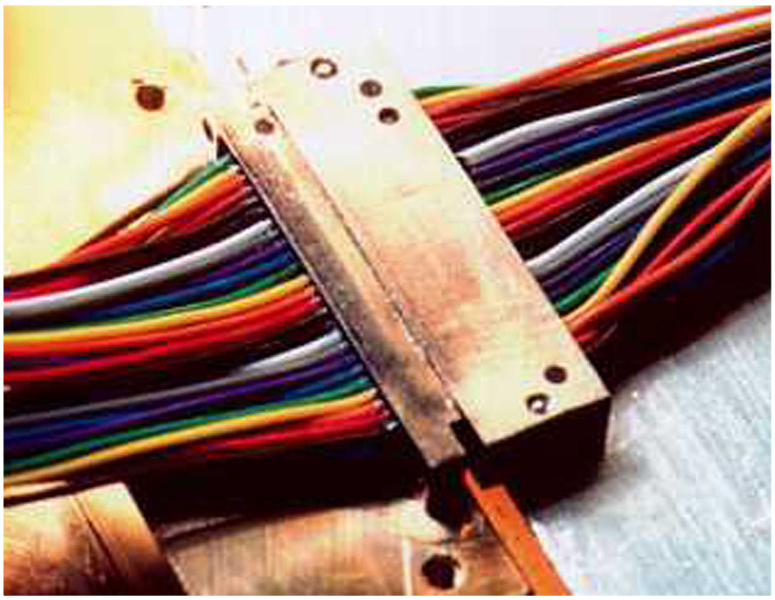

Figure 1 - Most failures in cellular telephones and similar systems are caused by connectors.

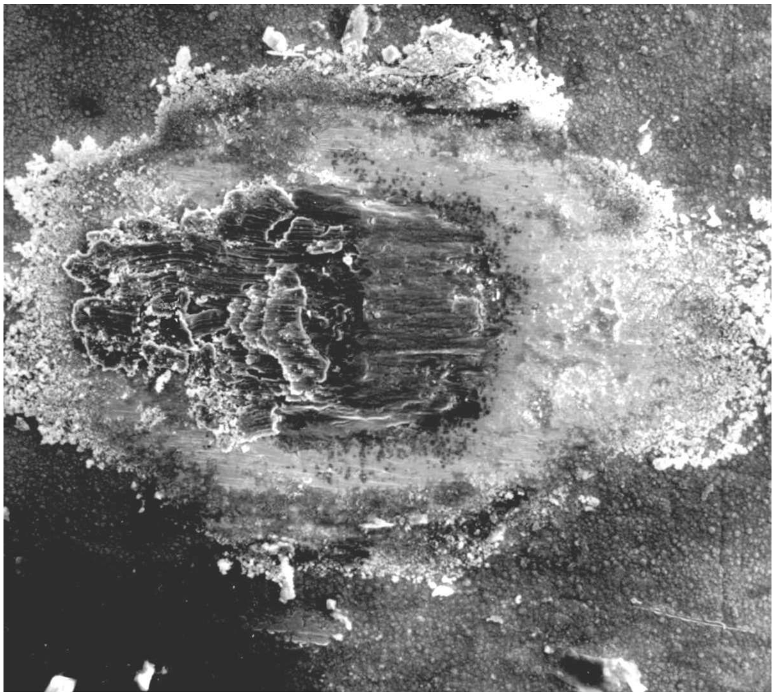

Figure 2 - Micromotion abraded this pin and created the burnished area at center where the tin-lead plating has been worn away to expose the copper beneath. Piled around the burnished area are oxidation products and metal particles that interfere with electrical transfer. The process is dynamic: as micromotion continues, more debris collects and more oxidation occurs.

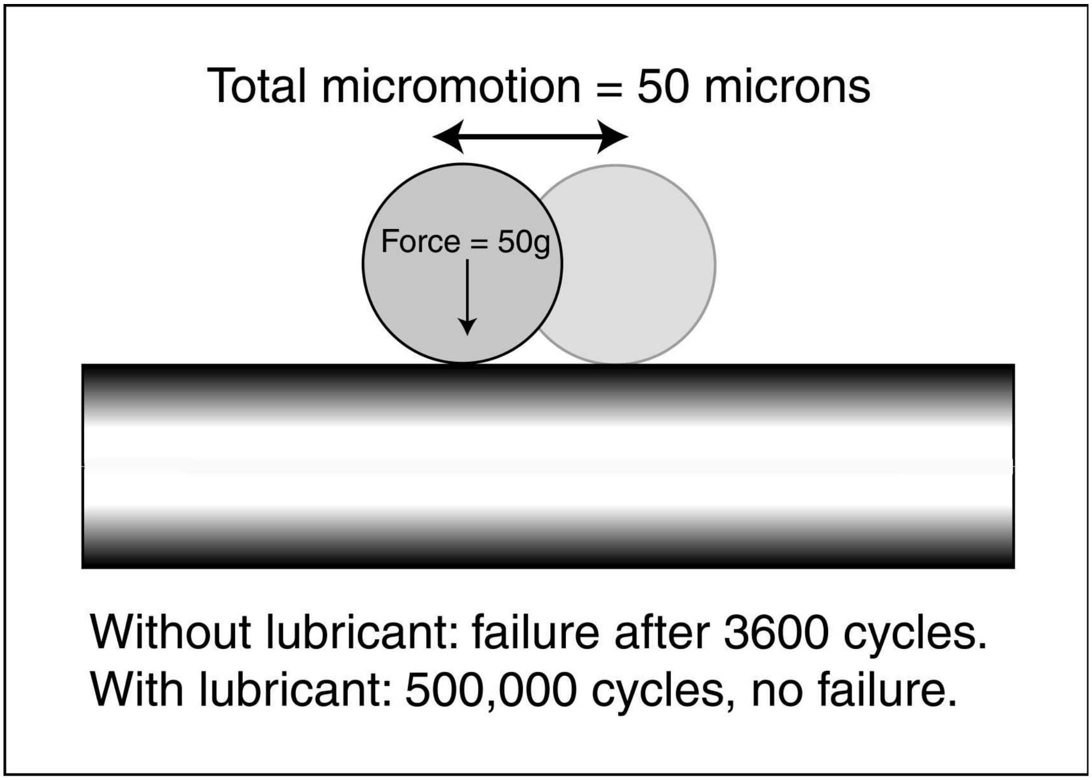

Figure 3 - A fretting machine test using two pins showed that unlubricated pins failed after 3600 cycles, while pins lubricated with polyphenyl ether had no damage after 500,000 cycles.

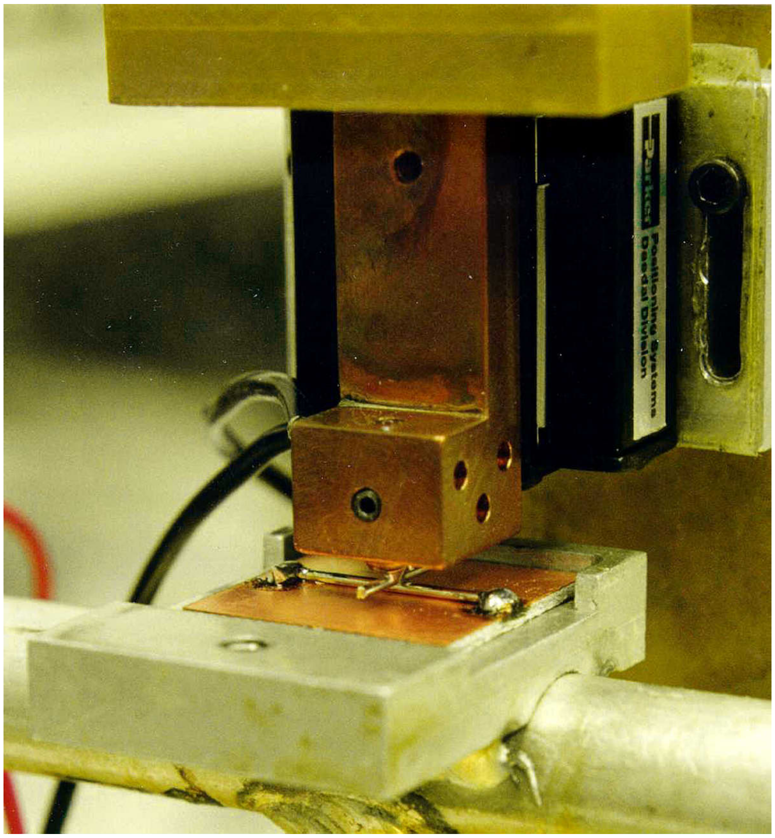

Figure 4 - Fretting machine used to simulate micromotion in both lubricated and unlubricated pins.

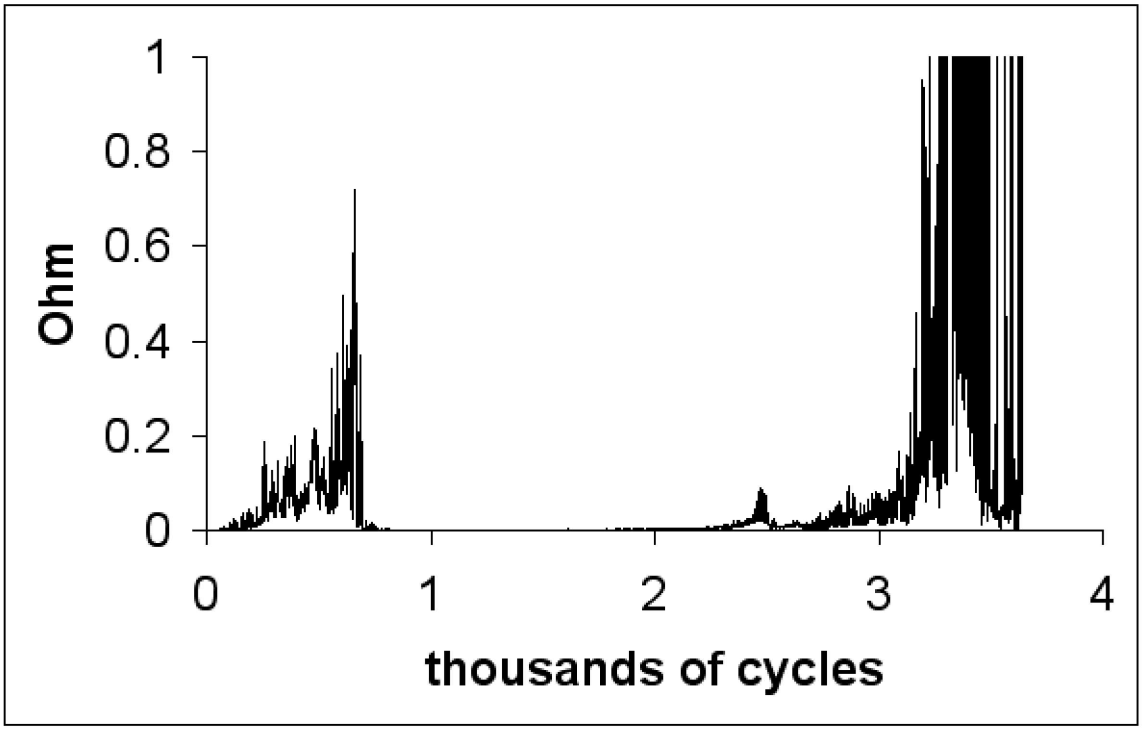

Figure 5 - Unlubricated pins were tested on a fretting machine to simulate micromotion. Early high resistance (peaks at left of chart) is followed by even higher resistance when tin-lead coating is worn through. Failure (at right) occurred after about 3600 cycles.

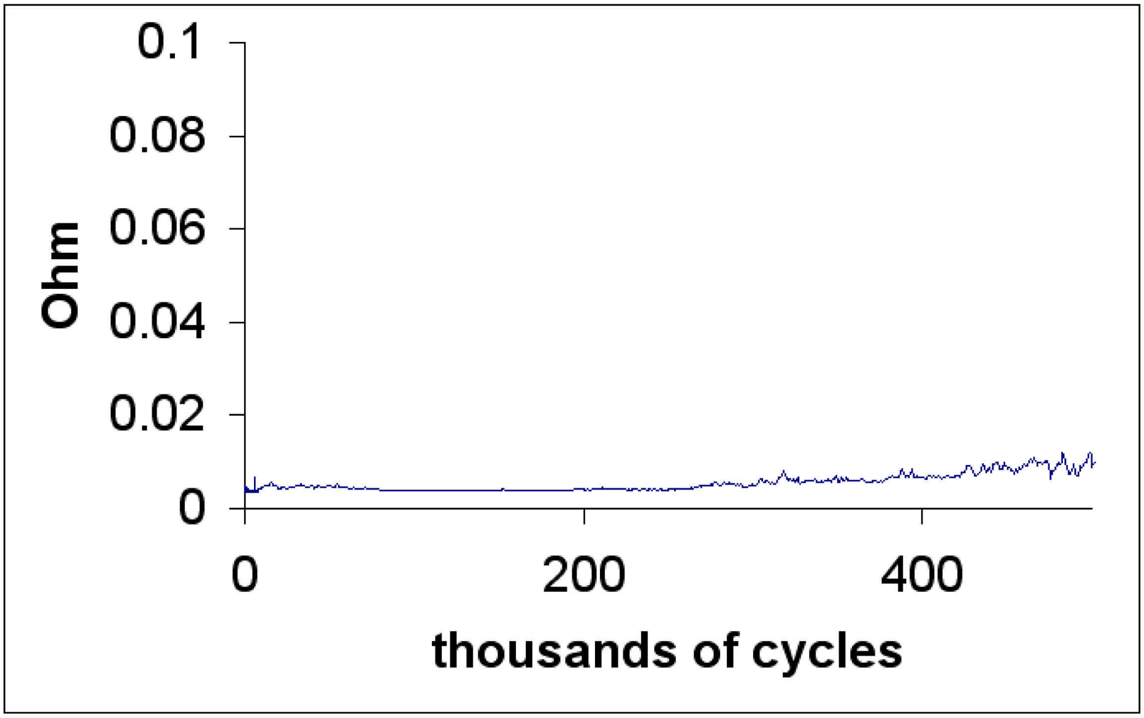

Figure 6 - Pins lubricated with polyphenyl ether were tested in the same way. Resistance (y axis) is lower throughout. The test was ended without failure after 500,000 cycles.

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