Low Friction and Wear on Non-Lubricated Connector Contact Surfaces

Dr. James Moran (Tribotek, Inc.)
Dr. Matthew Sweetland (Tribotek, Inc)
Professor Nam P. Suh (Massachusetts Institute of Technology)

Tribotek, Inc.
30 North Ave
Burlington, MA 01803

Introduction:

In mechanical systems there are three major sources of friction; asperity interaction, adhesion and plowing, (Suh and Sin. 1981; Suh. 1986). An asperity is a slight protrusion from a surface such as a bump or point. As two mechanical surfaces slide past each other these asperities collide, resisting motion. As the force increases asperities are sheared off or deform, eventually becoming loose wear particles as shown in figure 1.

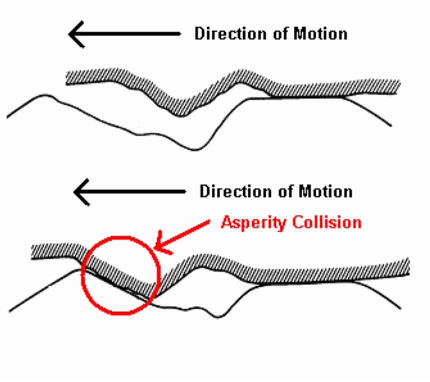

Figure 1: Asperity Interaction

Adhesion is actually local welding resulting from the high stress concentrations on microscopic points of contact. Adhesion may result where surfaces contact each other. Because no surface is perfectly smooth adhesion occurs at a discrete number of points as shown in figure 2. The welded adhesion junctions must be sheared before the surfaces can slide relative to each other. The breaking of these welds is one source of friction.

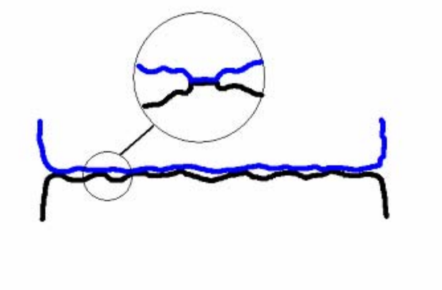

Figure 2: Example of Adhesion

The largest contribution to friction in most engineered systems is due to the plowing component by wear particles (Suh and Saka, 1987). When loose particles are trapped between the surfaces, excessive loads can be concentrated on these particles. This heavy loading results in the particles becoming partially embedded in one or both surfaces depending on their relative hardness, see figure 3. When the surfaces then move relative to each other, the particle cuts a groove in the surface(s). The energy required “to plow” the surface(s) is a component of friction, and the additional particles that are generated are both a component of wear and a source of additional particles that contribute to additional surface plowing. When friction is primarily due to plowing, the frictional force depends greatly on the depth of penetration with the coefficient of friction increasing nonlinearly as a function of the depth of penetration. In materials with dissimilar hardness the wear particle will penetrate one material further than the other while in materials with similar hardness the wear particle will penetrate both materials by approximately the same amount. This results in the total depth of penetration being greater for materials of a similar hardness than for materials with a dissimilar hardness. Again, because the coefficient of friction increases as a function of the depth of penetration, friction forces are greater for two materials of similar hardness.

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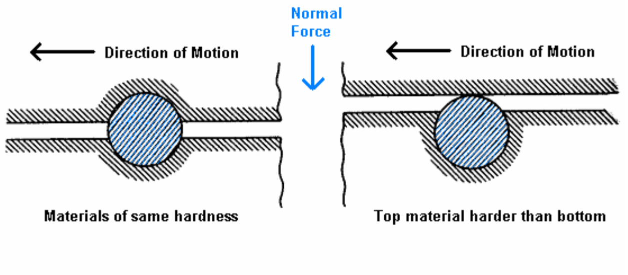

Figure 3: Friction from plowing

The relative magnitude of asperity interaction, adhesion and plowing varies from system to system. There is strong evidence to suggest that asperity interaction is responsible for the static coefficient of friction, which can vary between 0 – 0.5 (Suh and Sin, 1981). The adhesion component of friction between metals does not play much role in many engineering surfaces although it could vary between 0 – 0.4. Many experiments performed with undulated surfaces indicate that when the plowing by wear particles is eliminated the friction between sliding surfaces can be as low as boundary lubricated surfaces. Even the friction with boundary lubricants is caused by micro-plowing. To eliminate plowing by wear particles, undulated surfaces were created (Suh and Saka, 1987). Another way is to reduce the apparent area of contact to an extremely small size to allow the wear particles to escape.

Friction in Electrical Interconnects:

A typical electrical connector interface is shown in figure 4. In order to obtain low contact resistance the technical approach has been to use high normal forces and wiping action. The wipe was to remove surface particles, such as oxides or contaminants and the high normal force was to assure good electrical contact even when surface particles were trapped between the contact points. Typically a normal force of at least 50-100g is required to provide the minimal contact resistance (Mroczkowski, 1998).

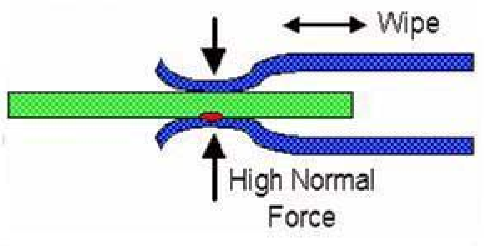

Figure 4: Electrical connector interface

A higher normal force results in a high friction force and higher wear. The wear is usually not a problem in low cycle applications but can be problematic in high cycle applications. The high friction force results in large insertion forces which in some applications necessitates the use of special fixtures and levers to insert the connectors. If there is any pin misalignment these forces can easily break the pins so connector alignment becomes an important issue. Also if a high insertion force connector is mounted on a circuit board, the board must have sufficient strength, using stiffeners if appropriate, to accommodate the large insertion force.

This normal force is usually provided by the electrical contact itself. Since copper has a low stiffness (~16Mpsi) a copper alloy, such as Beryllium Copper must be used. This has the disadvantage of having a lower electrical conductivity than pure copper resulting in a higher connector bulk resistance.

Traditional Methods of Friction Reduction:

Lubrication of the interface is obviously one commonly used method to reduce friction and wear. However, in many cases lubrication is not desired or even possible. Lubricants can attract foreign debris (eventually increasing friction and wear) and lubricated systems generally require frequent maintenance which can be time consuming and expensive.

Another method to reduce friction is to increase surface hardness of one surface. This concentrates the plowing action on only one soft surface, reducing the total depth of penetration and reducing the amount of friction.

Since the largest contribution to friction is made by the plowing mechanism, eliminating wear particles from the interface before they agglomerate can result in significant reductions in friction and wear. A means of removing particles from the sliding interface is to create "wear particle traps." These traps are generally created by providing undulating surfaces with valleys into which wear particles can fall. Research has shown that the coefficient of friction can be reduced by a factor of 5 or so through this technique. However particles traps have had less success and popularity since they are expensive to manufacture and produce features that are prone to increase stress and fracturing.

Alternate Approach:

Another solution for low friction electrical contacts is to generate multiple controlled contact points using a woven material interface, see figure 5. This multiple point of contact approach has been previously used in metal fiber brushes for electric motor design, (D.Kuhlmann-Wilsdorf, 1999). By using a tensioning fiber to generate the normal force between multiple conductive weave elements and a curved surface, multiple contacts points can be easily generated, each with a controlled normal force. Each point within the weave structure can move a small distance independently from the surrounding points. The required normal force at each point is very low. This type of contact interface results in a highly redundant interface that resists surface plowing due to the large amount of space between points of contact and the ability of each point to move independently to accommodate weave particles and asperity interactions. It also helps prevent plowing by wear particles because of the extremely small apparent contact area at any given point.

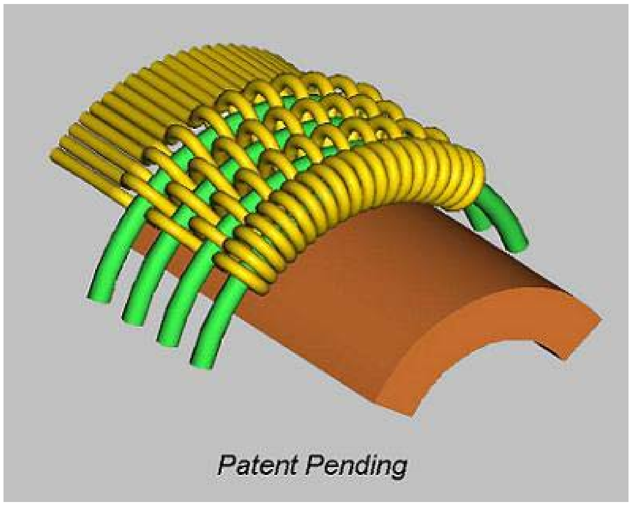

Figure 5: Woven material contact interface

At each of the contact points there is a separate low normal force of approximately 5g. This reduced normal force reduces friction caused by adhesion and plowing, as shown in figure 6. This "local compliance" can virtually eliminate the plowing component of friction and wear, significantly increasing the life of sliding contact surfaces.

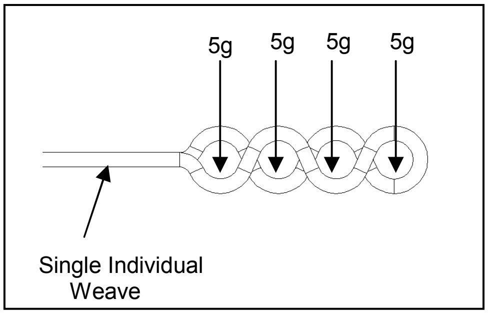

Figure 6: Normal forces on each individual weave element

This design approach has the additional advantage of allowing the separation of the functional requirements of generating the required normal force and providing an electrically conductive path. By separating the functional requirements, separate materials with optimal electrical and mechanical properties can be used unlike the materials often chosen for spring beam (fork and blade) type connectors. Therefore this design can use gold plated pure copper for the electrical contacts and not sacrifice conductor conductivity.

Experimental Setup and Results:

In order to verify that this design approach for a contact interface is feasible, it is necessary to show that a low contact resistance is possible with a low normal force. The goal is to understand the relationship between the individual contact geometry, overall weave structure, number of contact points, electrical performance, and wear characteristics. The following apparatus was built which enabled testing of various combinations and types of weave elements (Figure 7).

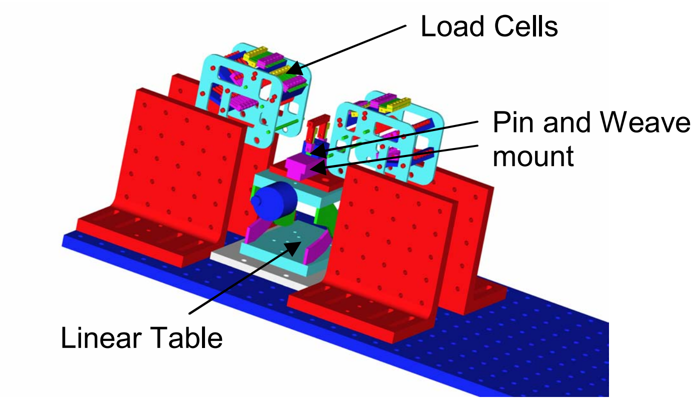

Figure 7: Apparatus for testing contact resistance of individual weave element

Engineering fiber was run through each of the ‘loops’ in the weave. The weave itself is made from various copper alloy wires, 0.005” in diameter, gold plated with 20μin of gold over 20μin of nickel. The fiber was attached to springs which varied the tension in each fiber strand. This tension was measured with miniature load cells. The weave element was placed on a male pin (also plated with 20 μin of gold over 20 μin of nickel) and the weave/pin assembly could be moved in the Z-direction. The combination of Z height and fiber tension and male pin surface diameter controlled the normal force at each contact point on the weave. The overall resistance of the weave/pin assembly was measured using a micro-ohmmeter, which is not shown in the figure.

Several different kinds of weave were tested. Weaves were tested with 4, 6 and 8 loops. Weaves were either ‘crossed’ which indicated that the copper wire crossed itself as it formed the loop or ‘uncrossed’. The testing was designed to measure the variation in separable contact resistance as a function of number of contact points, average point normal force and weave stiffness. Changing the copper alloy and the structure of the weave (crossed vs. straight) changes the relative mechanical stiffness of the weave structure. The results are shown in figure 8. As can be seen there is some scatter among the individual weaves but the trend line is similar for all. At a contact force of 0.005N (0.5g) the contact resistance is relatively high, varying between 7 and 14mohms. As the contact force is increased up to a value of 0.05N (5g) the resistance decreases, asymptotically approaching a steady state value of around 4 mohms. There is no point in increasing the design normal force beyond 0.05N as this does not lead to a comparable reduction in resistance. Therefore 0.05N is considered the optimal normal force for low insertion force and low wear, for all tested weave designs.

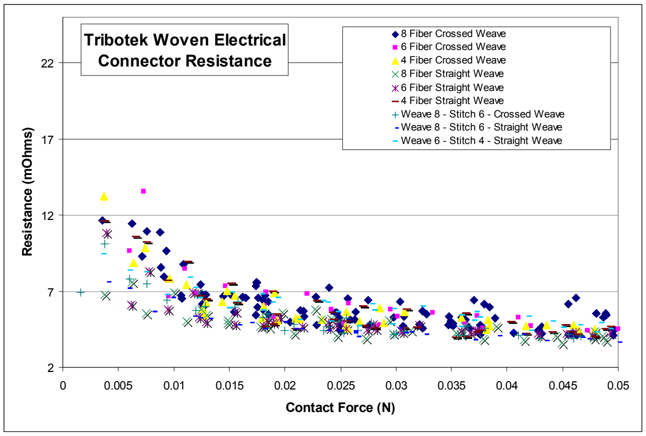

Figure 8: Contact Resistance measurements for individual weave elements

Wear Tests:

Similar experiments were run to identify wear mechanisms in a weave element. A single weave element of Beryllium Copper was used for this test. A normal force of 3.8g was applied to the weave. A male pin was cycled in and out of contact with the weave. The resistance was measured at each successive insertion. If the gold plating was prone to wear the resistance should increase over time. As can be seen from the data in figure 9 there was no increase in resistance over 5000 cycles. A microscopic examination of the weave under 300X magnification revealed no visible signs of wear either.

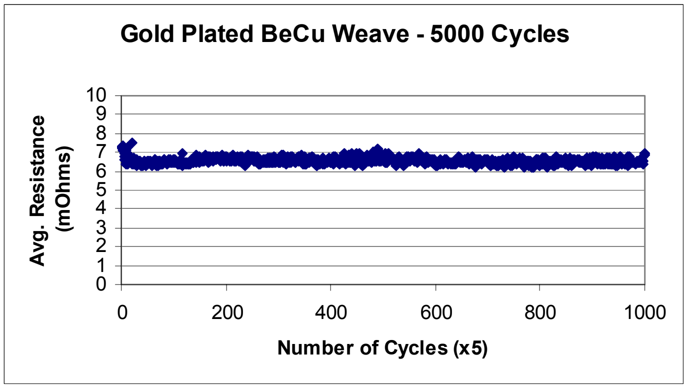

Figure 9: Wear tests for single weave

Conclusions:

Tribotek has developed a locally compliant contact interface based on fundamental principles of tribology that has multiple contact points, each with extremely small apparent contact areas. The design reduces friction and wear by having a compliant structure that deflects when contacting a particle. This reduces friction caused by adhesion and plowing. Multiple points of contact leads to large scale redundancy allowing the contact interface to make good electrical contact even in highly contaminated environments with very low normal forces. The friction is low because of the near absence of plowing that contributes to friction.

Experiments have shown that suitable normal forces are usually on the order of 5g which is an order of magnitude less than regular fork and blade interfaces. At these low normal forces, wear has been shown to be insignificant over 5000 repetitive cycles. This type of "locally compliant" interface can be used as the building block for a number if different applications where there is a requirement for a high quality separable electrical interface with low friction, low wear, and that is highly resistant to degradation from foreign particles and contamination.

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