# Contact Problems Due to Fretting and Their Solutions

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## ABSTRACT

**The phenomena of fretting and fretting corrosion of electrical or electronic contacts is described. A formula is given that permits prediction of the limit where slip starts to occur. The effects of connector design and application parameters such as coefficient of friction, normalforce, spring rate, size of displacement and lubrication are considered. Measurements carried out on the Micro-MaTch™ contact system confirm the validity of the approach.**

## INTRODUCTION

Due to external forces or simply because of local differences in thermal expansion, male and female parts of a connector can move relative to each other. When this takes place, it must be expected that in the contact regions some movement occurs also. Initially, such localized motion will happen without the contacting surfaces sliding against each other. They will move some distance together without slipping. Only when certain parameters exceed critical values, the contacting surfaces will begin to slip. This is usually associated with very small displacements and is referred to as *micro-motion*. Such slippage leads to the well known and much discussed fretting corrosion[1-9], the most important failure mechanism for tin plated contacts. Many of the referenced publications[1-9] describe the mechanism of accumulation of oxidation products at the contact spot caused by micro-motions. The results of micro-motion are resistance spikes during motion as well as a gradual increase of the contact resistance with increasing number of motion cycles.

The reason for the fact that male and female connector elements can move relative to each other without slippage of the contacting surfaces is frequently not well explained. Key to understanding this effect is to consider that a compliant spring can absorb such a motion. This will be addressed in this paper. Specifically its purpose is

* to illustrate on selected experimental results the effect,
* to discuss the parameters that determine the limit where slip is going to occur,
* to present a general, quantitative criterion for the conditions under which no slippage occurs,
* to describe briefly the phenomenon of fretting corrosion,
* to discuss contact lubrication as an alternative solution.

The paper also shows that an in-depth understanding of the mechanics of electrical and electronic interconnections is essential when designing connectors for optimum reliability. Such understanding becomes vital for complex assemblies comprising different materials and contacts with small center distances. Molded Interconnect Devices (MIDs) are examples of such structures.

## FRETTING WEAR AND FRETTING CORROSION

*Fretting wear* is defined as wear caused by small repetitive motion in an apparently stationary situation. Typical, well known examples are the fretting wear of ball bearings in cars during railway transportation, and fretting wear of gold plated rack and panel connectors when transported in assembled condition. In these cases the motion consists of internal vibrations that are caused by external excitation. However, micro-motion and fretting wear associated with it does not necessarily have to be in response to external, mechanical excitation. A well known, non-mechanical phenomenon that can cause it is the relative, small amplitude motion of surfaces in contact with each other due to different thermal expansion of the bodies carrying these surfaces. A specific example of such fretting wear is that of contacts in long edge connectors on printed circuit hoards that heat and cool in cycles. Fretting wear will occur with almost any combination of materials under conditions of cyclic slip under load.

*Fretting corrosion* refers to the combination of fretting wear and corrosion, e.g. such as oxidation. The combination of wear and oxidation is most detrimental particularly to tin-plated electrical contacts. The reason that tin is so sensitive to this type of corrosion is that it is a very soft metal on which a thin, but hard oxide layer is rapidly formed. Being supported by a soft substrate, this layer is easily broken and its fragments can be pressed into the underlying matrix of soft, ductile tin. There the fragments accumulate without changing drastically the appearance of the surface. However, they cause an increase in electrical resistance.

This raises the question why tin as a contact material is also very reliable in many applications. Part of the answer is found by a thorough mechanical analysis of the possibility of slippage.

## THE ONSET OF SLIPPAGE

For illustrative purposes the Micro-MaTch contact system shown in Figure 1 is introduced here. This choice does not limit the generality of the following discussion. Electrical contacts can be modelled as contact regions supported by springs as shown in Figure 2. For a single such contact the condition for slip can be expressed as

$$F_z > \mu_s \cdot F_y \qquad (1)$$

where

$F_z$ = insertion force,

$\mu_s$ = static coefficient of friction,

$F_y$ = contact normal force.

If the condition $F_z \leq \mu_s \cdot F_y$ is met, the spring will deflect without slip and the relation between force and deflection in the z direction is linear:

$$F_z = \Delta z \cdot k_z \qquad (2)$$

where

$\Delta z$ = displacement in the z-direction,

$k_z$ = spring rate in the z-direction (= constant).

The inequality (1) and equation (2) yield an expression for the maximum displacement, $\Delta z_{max}$, without slip:

$$\Delta z_{max} = \frac{\mu_s \cdot F_y}{k_z} \qquad (3)$$

This equation states that if the upper part of a connector travels a distance $\Delta z$ in the z-direction, the lower part will follow as long as $\Delta z$ does not exceed the product of static coefficient of friction $\mu_s$ and the normalforce $F_y$, divided by the spring constant $k_z$. Fretting wear and in tin systems also fretting corrosion will result if this limit is exceeded repetitively.

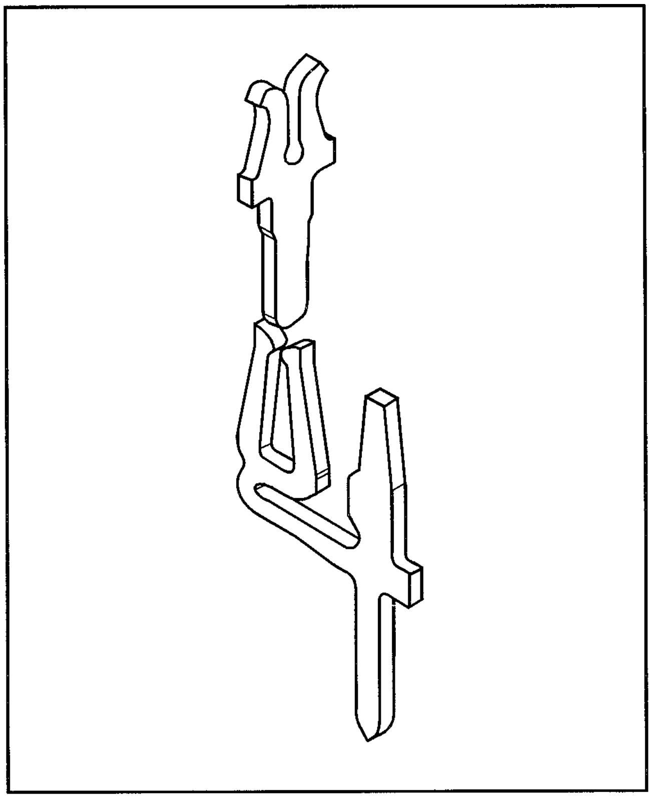

**Figure 1.** The Micro-MaTch™ contact system.

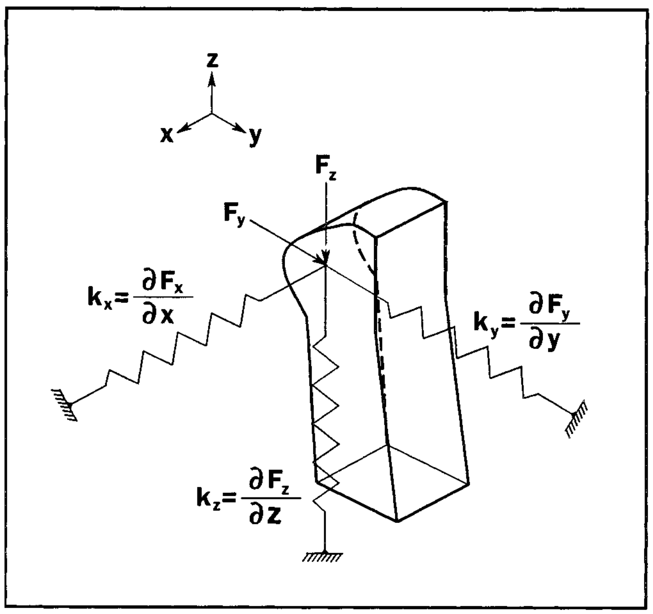


**Figure 2.** Schematic of a spring-supported contact region.

These considerations lead to the conclusion that four factors determine the mechanical stability of the contact:

(A) *The static coefficient of friction*.—A high static coefficient of friction will aid in preventing motion. However, although the dynamic coefficient of friction is usually less than the static coefficient, if movement of the contacting surfaces relative to each other has set in, a high coefficient of friction will also contribute to increased fretting wear. Lubrication usually reduces fretting corrosion but in some cases can jeopardize the mechanical stability.

(B) *The normalforce*.—High normalforce components contribute to prevention of motion. But they also lead to high insertion forces as well as to high wear. The overall effect of a high normalforce is the reduction of fretting problems partly because it generates a larger contact area, which lower contact resistance values and reduce the increase of these values with increasing number of mating cycles.

(C) *The spring rate in directions perpendicular to the normalforce*.—Low spring rates in these directions enhance mechanical stability without increasing insertion forces and wear. Of course, special, usually quite sophisticated contact spring designs are necessary to achieve these low spring rates. An extreme example for low spring rates would be a contact that has play in its housing. It can be regarded as having a spring rate equal to zero.

(D) *The displacement*.—In case of vibrating motion the distribution of mass, stiffness and damping determine the displacement at the contact area. Resonance frequencies of rack, panel or harness have the greatest effect. The connector itself is seldom the cause of the problem, but it is sometimes the place where it shows. If the motion originates from differential thermal expansion (DTE) of the contacts, the displacement $\Delta L$ can be calculated according to:

$$\Delta L = \Delta\alpha \cdot \Delta T \cdot L \qquad (4)$$

where

$\Delta L$ = displacement = change in length,

$\Delta\alpha$ = difference in coefficients of linear thermal expansion,

$\Delta T$ = temperature difference,

$L$ = initial length.

For mechanical stability against micro-motion, the displacements $\Delta L$ should be small. Equation (4) shows that this requires small differences in coefficient of expansion $\Delta\alpha$, small differences in temperature $\Delta T$ and a small dimension L. In most cases the length of the connector, L, is the most critical dimension.

## LUBRICATION

Although lubrication lowers the coefficient of friction and can jeopardize the mechanical stability, it can be beneficial when cyclic slip takes place. Proper lubrication considerably reduces fretting wear and fretting corrosion. An additional benefit is that it aids in reducing insertion forces.

Application of lubricants also raises some questions. Among them are concerns related to compliance with environmental regulations. Others are of a metrological nature, e.g., how does one measure quantity or layer thickness of the applied lubricant and how does one predict long term performance, particularly at elevated temperatures. A question to be addressed from the materials and processing viewpoint is how does one guarantee that the lubricant remains at the right place. Nevertheless, it has been shown in many cases that lubrication can reduce fretting problems in electrical contacts.

## EXPERIMENTAL

To confirm the validity of the approach introduced and discussed above, a number of experiments were carried out. The AMP Micro-MaTch™ contact was used as an example. Figures 3 to 6 show results of the experimental studies. It is important to note that instrumentation for studies on fretting requires accuracy for displacement measurements at the µm level, for force measurements at the cN level.[10]

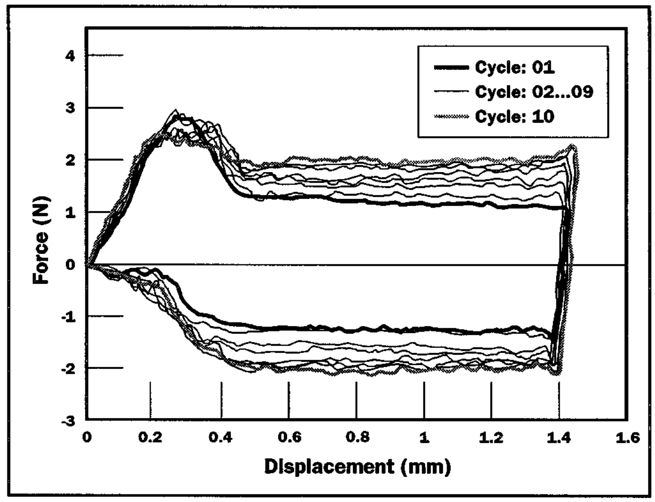


**Figure 3.** Force versus displacement for the first ten insertion/withdrawal cycles measured on non-lubricated contacts.

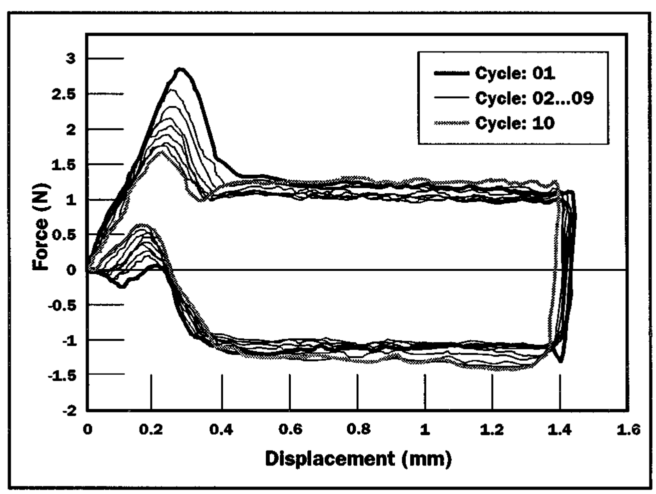


**Figure 4.** Force versus displacement for the first ten insertion/withdrawal cycles measured on lubricated contacts.

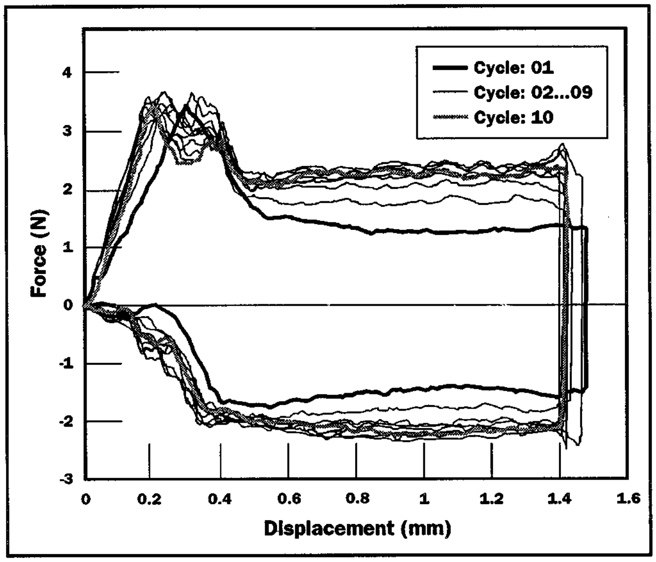


**Figure 5.** Force versus displacement for the first ten insertion/withdrawal cycles measured on contacts without position spring

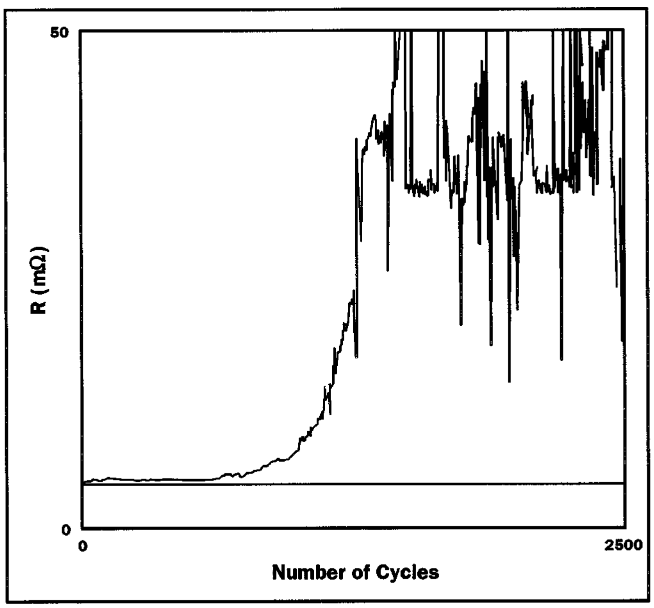


**Figure 6.** Changes of contact resistance versus number of cycles measured on contacts without position spring.

Figure 3 shows the force versus deflection curves for the first ten mating cycles. The sliding force is about 1.5 N and the coefficient of friction about 0.3, based on a normalforce of $F_y = 2.5$ N. Because friction occurs on both sides of the pin a factor 2 must be applied to calculate $F_z$:

$$F_z = 2\mu_s F_y$$

The maximum displacement without slippage is 0.04 mm, which yields the value for the spring rate

$$k_z \approx \frac{3}{0.04} = 75 \text{ N} \cdot \text{mm}^{-1}.$$

For instance, according to equation (4) a thermal displacement of 0.04 mm can be caused by the set of values $\Delta\alpha = 40 \cdot 10^{-6}$, $\Delta T = 100$ °K, L = 10 mm.

Whereas Figure 3 characterizes non-lubricated contacts, Figure 4 shows the force versus deflection curves for the first ten insertion/withdrawal cycles measured on lubricated contacts with a position spring in place. For the lubricated contact it is $\mu_s = 0.2$ and $F_z = 1$ N. With a spring rate of $k_z = 75$ N/mm we find for the maximum distance, $\Delta z_{max}$, the contacting surfaces can travel relative to each other without slippage

$$\Delta z_{max} \approx 2\left[\frac{1}{75}\right] = 0.026 \text{ mm}.$$

In Figure 5 the first 10 insertion/withdrawal curves for contacts without position spring are shown. Note the more vertical slope at the point where insertion ends and withdrawal starts. This shows that without the position spring the spring rate in the z-direction is very high and the slightest vertical displacement leads to slippage and the possibility of fretting.

For contacts without position spring, the change of contact resistance occurring during repeated mating and un-mating is given in Figure 6. It shows how the resistance increases during 2500 cycles. After about 1000 insertion/withdrawal cycles brief excursions to higher values were observed. In this experiment one cycle consisted of a linear up and down motion in the z-direction over a distance of 40 µm. It is important to note that the contacts with position spring do not show any resistance variation at all. The contacts without position spring but lubricated with an antifretting lubricant show only a slight, hardly noticeable variation.

## SUMMARY AND CONCLUSIONS

When male and female parts of a connector move relative to each other, the contact regions will initially jointly move some distance without slipping. They will then start to slip with a predictable and measurable displacement. This slipping can be prevented by making the counterparts elastic enough so that they move together. The following conclusions can be drawn:

* There exists a certain, finite distance over which contacts can move relative to each other without slippage taking place.
* A lower spring rate is an attractive option for increasing this distance without increasing insertion force and mating wear.
* Lubrication has a positive effect against fretting corrosion but does promote slip rather than prevent it.
* Reliability is better served by avoiding slip than by application of lubricants or by selecting other materials.

* Experimental arrangements for validating mechanical analyses related to fretting requires accuracy for displacement measurements at the µm level, for force measurements at the cN level.

## ACKNOWLEDGMENTS

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