A DESIGN SOLUTION FOR FRETTING CORROSION

by
Piet van Dijk and Frank van Meijl

AMP Technology Europe
The Netherlands

ABSTRACT

Application of electronics in systems that are exposed to high vibratory and shock stresses requires the use of fretting protected electrical connections. Fretting corrosion is caused by a relative motion of mated contact surfaces and results in contact failures. This paper presents a design concept that eliminates the relative motion at the contact point by introducing an additional elastic element.
When the male half of a connector assembly moves relative to the female half, the contact regions on the male and female contacts will move some distance together before they start slipping. The onset of slip is predictable and measurable.
This paper discusses the formula that determines the limit from where slip starts to occur. Also discussed are the effects of connector and application parameters such as coefficient of friction, normalforce, spring rate, size of displacement and lubrication. Evidence is presented that confirms the validity of the approach. The AMP Micro-MaTch™ contact system is used as example.

1. INTRODUCTION

Fretting corrosion is the most important failure mechanism for tin plated contacts and has been discussed in many publications [1-10]. Many of these publications describe the mechanism of accumulation of oxidation products at the contact spot caused by the so-called micro-motions. This results in resistance spikes during motion as well as in an uncontrolled increase of the contact resistance at longer term. Some motion does always take place in a contact system, for instance due to differences in thermal expansion or vibration.
The fact that a compliant spring can absorb such a motion, thus preventing slip at the contact spot, is often not well understood.
It is the intention of this paper to demonstrate the effect and to discuss the parameters that determine the limit where slip is going to occur. Also the phenomenon of fretting corrosion will be discussed, and lubrication as an alternative solution.
What follows is that a good insight in the mechanical behaviour of electr(on)ic assemblies involving connectors or sockets is vital to their reliability. Its importance becomes critical in complex assemblies with different materials and contacts fixed at small center distances. MID (Molded Interconnect Devices) structures are examples of such structures [12].

2. THE PHENOMENA OF FRETTING WEAR AND FRETTING CORROSION

Fretting wear is defined as wear caused by small repetitive motions in an apparently stationary situation. Classic examples are the fretting wear of ball-bearings in car wheels during rail-way transportation and fretting wear of gold plated rack and panel connectors when transported in assembled condition. In these cases the motion is caused by internal vibrations as a response to external excitation. An example of fretting wear caused by motion due to difference in thermal expansion is fretting wear of contacts in long edge connectors on printed circuit boards that warm up and cool down in a cyclic fashion. Fretting wear will occur with any material under conditions of cyclic slip under load.
Fretting corrosion refers to the combination of fretting wear and corrosion such as oxidation. It is this combination of wear and oxidation that is most detrimental to base metal and especially tinplated electrical contacts. Tin is very sensitive to this type of corrosion, it is a very soft metal and rapidly forms a thin and hard oxide layer, which is easily disrupted. The hard oxide layer gets broken and pressed into the matrix of soft and ductile tin where it accumulates and causes a high electrical resistance at apparently still good looking contacts.
This raises the question why tin as a contact material has performed reliably in many applications. The answer to this question is to be found in careful mechanical analysis of the possibility of slip: without slip tinplated contacts make perfect electrical connections also for small currents and low voltages.

3. THE ONSET OF SLIP

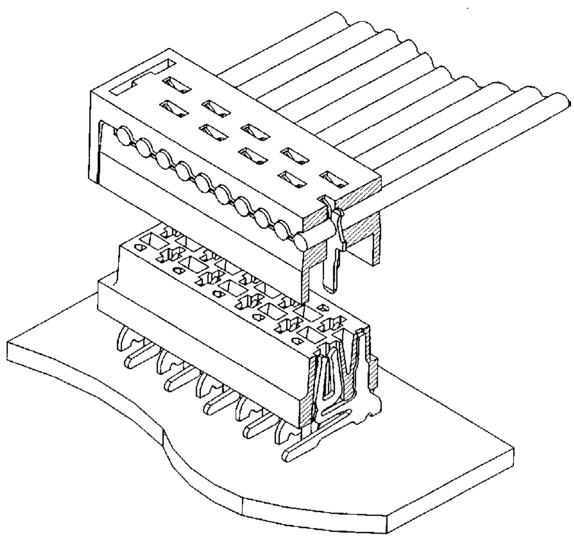

fig.1 The Micro-MaTch™ surface mount version connects a ribbon-cable to a PCB.

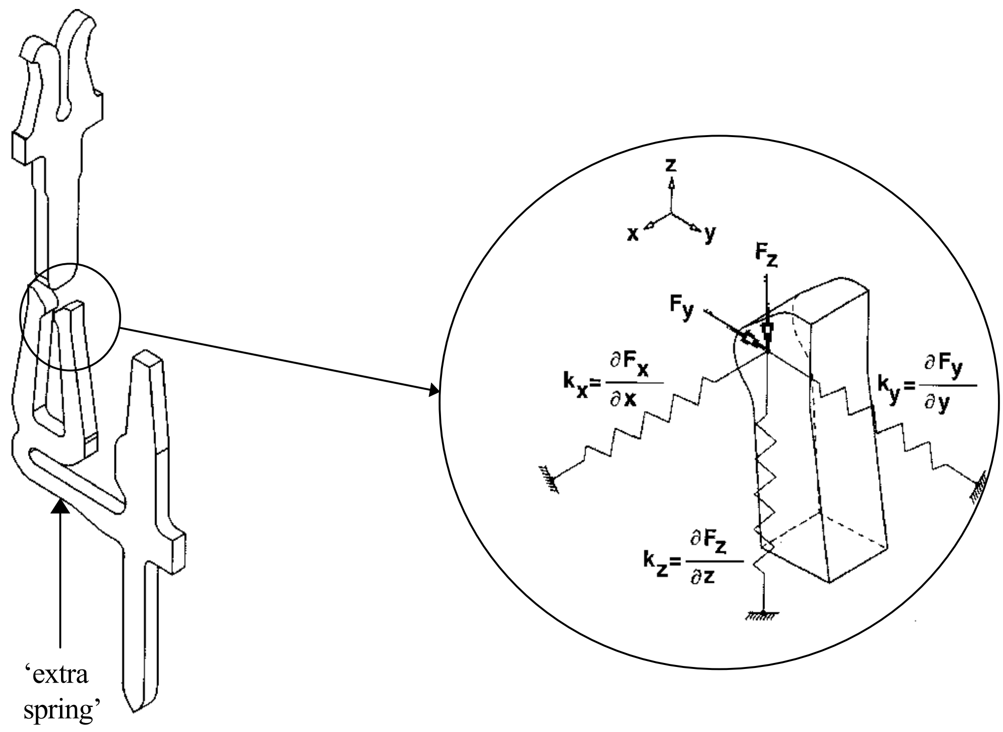

Figure 2. The Micro-MaTch™ contact system, with the extra spring arm.

Figure 3. Scheme of contact region supported by springs

Electrical contacts can be schematized as contact regions supported by springs as shown in figures 2 and 3. The **condition** for slip for a single contact beam, like shown in figure 3, can be expressed in a formula:

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

with: F_z = *force in insertion direction [N]*

μ_s = *static coefficient of friction [-]*
F_y= *contact normalforce [N]*

For $F_z \leq \mu_s \times F_y$ the spring deflects without slip, hence the relation between force and deflection in z-direction is linear:

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

with: Δz = *displacement in z-direction [mm]*
k_z = *spring rate in z-direction [N/mm]*

From (1) and (2) we can derive the formula for the maximum distance without slip:

$$\Delta z = \frac{\mu_s \times F_y}{k_z} \qquad (3)$$

If the male part travels a distance Δz in z-direction, then the female part moves along as long as Δz does not exceed the product of μ_s and F_y, divided by k_z.
Fretting wear and fretting corrosion will result if this limit is exceeded in a repetitive mode.

It follows that four factors determine the mechanical stability:
3.1 The static coefficient of friction.
A high coefficient of friction will help prevent motion, however if motion will still take place then it also increases the fretting wear. Lubrication, having mostly a positive effect on fretting corrosion, can be a risk to the mechanical stability in some cases.
3.2 The normal force.
A high normal force can prevent motion, however higher normal forces lead to high insertion forces and to more wear. Still the overall effect of high normal forces is to reduce fretting problems, partly because it also

leads to larger contact areas, hence lower resistances and less resistance increase.

3.3 The spring rate in directions perpendicular to the normalforce.

Low spring rates in these directions enhance mechanical stability without increasing insertion forces and wear. More sophisticated contact spring designs are necessary to achieve the lower spring rates. We note as an aside that a contact that has play in its housing can be regarded as having a spring rate equal to zero.

3.4 The length of displacement.

3.4.1 Thermal expansion.

In case of DTE (Differential Thermal Expansion) the displacement ΔL can be calculated with the formula:

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

with: ΔL = *change in length [mm]*
$\Delta\alpha$ = *difference in coefficient of thermal expansion [K^{-1}]*
ΔT = *difference in temperature [K]*
L = *length [mm]*

Mechanical stability is enhanced by having small differences in coefficient of expansion $\Delta\alpha$, small differences in temperature ΔT and a small dimension L. It is clear that the length of the connector is the most critical dimension in this respect.

3.4.2 Vibration.

In case of vibrating motion the distribution of mass, stiffness and damping determine the length of the displacements. Mostly the resonance frequencies of the rack, the panel or the harness cause the problem. The connector is seldom cause of the problem, but it is sometimes the point where the problem surfaces.

4. LUBRICATION

The use of lubricants that shield the surface from air and moisture is also a method of inhibiting the increase of contact resistance. It considerably slows down the oxidation process. Lubrication also reduces friction, hence insertion forces and wear. However it can put the mechanical stability at risk as explained in section 3.1 of this paper.

The application of lubricants does also raise other concerns like:

- compliance to environmental requirements
- compatibility with other materials
- how to measure quantity or layer thickness
- how to ensure that it remains at the right place.
- how to predict the long term performance, especially at elevated temperatures.
- behavior at low temperatures.

Therefore, the effectiveness of lubrication is limited and lubrication is not a satisfactory solution for elimination of severe fretting. Notwithstanding these concerns it has been shown in many cases that lubrication reduces problems with fretting of electrical contacts.

5. EXPERIMENTAL

5.1 Method

The objective is to demonstrate the effect of the extra spring and compare it to the effect of anti-fretting lubricant. We measured the curves of the insertion/withdrawal force versus displacement of 10 mating cycles of the AMP Micro-MaTch™ contact in three conditions:

1. *'as received'*
2. *'without extra spring'*
3. *'without extra spring, lubricated'*

From these curves we can see over how long a distance the contacts move without slip. Based on these curves we picked 0.04 mm as amplitude for a fretting experiment with 10,000 cycles, with a frequency of 1 Hz and a normalforce of 2.5 N.

Then we evaluated the wear behavior after cycling using SEM and X-ray analysis, and the electrical behavior during wear cycling with a four wire set up with a current of 10 mA (V<20 mV). The instrument used for the experiments is the DISC (short for Dutch Instrument for Support in Contact Physics), the set up is described in earlier publications [12,13]. Measurements without extra spring where carried out by blocking its spring action in the fixation of the contact. The lubricant used has been AMP anti fretting lubricant pn.985140-2

5.2 Results

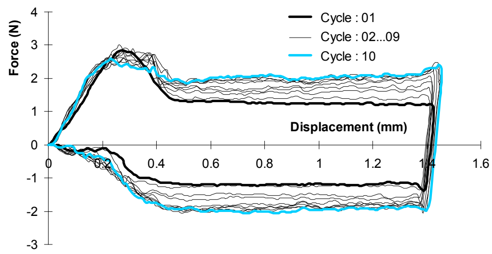

Figure 4. 'as received', 10 insertion/withdrawal cycles

Figure 4 shows the curves of the insertion/ withdrawal force versus displacement of the first 10 mating cycles of the AMP Micro-MaTch™ contact in the *'as received'* condition. The insertion/withdrawal force in the sliding part of the curve increases from 1.5 to 2 N during the 10 cycles, which is from 0.75 to 1 N per side, it follows that the coefficient of friction increased from 0.3 to 0.4 (the normalforce of the contacts is 2.5 N).

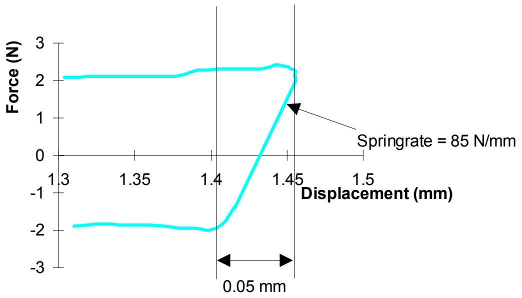

Figure 5. 'as received',
transition from insertion to withdrawal.

Figure 5 enlarges the transition from insertion to withdrawal of figure 4. In figure 5 we can establish the distance without slip, the linear part of the curve, which is about 0.05 mm in the 10th cycle. Also we can measure that the spring rate in the Z-direction, k_z in formula (2), is 85 N/mm.

We chose the amplitude of 0.04 mm so that it will not slip in the *'as received'* condition, with the extra spring.

It also safe for DTE problems, applying formula (4) with $\Delta\alpha = \alpha_{plastic} - \alpha_{metal} \approx 40x10^{-6}$, ΔT=100 K and L=10 mm results also in a ΔL of 0.04 mm.

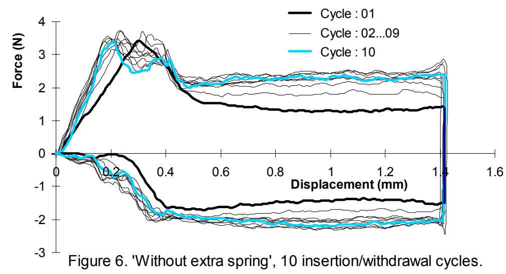

Figure 6. 'Without extra spring', 10 insertion/withdrawal cycles.

Figure 6 shows the first 10 insertion/ withdrawal curves for the contacts *'without extra spring'*. Note the vertical slope at the point where insertion ends and withdrawal starts. This shows that the spring rate in z-direction is very high without the extra spring, hence the slightest vertical displacement leads to slip and the possibility of fretting motion.

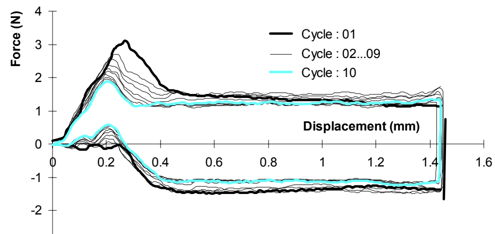

Fig 7. 'Without extra spring, lubricated',
10 insertion/withdrawal cycles.

Figure 7 shows 10 insertion/ withdrawal curves for the contacts *'without extra spring, lubricated'*. Note the lower wear and lower friction. In the lubricated state μ_s = 0.2.

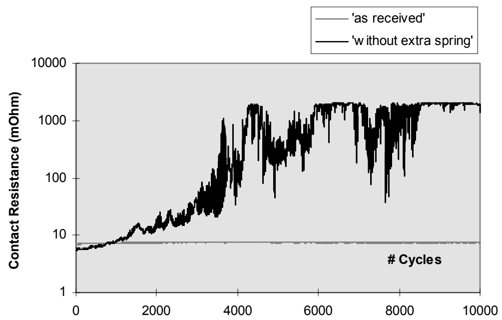

Fig 8. Contact resistance during 10.000 cycles.

Figure 8 shows the contact resistance for the contact *'without extra spring'* during 10,000 cycles. One cycle is a linear motion up and down in z-direction over 0.04 mm distance. In about 2000 cycles the resistance increases gradually to a level of about 20 mΩ, then it starts to increase in a more unpredictable fashion and reaches the 2Ω measurement limit after another 2000 cycles. The resistance of the *'as received'* contact is added for reference.

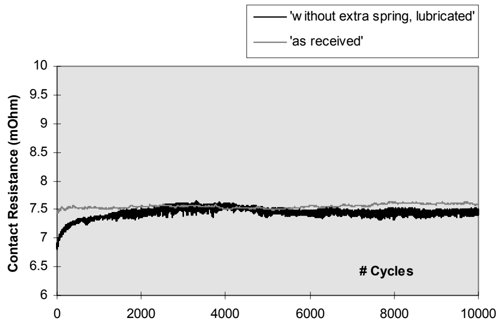

Fig 9. Contact resistance during 10.000 cycles

Figure 9 shows the curves of the *'as received'* and *'without extra spring, lubricated'* versions at a scale from 6 to 10 mΩ.
The higher initial resistance of the *'as received'* version is due to the bulk resistance of the extra spring. The contact is electrically intrinsically stable. The lubricated version does move and shows more variation, it thanks its electrical stability to the oxidation prevention by the anti-fretting lubricant.

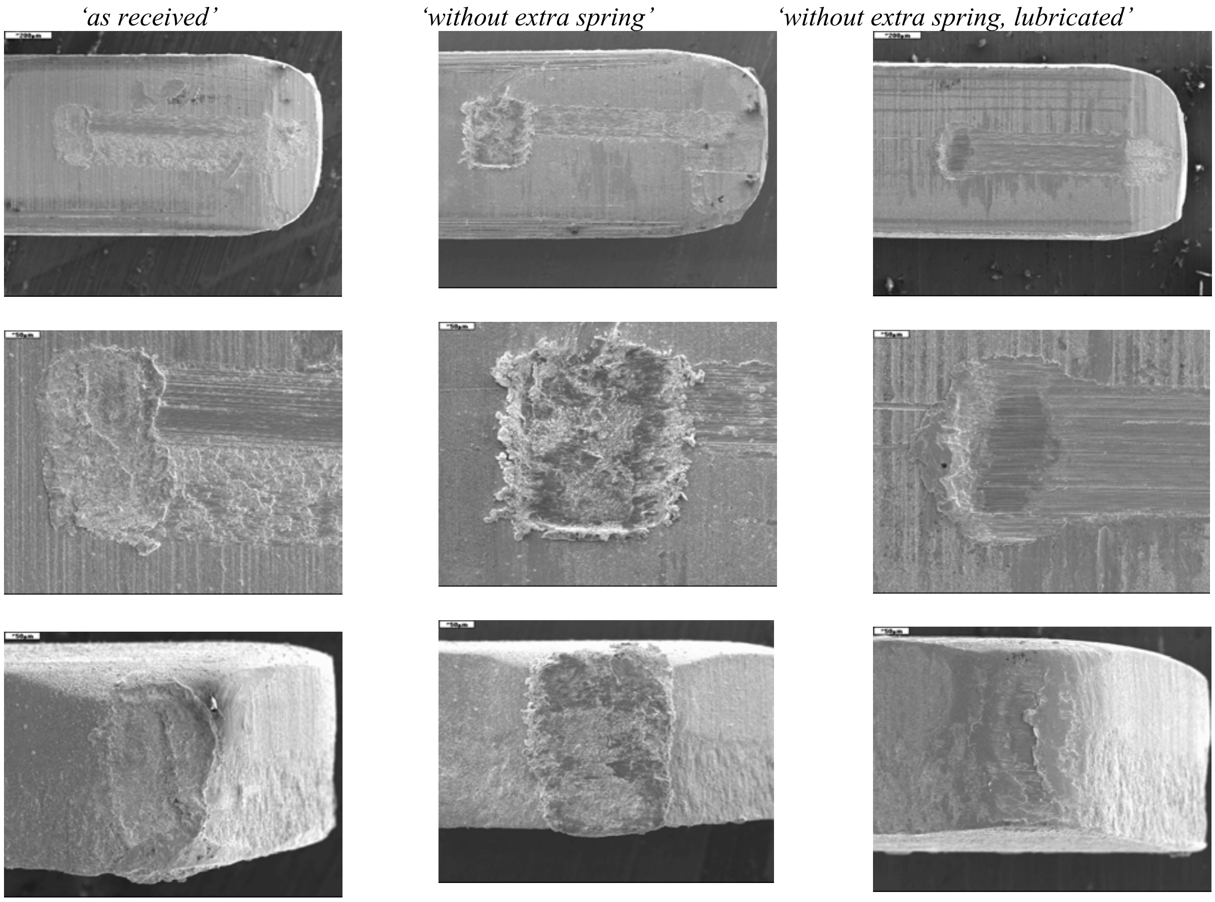

Fig. 10 SEM pictures.

Figure 10 shows SEM pictures of the wear spots. It compares from left to right the three versions: *'as received'*, *'without extra spring'* and *'without extra spring, lubricated'*, and from top to bottom:

- the wear track on the male pin of one insertion with at the end the contact spot
- the contact spot on the male pin
- the contact spot on the female part

Notable is the severe wear *'without extra spring'* and the combination of strong wear at the pin with hardly any wear at the female part for the version *'without extra spring, lubricated'*.

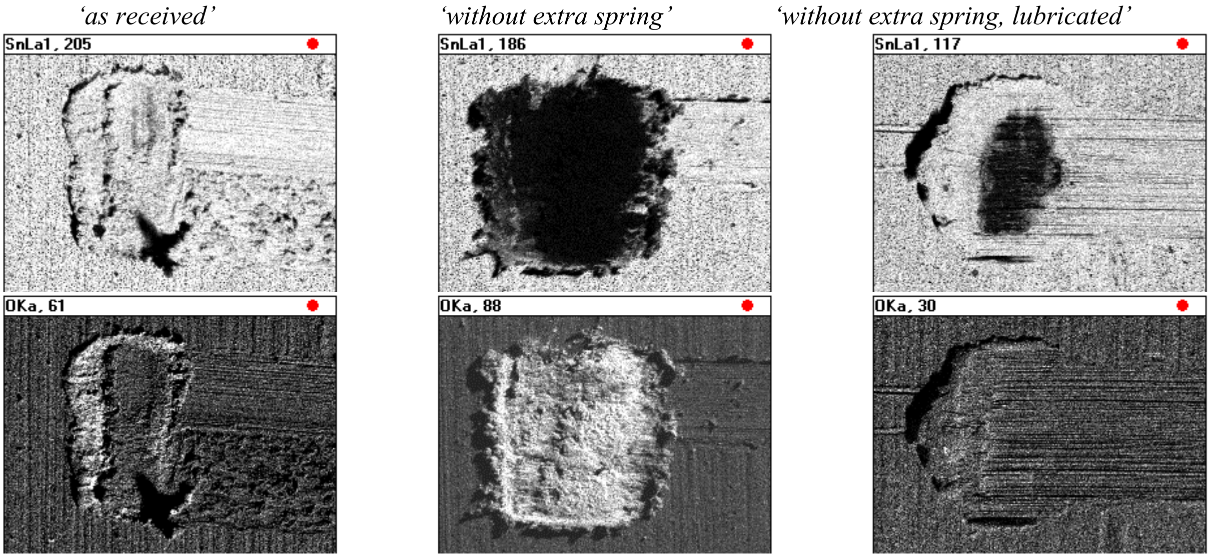

Fig. 11 X-ray analysis results

Figure 11 shows the results of tin and oxygen element scans on the contact spots on the male pins. Again from left to right: *'as received'*, *'without extra spring'* and *'without extra spring, lubricated'*.
The upper pictures show the presence (light colored) or absence (dark colored) of tin. The lower pictures the presence (light) or absence (dark) of oxygen. For the *'as received'* version we see an uninterrupted tin layer with some oxygen accumulation in the periphery. For the version *'without extra spring'* it is clear that the tin layer is completely worn away, and that the whole wear spot is covered with oxide. In the version *'without extra spring, lubricated'* the tin layer is also worn away, however there is no oxide accumulation in the contact area.

6. Conclusions

- There exists a certain distance that contacts move relative to each other without slip taking place.
- A low spring rate is a more attractive option to increase the distance to slip than a high normalforce, because it does not increase 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 with avoiding slip than with lubrication or selection of other materials.
- A sensitive measuring set-up is required to validate mechanical analysis: motion accuracy in micrometers, force accuracy in centiNewtons.

Acknowledgment:
We thank Maria Weisenborn for metallurgical support, Richard Schets for his help in taking measurements and Huub van Delft for his help preparing figures.

7. Literature

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