Avoiding Fretting Corrosion by Design

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ABSTRACT

Fretting corrosion is caused by a relative movement of mated contact surfaces and results in contact failures. A new design concept that eliminates the relative movement at the contact point by introducing an additional elastic element is presented. Specific requirements are discussed. The successful application of the new concept in a PCB socket is described.

INTRODUCTION

An important contact failure mode of mechanically highly stressed electrical contacts is fretting corrosion, which causes unacceptable increases of contact resistance in mated connectors. Fretting corrosion occurs in separable contacts, when the contacting surfaces are submitted to small amplitude movement relative to each other. Oscillatory sliding with amplitudes at the micro-to millimeter level can be induced by external mechanical vibration, shock, differential thermal expansion, and electrodynamics forces. Contact movement causes severe wear and metal transfer at the interfaces.

If the contact surface consists of a base metal, then a rapid oxidation of surfaces or of wear debris occurs. The result of this corrosion process is the formation of an insulating interlayer and the accumulation of oxide particles in the contact region. In case of a noble metal contact finish the relative movement causes wear of the noble metal layer leading to exposure of the base underlayer or the base metal substrate. Subsequently, fretting corrosion with its associated increase of contact resistance occurs. Another unwanted effect may be frictional polymerization of organic air pollutants, whereby insulating polymers are formed.[1]

The process of fretting corrosion causes resistance spikes of short duration and also uncontrolled long term changes of contact resistance. This leads to contact failures, especially in high-data-rate digital circuits. The tendency of a connector to degrade by fretting depends on the contact design, on the materials used, and on the environmental and electrical conditions during use.

METHODS TO PREVENT FRETTING

Application of electronics in systems that are exposed to high vibratory and shock stresses requires the use of fretting protected electrical connections. One method of inhibiting the increase of contact resistance is the use of lubricants, which reduce friction and wear. To some extent they also shield the surface from air. The rate of oxide formation can be decreased by cutting down available oxygen combined with reducing mechanical deformation at the interface. The effectiveness of a lubricant to inhibit fretting depends on its composition, viscosity, long term stability, and on its consumption at the surfaces.[2] Therefore, the effectiveness of lubrication is limited and is not a satisfactory solution for eliminating severe fretting. The best and most effective method of preventing fretting corrosion is to avoid the relative motion in the contact region of mated connector parts by a special contact design. This is the subject of this paper.

PRINCIPLE OF AN ANTIFRETTING DESIGN

Printed circuit board (PCB) connectors used in automobiles are exposed to high vibrational environments and to frequent changes of temperature. Because these demanding conditions were expected to be the reason for fretting and contact failures, a PCB connector was designed based on a new concept.

It is impossible to eliminate entirely the relative motion between the PCB and a connector. However, it is possible to avoid movement at the contact point. This is realized by an elastic element.[3]

The new version of the socket contact contains, compared to the older, conventional version, an additional spring with the spring stiffness C_x. This spring acts in the direction of the main movement and normal to the contact spring. Figure 1 illustrates the principle of the new design concept. If at the contact point K the friction force F_r between pin and socket is higher than the force F_x, the position of K is stable and motion takes place inside the spring.

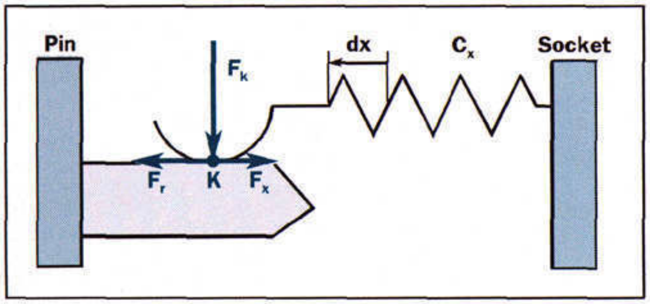

Figure 1. Principle of the new antifretting design with an elastic element of axial stiffness C_x. K = contact point. F_k= contact normal force. F_r = friction force.

Static analysis yields the following relations for a stable position of the contact point

$$F_x < F_r, \tag{1}$$

$$C_x \cdot dx < F_r, \tag{2}$$

where dx is the axial spring deflection.

Introducing the abbreviations F_{rs}= friction force for mating, F_{rz}= friction force for unmating, assuming that the socket has n contact points, and that the force F_r depends on the static friction coefficient μ, on the tab thickness d and on the direction of the friction force one finds in the case of Figure 1:

$$C_x \cdot dx_s < n \cdot F_{rs}. \tag{3}$$

$$F_{rs} = \frac{\mu \cdot C_{k0} \cdot d}{\left(1 - \mu \cdot \dfrac{C_{k0}}{C_{k1}}\right)}. \tag{4}$$

$$C_x \cdot dx_z < n \cdot F_{rz}. \tag{5}$$

$$F_{rz} = \frac{\mu \cdot C_{k0} \cdot d}{\left(1 + \mu \cdot \dfrac{C_{k0}}{C_{k1}}\right)}. \tag{6}$$

C_{k0} and C_{kl} are the stiffness factors of the contact spring.[4]

The maximum allowed distance between pin and socket dx_s and dx_z in the mating and unmating directions, respectively, is found from equations (3) to (6). Figure 2 illustrates its dependence on μ and d. Introduction of the additional spring may cause low frequency resonances. They can be avoided by designing the system so that the spring stiffness C_x is higher than the spring stiffness C_{k0} of the contact spring. The friction at point K supports suppression of resonances because of its dampening effect.

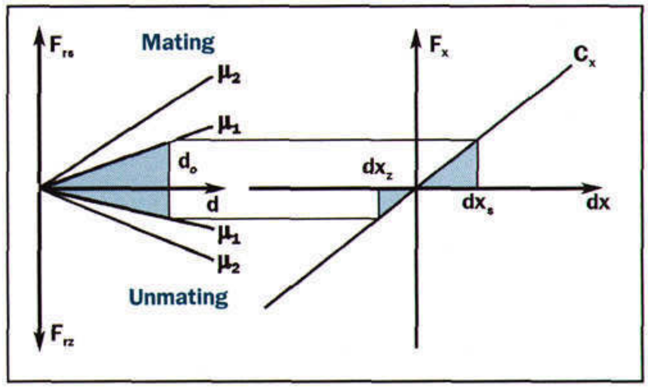

Figure 2. Dependence of axial movement dx on the friction coefficient μ and pin thickness d; $\mu_1 < \mu_2$.

The dynamic analysis is based on Figure 3. In a fixed coordinate system, the position of the pin is described by the coordinates $x_1(t)$, $y_1(t)$, $z_1(t)$ and the position of the socket is given by $x_2(t)$, $y_2(t)$, $z_2(t)$. Both parts may perform an accelerated motion induced by external vibrations. The accelerations in the various directions are

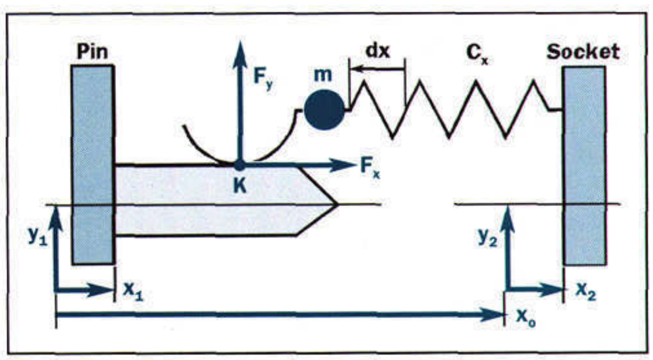

Figure 3. Model for dynamic analysis.

$$\ddot{x}_1, \ddot{y}_1, \ddot{z}_1, \ddot{x}_2, \ddot{y}_2, \ddot{z}_2. \tag{7}$$

In the fixed coordinate system of Figure 3, the following relations are valid for the spring deflection dx and for the contact force F_k

$$
\begin{aligned}
dx &= 0 \quad \text{if} \quad x_2 - x_1 = x_0 \\
F_k &= F_{k0} \quad \text{if} \quad y_2 - y_1 = 0.
\end{aligned}
\tag{8}
$$

In the case of a stable position of the contact point K, the forces between pin and socket at K are given by

$$F_x = m \cdot \ddot{x}_1 + C_x \cdot (x_2 - x_1 - x_0), \tag{9}$$

$$F_y = m \cdot \ddot{y}_1 - F_{k0} + \frac{C_{k0} \cdot C_y \cdot (y_2 - y_1)}{(C_{k0} + C_y)}, \tag{10}$$

$$F_z = m \cdot \ddot{z}_1 + C_z \cdot (z_2 - z_1), \tag{11}$$

with the conditions for the stability

$$|F_x| < \mu \cdot |F_y|, \tag{12}$$

$$F_y < 0, \tag{13}$$

$$|F_z| < \mu \cdot |F_y|. \tag{14}$$

Dampening effects are not considered.

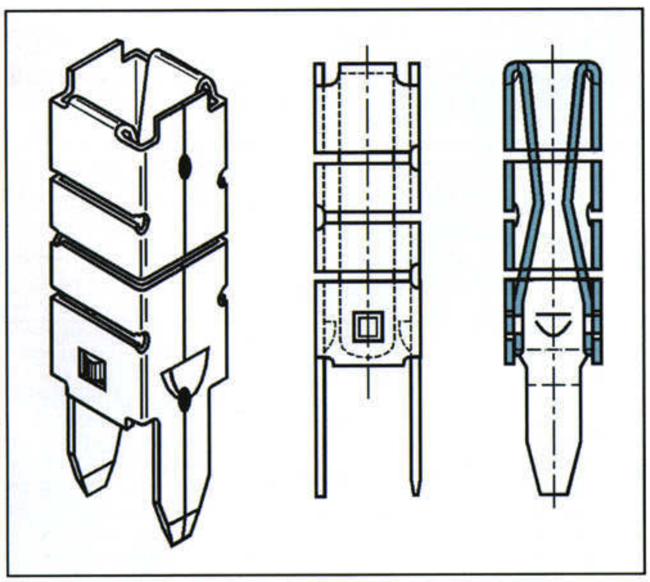

Figure 4. AMPMODU contact with antifretting design.

Acceleration of the socket does not influence the stability of the contact point K. To obtain low forces of inertia in all directions, even at high accelerations of the pin, the movable mass m should be low. Assuming a worst case condition at an acceleration level of 1 km/s^2, then for the contact design considered here, this force would be less than 10% of the total force. Not only is a low magnitude change of the forces F_x, F_y, F_z important for the stability of the position of K, but a low-level cyclical change of normal and tangential forces at the contact point will also result in low fatigue wear of the plating. Equations (9) to (14) show that this principle also works at high acceleration levels. Relative movement of pin and socket with a time-dependent, limited amplitude is compensated for inside the connection without relative movement at the contact point K.

APPLICATION AND RESULTS

Based on the new concept, a PCB socket of the AMPMODU type was designed as shown in Figure 4. The socket is connected to the PCB using two soldering pins. The pin contact is inserted into the socket contact springs inside the box. The box works like a telescopic spring and compensates for relative movement between the pin and the PCB. To avoid overstressing the telescopic spring during insertion, the deflection is limited by a stop set at ±0.15 mm.

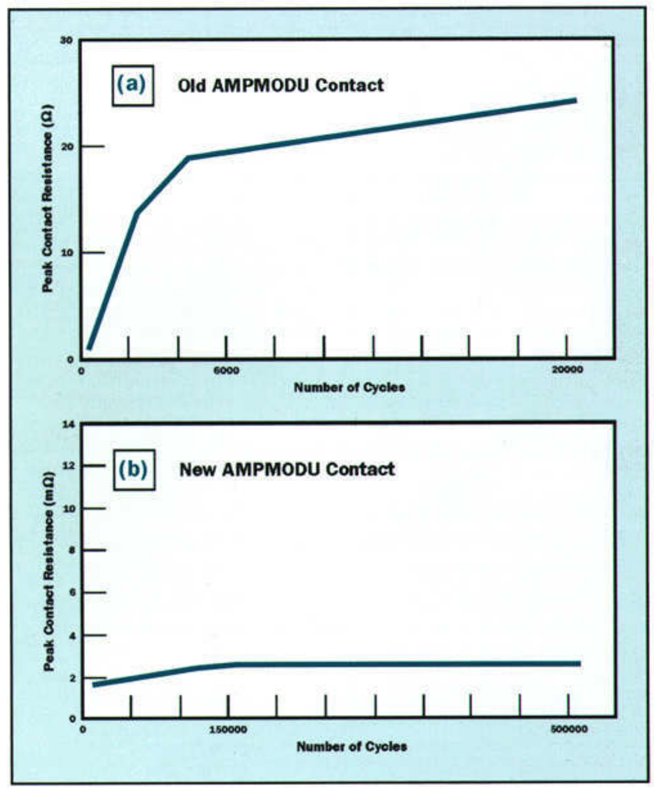

Figure 5. Contact resistance R_k as a function of the number of vibration cycles; dx = 50 µm. (a) old AMPMODU contact; (b) new AMPMODU contact based on the new antifretting design.

The new AMPMODU socket was tested and compared with the older AMPMODU version, which was not equipped with a telescopic spring. The socket and pin are tin plated. During the test the pin was moved cyclically, relative to the socket, at a frequency of 1.5 Hz and an amplitude of 50 µm. Contact resistance, measured under dry circuit conditions, was monitored as a function of the number of cycles. Figure 5 shows the results. Fretting corrosion caused the contact resistance of the old AMPMODU contact to increase steeply after 300 cycles. The AMPMODU socket designed according to the new concept maintained low and stable contact resistance even after 500,000 cycles. Fretting corrosion was not observed.

CONCLUSION

Control of fretting corrosion can be achieved by proper design of connectors. Static and dynamic analysis of forces at the contact point and introduction of a stability requirement for this point lead to a new design principle. An additional elastic element inside a separable connection compensates for movement between the mated pin and socket at the contact point. This concept offers an optimal approach for preventing fretting corrosion. The new principle was successfully applied in the AMPMODU socket and in a 2.5 mm socket for PCB.

The application in single-wire sealed connections is in preparation.

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[a]Read July 1, 1992.
[b]Editor's note: A copy of this thesis, submitted by Dr. rer. nat. Jochen Horn on July 12,1984 in partial fulfillment of the requirements for obtaining the degree of Dr. sc. nat., is deposited at the Technology Information Center, Mail Stop 21-02, AMP Incorporated, P.O. Box 3608, Harrisburg, PA 17105-3608.

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