By David P. Scopelliti

INTRODUCTION:
The following paper is intended to inform on the subject at hand and is based on years of laboratory observations.

Fretting motion, fretting wear, fretting corrosion … what does it all mean and can it be prevented or at least mitigated?

WHAT IS FRETTING?

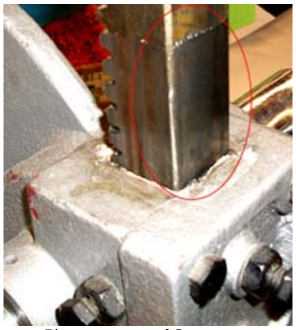

Photo courtesy of Samtec
Photo 1

Photo courtesy of Samtec
Photo 2

The science is called Tribology, the study of moving, contacting surfaces, wear, friction, lubrication, etc. You may or may not remember studying Triboelectric charge in school (the electricity created by rubbing materials together). Our interest is in the phenomena known as Fretting Corrosion (and fretting motion, the driving force behind fretting corrosion).

How is this different from normal plain old wear? The big difference is that fretting is a micro-motion issue typically less than 0.005" of movement. Just about any material that oxidizes is in danger of fretting corrosion under the right conditions.

Everyone who has ever ridden a bicycle has seen the black residue on the chain and sprockets. It is not the macro-motion of the chain around the sprocket that causes fretting; it is the "jittering" of the chain against the sprocket and the rubbing of the individual chain components as well. The tiny vibrations set up by the chain/sprocket interaction along with the vibration generated as the bike travels is what we are talking about. As the surfaces of the chain and sprocket grind together, pulverized metal particles are frictionally heated and react with the moisture and oxygen in the air and any number of other corrosive gases or liquids in the ambient environment.

The result is a microscopic, black, gritty, abrasive residue (fretting corrosion products) that will add to the wear and further exacerbate the propagation of said corrosion and corrosive products.

Our interest and the remainder of this paper will deal with fretting corrosion from an *electrical connector* perspective.

In electrical connectors:

1. Fretting motion (relative motion (micro-motion) between the mating elements).

Leads to:

2. Fretting wear (wear through of the surface coating/plating).

Typically resulting in:

3. Fretting corrosion (highly resistive corrosive products in the contact interface).

NOTE: It is important to note that for noble metal plated contacts, the fretting corrosion does not begin until the material under the noble metal (typically Nickel) has been exposed. It is the Nickel (and Copper alloy if the wear progresses that far) that is prone to fretting corrosion. Non-noble metals like tin are always susceptible if micro-motion occurs.

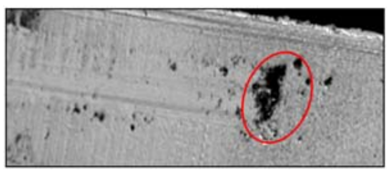

Photo courtesy of Samtec
Photo 3
An example of fretting corrosion at the contact interface
(Notice the wear track comes in from the left.)

In the above micrograph (Photo 3), the Gold has not been compromised in the wear track, but has worn through to the Nickel at the contact interface. This was a result of micro-motion between the mating surfaces.

WHY IS FRETTING A PROBLEM?

So what happens to your interconnect system when fretting starts to take over? You have this micro-motion at your contact interface generating this non-conductive (highly resistive) grit. Why is that a problem?

Digital Signal Issues:
For high speed data transmission systems, glitches and shifts in resistance can be seen as erroneous data. These errors are handled by whatever correction algorithms are being utilized, thus slowing the data throughput. In extreme cases, the shift in impedance can result in other issues such as crosstalk, signal reflections and “race” conditions due to shifts in propagation delay.

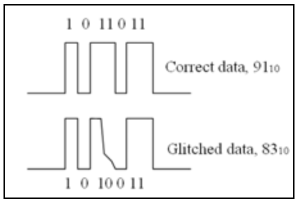

Figure 1
Data error example

Analog Signal Issues:
Many sensitive analog systems are still in use today in sensor applications, audio systems, Analog to Digital converters, etc. Changes in the contact resistance are seen as actual analogue signals in these applications and can result in conditions like noisy audio or erroneous sensor readings such as false temperature indications of your automobile engine. High speed / impedance matched analog systems may have the same mismatched impedance issues as high speed digital signals regarding crosstalk, reflected signals, etc.

Power Issues:
An increase in resistance due to fretting corrosion/debris is typically not the same as with signal applications since the higher levels may “overwhelm” the tiny changes typically associated with fretting issues. It can over time result in micro-arcing and an increase in resistance / temperature rise since the two are directly related by the following formula:

$$\text{Power (Watts)} = \text{Current}^2\ (\text{Amps}^2) * \text{Resistance (Ohms)}$$
or
$$P = I^2 * R$$
More power = more heat

This increased heat within a power system can lead to a thermal runaway situation where the excess heat causes the corrosive effect (and other degradation) to accelerate thus increasing the resistance which then increases the temperature further and so it goes until the part fails catastrophically and ultimately shuts down the entire system. Of course, arcing can also occur during fretting motion in power systems leading to actual burns on the contact surfaces resulting in the same thermal runaway condition.

WHAT CAUSES FRETTING CORROSION?

The most common cause:
Mechanically unstable systems (or vibrating system components) can cause the two mating components to move relative to one another during vibration.

You can see in Figure 2 that the flexing of the printed circuit board (PCB) causes the pin to slide across the receptacle contact, thus creating the fretting motion.

This motion can be very small, in the thousandths of an inch range, and can be very destructive to the fretting surfaces. Depending on the susceptible frequency band, this motion can happen hundreds or even thousands of times per second. This is somewhat analogous to mating and unmating the contacts many times.

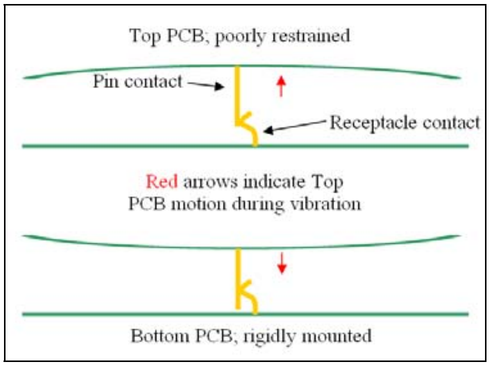

Figure 2
Exaggerated fretting motion caused by improperly restrained printed circuit boards

Onboard fans, transformers, solenoids, motors, relays, etc. can all be sources of vibration that can be injected into the contact system.

The axis of this motion is not confined to the vertical plane. Radial, axial or transverse motions can be just as damaging.

If the contacts are moving relative to one another, you are in danger of developing fretting wear and thus fretting corrosion.

The second most common cause:
Repeated thermal excursions within a system can also cause the two mating components to move relative to one another due to thermal expansion and contraction resulting in similar micro-motion at the contact level. You can see in Figure 3 that the thermal expansion of the contacts themselves can cause the pin to slide across the receptacle contact (or vice versa), thus creating the fretting motion, but this is probably not the most common manifestation of thermally induced fretting failures.

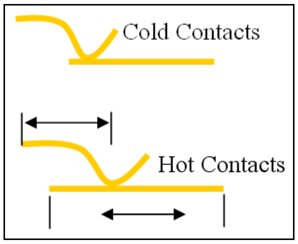

Figure 3
Illustration of thermal expansion

Figure 3 shows the contacts themselves expanding during heating. Thermal motion is just as likely to be caused by other components in the system such as the standoffs, heat sinks, connector housings, etc. whose thermal characteristics (and associated physical/mechanical shifting) within the system cause motion between the mating elements of the connector.

Other less likely causes:
Although it is much less likely that a changing electromagnetic field could cause the contacts to move relative to one another, this could possibly happen in some extreme cases where connectors are placed near high output/high magnetic field transformers, contactors, inductors, etc.

Electrostatic fields are also a very remotely possible source of contact motion, but I have never encountered either an electromagnetic or electrostatic related fretting issue.

HOW CAN WE STOP IT?

The stock answer is "stop the fretting motion". If you can prevent the surfaces from burnishing/wiping/banging against each other, then you are home free (and fretting corrosion free). While this may sound simple, it is not so easy to do in the real world.

In an interconnect system, there are several techniques that can be used in order to mitigate this condition:

1. Certain contact designs are more or less susceptible to fretting motion either by way of normal force, contact geometry, base materials, plating materials, multiple contact points within each contact position, etc. The susceptibility must be tested for specific applications, and no single fix will work for every application.

2. Lubricate the contacts so that even if they do move relative to one another, the fretting wear will be minimized, hopefully beyond the expected life of the product. Lubricants can be an excellent way to help mitigate the associated wear, when the fretting motion cannot be stopped completely. There is a minor chance of "non-dry" lubricants to hold particulate contamination due to their "wet" nature, but in general, most of the newer dry lubrication methods have almost completely eliminated this issue.

3. Make the system/application/product robust enough that the contacts cannot move relative to one another due to normal force and rugged, mechanical system design.

4. More durable plating systems such as thick (30µin) hard Gold or Palladium alloys with Gold flash can be helpful in some applications, but this plating option may not be available for all products.

5. Allow the contacts to "float together" so that when motion does occur, there is no relative motion. In other words, the contacts move in phase with each other eliminating the relative fretting micro-motion.

6. Very light normal force can allow contacts to move and slide without damaging the surfaces. However, lighter normal forces can lead to other failure modes, so this method is very much a "balancing act" where too much normal force gives you excessive wear and not enough normal force gives you poorer general performance.

DESIGN SUSCEPTIBILITY:

The entire system (final product) must be designed not to allow relative motion within the connector systems and to select connector systems that have passed the applicable environmental stress tests associated with said final product.

Contact geometry, normal force, plating materials, base materials, etc. all play a part in this balancing act. Is more normal force better? Should I use a Hertzian bump or not? Each case must be dealt with individually due to the number of variables.

NOTE: A Hertzian bump is typically a hemispherical feature at the contact interface designed to decrease the contact surface area, thus increasing the contact pressure (the force stays the same, but the area is decreased thus increasing the "PSI").

Certain contact/connector designs are inherently prone to fretting motion and thus fretting corrosion.

Single beam contacts in general are less reliable, mostly because of the lack of redundant contact points, but they are also physically prone to this micro-motion due to their long thin beam geometry. They will grow more from thermal expansion, and they will be easier to disturb mechanically for the same reason.

If you have more contact points, then you have more chances to have secondary (or tertiary) contact interfaces that still work properly since the fretting motion may not effect all contact beams the same.

TESTING IS THE KEY:

Proper testing can indicate which contact styles and which connector types are more and/or less prone to fretting.

Several factors must be evaluated:
Vibration testing will assess the mechanical integrity of the connector system where the application (test configuration) is designed to eliminate fretting motion in the test system. This method is used to judge the performance of the connector system where no intentional relative motion is occurring between the connector body halves. This tests the contact and connector design itself for fretting susceptibility. In the case where this product passes vibration testing without exhibiting increased contact resistance or resistance glitches as detected through low nano-second event detection, then this product would be considered *not susceptible to fretting motion as designed*.

Current Cycling is another important test which will examine the performance of thermal excursions caused by repeated ON-OFF cycling, thus providing a thermal "breathing" effect that will assess simulated actual life performance regarding power on and power off cycles. Passing this test evaluates the susceptibility the system is to increased resistance/thermal runaway due to normal thermal excursions experienced from typical power cycling.

Thermal Cycling (Temperature cycling with humidity and Thermal shock) tests provide the stress of externally sourced thermal excursions, thus evaluating the ability of the connector system (and associated contacts) to work within the thermal limits of the connector design.

The *Thermal Shock Test* exposes the connector assemblies to extreme thermal excursions approaching the temperature limits of the materials under evaluation. Repeated cycles (at least 100 cycles of -55°C to +85°C) followed by LLCR is recommended.

The *Humidity Test* uses less severe thermal excursions while adding humidity to accelerate the formation of oxides. A 10 day test of +25°C to +65°C with a relative humidity of 90% (temperature and RH values may vary depending on the specifications used) would be a minimum exposure for such evaluations.

CONCLUSIONS:

Know your application *FIRST*:
Understand the demands of your system and application before selecting the interconnect designs to be utilized. Through the use of modeling, proper component selection and intelligent system configuration, most fretting issues can be mitigated in the product design phase.

Evaluate existing designs:
Review published qualification reports and/or test data specifically designed to assess the susceptibility of connectors to be used in your type of system.

Use lubrication:
There are many suitable lubricants that can help to extend the contact life for systems that cannot eliminate the motion. The goal would be to make the contacts last just beyond the expected product end of life.

Use more durable contact finishes:
The same is true for thin Gold/Gold flash plated contacts; these will wear through faster and be less reliable in high vibration (or high thermal excursion) environments. Thicker Gold and Palladium alloys (with minimal Gold plating/flash) can help to reduce wear-through and increase the life expectancy of product subjected to fretting environments.

Single beam contacts are not normally good choices:
Where high levels of vibration (and/or thermal excursions) will be imposed on the connector system or where known relative motion may be inevitable, multi-beam contact systems are typically more reliable with lubrication as required.