FRETTING AND ELECTRICAL EROSION: A POSSIBLE FAILURE MECHANISM

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INTRODUCTION

In the past, the phenomenon of fretting has been evaluated on unpowered contact systems to determine their susceptibility to fretting corrosion. It is the intent of this paper to describe the results of a recent study which was initiated by Naval Air Warfare Center involving fretting of both powered and unpowered contacts. The study yielded both anticipated and unanticipated results.

The phenomenon of fretting and fretting corrosion has been discussed in detail by other authors and will not be repeated herein. It also has been shown that it is a real world failure mechanism caused by mechanical vibration or temperature cycling and not just a laboratory phenomenon.

When evaluating fretting and the resultant potential of fretting corrosion in connectors, two basic questions have to be addressed:

1) By inducing fretting motion, are the materials and configuration in contact prone to fretting corrosion and under what dynamic conditions?
2) Will fretting corrosion occur when the same materials and configurations are used in a connector?

Item #1 is evaluated by forcing fretting motion. Item #2 is evaluated by testing the connector system to a set of environmental severity levels which are based on application specific conditions to determine if susceptibility to fretting and hence fretting corrosion exists. If fretting motion/corrosion does not occur in the connector system, then item #1 is of academic interest only. One must not also forget that other variables come into play as well, such as

a) normal force
b) surface conditions
c) contact geometry's and configurations
d) amplitudes

Thus, a comprehensive study is complex at best. This paper will concentrate on the force motion portion of the program which was performed to answer question No.1 using specific contact parameters.

EXPERIMENTAL CONDITIONS

The program involved dealt with the concerns of vibratory conditions which may occur in aircraft or helicopter type applications. The forced motion fretting test was developed using the "Taquchi method". Three contact configurations were chosen for the study and were as follows.

Contact No. 1 -

No. of Tynes	: 6 to 7
Plating	: 50 µin Au/50 µin Ni
Normal Force	: ≈ 20-35 Grams

Contact No. 2 -

No. of Tynes	: 2
Plating	: 50 µin Au/50 µin Ni
Normal Force	: ≈ 75 Grams

Contact No. 2A -

Same as No. 2 except

Plating	: Au flash/50 µin PdNi (80/20)/50 µin Ni

Contact No.3 -

No. of Tynes : 2
Plating : 50 µin Au/50 µin Ni
Normal Force : >100 Grams

Contact No.1 was a brush type configuration and the other contacts were "blade and tuning fork" type. Contact #3 has been in use for over 20 years with a long history of field usage. The gold/nickel plating system is standard for this type of product. The gold flash PdNi system was chosen for its perceived durability properties.
The following are the test conditions which were specified for the study involved.:

	Test Run	Amplitude (inches)	Duration No.Cycles	Pre-Condition (Cycles)
Contact No.1	1	0.0002	10^6	0
	5	0.0005	10^5	50
	9	0.0100	10^7	5
	13	0.0250	$5x10^7$	10

	Test Run	Amplitude (inches)	Duration No.Cycles	
Contact No.2	2	0.0002	10^5	5
	6	0.0005	10^6	10
	10	0.0100	$5x10^7$	0
	14	0.0250	10^7	50

	Test Run	Amplitude (inches)	Duration No.Cycles	
Contact No.2A	3	0.0002	10^7	10
	7	0.0005	$5x10^7$	5
	11	0.0100	10^5	50
	15	0.0250	10^6	0

	Test Run	Amplitude (inches)	Duration No.Cycles	
Contact No.3	4	0.0002	$5x10^7$	50
	8	0.0005	10^7	0
	12	0.0100	10^6	10
	16	0.0250	10^5	5

The test was performed at a 200 HZ frequency level. The preconditioning (durability) was simply the number of mating/unmating cycles performed on the connectors prior to exposing them to the forced motion portion of the evaluation. Each test run was performed on an untested sample.

ATTRIBUTE MONITORING

Two attributes were monitored on all connectors tested.

1. Low Level Circuit Resistance: This attribute was performed in accordance with MIL-STD-1344, Method 3002. It is a four wire technique using a 100 ma test current and 20 mv open circuit voltage.
   This attribute was measured initially, after preconditioning as applicable and at discrete intervals contingent on the test duration (after 10^4, 10^5, $3x10^5$, $6x10^5$, 10^6, 10^7 and $5x10^7$ cycles as applicable).
2. Low Nano Second Events: This attribute was set to detect unacceptable events which were a result of a 2.0 ohm change which would last longer than 10.0 nanoseconds. The attribute was performed in accordance with EIA (Electronic Industries Association) 364, TP 87 proposed using a 3 volt, 100 ma powered system. In essence, the system was set to detect a voltage shift of 0.2 V in the time frame of interest.

TEST SET UP

1. The backplane connectors were mounted to 1/8 inch thick test boards and hand soldered in place. A common bus was provided on the current and voltage probe placement, The module connector was mounted to a 1/16 inch module card with individual traces which were accessible for LLCR probes and for interconnecting to the event detectors. A backup structure was attached to these cards for strength purposes. All connector leads were hand soldered to the traces of the test card.
   After soldering, all test samples were cleaned via DI water wash, isopropyl alcohol rinse and vapor degrease in order indicated for removal of any residual flux.
   Figure No.1 indicates the positions to be monitored for LLCR (small numbers) and low nanosecond events (large bold numbers).
   Figure No. 2 indicates the resistance set up used to monitor LLCR. The module connector contained the plug contacts. The backplane connector contained the receptacle contacts.
   All contacts and housings were actual product hardware which can be used in actual working systems.

2) Photonic System:

   Special holes were drilled in the connectors at locations where attribute monitoring would not be performed. Special pins (0.125 inch diameter) with highly polished surfaces were mounted in the backplane connector and fixed in place with an adhesive.
   Two photonic probes were held in slots in the stationary portion of the test fixture perpendicular to the direction of the subsequent motion. The probes were adjusted above the polished surfaces of the pins so as to be operating within the calibrated range of the system. Prior to actual test, the driving system causing movement was initiated until the specified displacement or amplitude was obtained and maintained. During the actual test, the photonic system was monitored to assure the specified amplitude was being maintained.
   The photonic probes were verified by using a special micrometer calibrator and calibration charts supplied by the equipment manufacturer. The probes were accurate to $\leq$ 50 microinches.
   Figure #3 is a typical set up of a photonic probe.

3. Driving System :

   The driving system used was a vibration system and the basic set up is shown in Figure #4.
   The module (plug) connector was fixtured to the stationary fixture which was isolated from the “shaker table”. The backplane connector was fixtured to a base plate attached to the shaker table. Prior to actual testing, dummy loaded test samples were fixtured in the driving system set up and the units evaluated to assure the following:
   a) The stationary fixture would have no evidence of movement which would be induced by the shaker system.
   b) There would be no movement of the module card relative to the stationary fixture.
   c) There would be no movement or “oil canning” of the backplane

connector system relative to the base plate/shaker system.

It was established that no such movement was observed. The 200 HZ frequency accuracy was within ± 2%.

4. Preconditioning:

   For those samples requiring preconditioning, said conditioning was performed manually using a rate not exceeding 1.0 inch/minute. The samples were fixtured to allow axial alignment and self centering.

5. Low Nano Second Event Detection:

   Figure #5 indicates the nanosecond event detection set up. Prior to testing the connector systems were characterized to assure the desired event being monitored was capable of being detected. It was determined that one contact pair per detector channel could be monitored for the level desired.

   The detectors were interconnected to a data acquisition/computer system. If an unwanted event occurs, the time of occurrence is recorded. The scanner system scans all detectors constantly and any unwanted events were recorded and logged. The system will automatically reset.

   Figure #6 is a basic illustration and explanation of the characterization plot. All channels per samples were so characterized. The reference voltage of the DVT was set at 200 mv below V marker 1.

RESULTS

The low level circuit resistance results are shown in Table 1 thru 4 as well as Figures #7 thru #9. The data for the 0.010 and 0.025 inch displacement is not shown due to physical damage which occurred on all samples. The damage occurred in the termination area (fractured leads) of the module connectors and is considered as unrealistic displacements.

A) Gold Over Nickel Contacts Results:

TABLE 1
CHANGE IN
LOW LEVEL CIRCUIT RESISTANCE
MULTIPLE TYNE :
<25 to 35 GRAMS Au/Ni
Contact No.1

	0.0002 in d		0.0005 in d	
Cycles	Avg. Change	Max. Change	Avg. Change	Max. Change
Precond.	-0.2	+1.1	-0.6	+2.2
10^4	-0.1	+1.2	-0.6	+0.6
10^5	0.0	+1.3	-0.5	+0.6
$3x10^5$	+0.2	+1.5	N/A	N/A
$6x10^5$	+0.1	+1.6	N/A	N/A
10^6	+0.5	+1.9	N/A	N/A
10^7	N/A	N/A	N/A	N/A

TABLE 2
CHANGE IN
LOW LEVEL CIRCUIT RESISTANCE
DUAL TYNE : ≈ 75GRAMS, Au/Ni
Contact No. 2

	0.0002 in d		0.0005 in d	
Cycles	Avg. Change	Max. Change	Avg. Change	Max. Change
Precond.	N/A	N/A	-2.0	+1.9
10^4	-1.6	+1.8	-1.3	+7.0
10^5	-1.2	+1.7	-2.6	-0.3
$3x10^5$	N/A	N/A	-2.3	+0.5
$6x10^5$	N/A	N/A	-2.8	-0.8
10^6	N/A	N/A	-2.8	-0.4

end of the connector as well. This can be attributed to the higher normal force which resulted in wearing through the gold and contacting the nickel interface. The dynamics of this evaluation are considered too severe for this design.

TABLE 3
CHANGE IN
LOW LEVEL CIRCUIT RESISTANCE
DUAL TYNE : 125-150 GRAMS,
Au/Ni (CONTROL)
Contact No. 3

	0.0002 in d		0.0005 in d	
Cycles	Avg. Change	Max. Change	Avg. Change	Max. Change
Precond.	+0.3	+1.7	N/A	N/A
10^4	+0.1	+2.9	-0.6	+1.0
10^5	-0.5	+1.1	+1.2	+5.8
$3x10^5$	+0.5	+4.5	+1.3	+2.9
$6x10^5$	+1.0	+16.2	+1.6	+6.4
10^6	+1.1	+30.2	+0.9	+8.3
10^7	+0.2	+2.9	+1.6	+18.1
$5x10^7$	+4.7	+40.2	N/A	N/A

The low force (<100 grams) systems, regardless of the number of tynes, remained stable throughout the tests. There was no evidence of fretting corrosion. There was no evidence of low nanosecond events for the displacements shown. The higher force samples did have evidence of physical damage on a few contacts (fractured termination on the module connector). These contacts, although similar in design to its low force counterpart, had dimensional characteristics which were significantly different causing higher stress in the termination areas. There was also evidence of fretting corrosion at each

B) Gold Flash Pd Ni Contact Results:

TABLE 4
CHANGE IN
LOW LEVEL CIRCUIT RESISTANCE
(Milliohms)
DUAL TYNE : ≈ 75 Grams, Au Flash/Pd Ni/Ni
Contact No. 2A

	0.0002 in d		0.0005 in d	
Cycles	Avg. Change	Max. Change	Avg. Change	Max. Change
Precond.	+0.4	+2.0	+0.2	+2.9
10^4	+4.3	+16.0	+6.7	+13.9
10^5	+4.7	+16.0	+20.8	+86.3
$3x10^5$	+4.9	+16.9	+8.9	+15.5
$6x10^5$	+5.7	+27.7	+10.5	+21.3
10^6	+6.9	+70.9	+968.3	+6477.6
10^7	+5.6	+33.9	N/A	N/A

The results of these contacts, as can be seen, were significantly different than the standard plated contacts. On the surface, the results tend to confirm that in a fretting application, the gold flash wears quickly exposing the Pd Ni which is prone to the corrosion mechanism.
Low nanosecond events initiated after only 12,000 cycles and became intense after 100,000 cycles (detectors would not reset).
Visual examination indicated that the tuning fork contact was heavily discolored in those position's being

monitored for LNS when compared to the unpowered positions. Further examination indicated that there was catastrophic wear on the powered tuning fork contacts (at least 0.005 inch being worn away). Contacts from the 0.0002 inch displacement sample were only slightly discolored with normal wear patterns. The same was true on the unpowered contacts for the 0.0005 d but with strong evidence of fretting corrosion on the mating blades. Since LNS was being monitored for a 2.0 ohm change and by 10^6 cycles the detectors would no longer reset, it was decided to measure LLCR on the 12 positions being so monitored. All positions were in excess of 10 ohms which was significantly different than the unpowered contacts. This in combination with the visual observations resulted in the development of the following hypothesis. This hypothesis involves the occurrence of electrical erosion relative to the powered contacts.

1. The LNS contacts, as previously indicated, were powered at 3V with 100 ma. The current flow was through the blade into the tuning fork.
2. As motion is initiated, the protective gold flash is worn or removed very quickly (between 10^4 to 10^5 cycles).
3. Motion continues on the Pd Ni surface which can result in frictional polymer formation and will, by itself, result in increased resistance.
4. As motion continues, debris around and in the fretting area is created.
5. When the tuning fork contact area begins to "ride up" on the debris, or the corroded area, microarcing occurs attacking the surface aspirates ('a' spots) in the clean areas on the tuning fork (see Figure #10). Microarcing will continue until the clean areas are sufficiently covered with insulating film.
6. The micro damage to the contact aspirates result in erosion of the surface in combination with continuing wear. Wear will become somewhat exaggerated as the 'a' spots weaken due to arcing and are removed or displaced which results from the continuing motion.
7. The above action can create new aspirates which are further eroded or displaced increasing wear as well within the surface area in contact (see Figure #11).
8. Since the distance between the contacts, (on the debris spot), and a clean area may be a few microinches, microarcing is possible although due to contact motion may not be continuous. The above hypothesis may explain the dramatic fretting failures which occurred in this evaluation.
9. For microarcing to occur all tynes must be on the insulating medium simultaneously.

<u>CONCLUSIONS</u>

1. For standard gold plated contacts with the geometry's evaluated, fretting corrosion did not occur with normal forces <100 grams. Fretting corrosion did initiate for the variation with normal force >100 grams.
2. For the standard gold plated contacts, the magnitude in change in resistance decreased as the displacement increased (as expected).
3. Unpowered Gold flash Pd Ni contacts did not remain stable in this

application. The results as seen are consistent with other work performed. Degradation also initiated within the same time frame as indicated in these other independent studies.
4. Powered Gold flash Pd Ni contacts had catastrophic failures which are tentatively attributed to the additional mechanisms of electrical erosion.

The reader should be cautioned that it is premature to apply the electrical erosion phenomenon as an "across the board" failure mechanism. Additional work is required which evaluates the following variables among others:

a) Current flow direction.
b) Other material systems (ie, gold flash contacts).
c) Other contact geometries.
d) Other environments inducing fretting.
e) Normal force variation.
f) Combination of the above.

The work contained herein introduces additional information which hopefully will initiate further work to put this phenomenon in proper perspective. However, the results do indicate and confirm that Au flash Pd/Ni foes not perform well in a fretting application induced by a vibratory medium.

The reader should also put the data as shown in perspective. The evaluation was a forced motion test which indicates what could happen when the materials and the contact design evaluated fret. It does not answer the question if fretting will occur in connector configurations with these designs or material systems when exposed to application specific vibration conditions. Thermal cycling which is the other main driving medium was beyond the scope and concerns of the test sponsors.

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BIOGRAPHY

Max Peel graduated from Norwich University with a degree in Electronic Engineering and MIT Sloan School of Management. He has been involved with the design and testing of electrical connectors for over 35 years with 30 plus papers at various conferences.