The Evaluation of Wear in the Fretting of Electrical Contact Surfaces

J.W.McBride, K.J.Cross*

School of Engineering Sciences
University of Southampton
Southampton, UK.
jwm@soton.ac.uk

*TaiCaan Technologies Ltd.
2 Venture Road
Southampton, UK.
info@taicaan.com

***Abstract*— Consideration is given to methods for the evaluation of surface wear from fretted electrical contact surfaces. The surfaces under consideration are selected for in-vivo applications, they are testing using purpose built fretting apparatus to investigate intermittency. The intermittency is associated with high frequency transients in the contact resistance between the two interfaces. These events can have serious consequences for the electronic signal and sensing systems. The intermittency events have been shown to be related to the wear processes occurring at the interface. Consideration is given to two optical scanning methods for the evaluation of the surface wear in terms of the volumetric wear of the surfaces.**

Keywords-Surface Contact Mechanics, Wear, Fretting, Intermittency, Conduction Polymer contacts.

I. Introduction

Fretting is defined as a low level relative movement between mated contacts, caused by either by differential thermal expansion of materials or vibration. Although many electronic connectors have been designed with the aim to endure fretting, this phenomenon remains as one of the major deterioration mechanisms of non-arcing electrical contacts. The study of fretting is therefore critical to understanding the reliability of connector systems. With the increasing application of electronic signal transmission in all aspects of technology, the role of the connector as the potential weak link in these systems should not be underestimated.

In recent years, increasing levels of integrated wiring in the automotive application have lead to a number of investigations into fretting. The automotive environment provides harsh environmental conditions such as thermal variations, mechanical vibrations and corrosive stresses. The results of these influences can be detrimental; it has been shown that more than 60% of the electric problems in automotive systems are related to fretting contact problems.

Fretting is known to be a major cause of contact deterioration and failure; commonly exhibited as the contact resistance increases from a few milliohms, in the case of a new metallic contacts, to in excess of several ohms for exposed contacts. Fretting is generated by external influences on the electrical contact interface, such as vibration and temperature changes, and as such applies to both power and electronic connections. The fretting process leads to complex interactions of physical processes, and as such has been the subject of numerous research studies, [1-4].

II. Defining The Fretting Process

The fretting process is a special case of the surface sliding problem, where the sliding surface is limited and cyclically loaded with low amplitude displacement. In 1980 Antler [2], gave a review of the fretting process from the mechanical perspective with a strong emphasis on the wear processes. The review does not consider the link to the external influences, and does not offer an understanding of the processes with current flowing through the contacts or the limitations on the fretting process. A further detailed analysis of the tribology of electronic connectors was covered by Antler in [3]. In both studies the fretting process is defined as consisting of 4 regimes;

- Stick, where the movement between the contact surfaces is accommodated by the elastic deformation in the near surface regions.
- Mixed Stick-Slip, where there is a central stick area surrounded by an annular slip region.
- Gross Slip, where asperities are broken during each cycle, movements between 10-100µm.
- Reciprocating sliding, where the movements are more than 100-200µm.

To add further clarity to the 4 regimes, in 2001, a study by Hannel et.al. [5] lead to the observation of the displacement magnitudes associated with the early stages of the process, based on a partial slip, mixed fretting and gross slip regime.

A. *Real Devices*

The automotive environment combines external vibrations with strong environmental factors, of temperature and humidity. In 2000 Maul et.al. [6] showed the complexity of the problem, in a study on a test vehicle where the external temperatures of connectors were monitored. The study has recently been enhanced with a number of micro-sensors embedded within a connector housing. This for the first time allows real information about the events occurring at the connector interface [7]. In [8] a novel in-situ position sensor for monitoring fretting motion has been designed and developed using thick film. The sensor allows real displacements measurements to be made at the connector interface in-situ. The results show that after calibration and laboratory testing, the device can be used in a real application, in this case a road tested vehicle. In a field test study, [8] the samples were placed in the engine compartment of a vehicle which was driven for a number of tests, each lasting approximately 10 minutes. It was found that the trends of results obtained from the field test agreed with results from laboratory experiments, although the respective absolute magnitudes were different. The field experiment has demonstrated the viability of using the novel thick film sensor for in-situ displacement at the contact interface for practical applications, and that fretting displacement can be measured directly in a real operation environment. Typical displacements are greater that 10µm, falling within the gross slip regime, as shown in Fig.1.

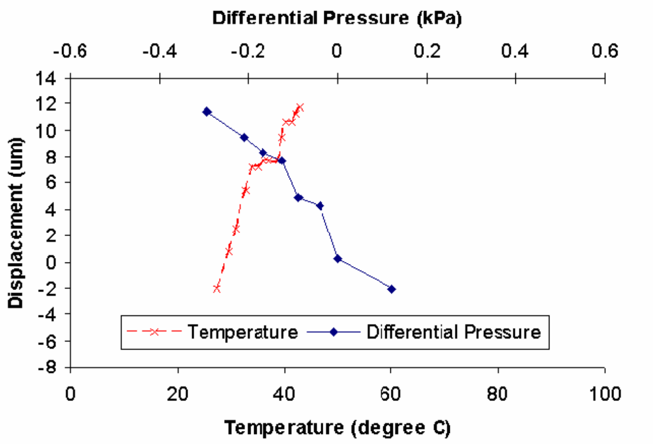

Fig1 The influence of environmental parameters on displacement in field tests.

III. Wear Evauation

Fretting is a wear process which is complemented by time, thermal and chemical processes. Many of the surfaces studied will have some surface geometric form, for example spherical or cylindrical surfaces. The measurement of the wear of surfaces was conventionally undertaken using mass evaluation, where the sample is removed from the test fixture. The mass evaluation method has been recently improved by as a result of advances in 3D surface scanning which allows a simple evaluation of the wear, taking into consideration the underlying form of the surface. The 3D scanning methods or areal methods allows the user to evaluate geometric parameters such as the length of the wear scar, surface area, volumetric wear removal and volumetric gain.

Recent reviews of the methodology used [9-11], have been undertaken. In [11] a review is presented of current methods for the measurement of precision surfaces, and it is shown that the con-focal method offers the most flexibility, however consideration should also be given to the light or laser spot size and the resolution of the sensor used. The application of the laser con-focal system has been shown to be most applicable for MEMS devices, while the white-light system is best suited for precision measurement of spherical and near spherical surfaces. Both technologies are suited for wear analysis but the con-focal laser system is favoured with its generally lower spot size, of 2µm.

A. Form Removal for Wear Analysis

Consideration is given here to the issue of form removal. In previous methodologies the underlying form is determined and then removed from the data set. This also removes the form from the wear region, generating an error in the evaluation of volumetric wear. This issue has been addressed by Zheng [12], where an automated process has been demonstrated for the determination of the wear region. The automated process needs a prior understanding of the expected wear and surface form. To overcome the difficulties a manual method has been developed. In this case the user removes the wear region from the data before form fitting, and then replaces the wear area after form removal. This results in the most precise method for evaluating the wear on surfaces with non-flat geometry. The experimental method is extended in this study in (VI).

IV. Intermittency Studies

The most important performance parameter for electrical connectors, the contact resistance, generally increases slowly with time, during fretting. Over several hundred or several thousand cycles in a fretting experiment the contact resistance increases from a few milliohms, in the case of a new contact, to in excess of several ohms. Superimposed on this slow increase in contact resistance are rapid changes in contact resistance within fractions of a second, called intermittences or short duration discontinuities (typically of µsec-ms duration), an example is shown in Fig.2, where the event is approximately 80ms, however also exhibiting µsec events, such as that at A.

Intermittency is of particular importance in electronic signal transmission. Fretting at the connector interface leads to high frequency changes in the contact resistance, including near open circuit values. These events can cause severe problems electronic systems. There are many applications where such events could be critical to system integrity.

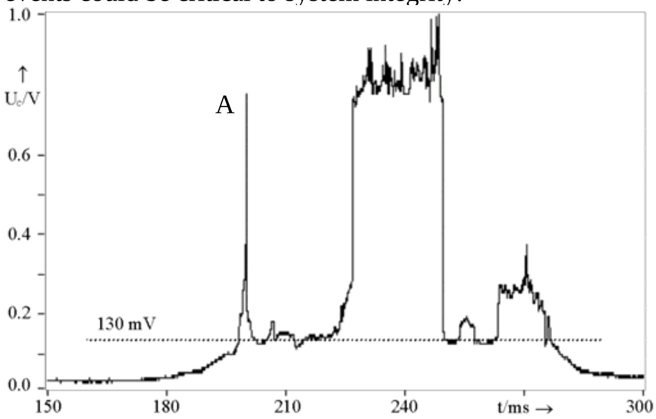

Fig.2 An intermittency event in a Sn-Sn fretting study. The softening and melting voltages are often exceeded F = 500 mN, U = 14.0 V; I = 54 mA; v = 0.1 mm/s

An important observation is that, as shown in Fig. 2; the events monitored often exceed the melting voltage for the materials selected. For Sn the melting voltage is shown in the dotted line at 130mV. Although the occurrence of short duration discontinuities has been known for a number of years, they are frequently overlooked in traditional fretting experiments [1], because the commonly used instruments to measure contact resistance are not capable of recording rapid changes in contact resistance. The intermittency study using high frequency sampling is demonstrated in [13-16].

V. INTERMITTENCY APPLIED TO IN-VIV ELECTRONICS

Increasingly electronic devices are being used in-vivo to aid biological activity, examples include cardiac pacemakers, neurostimulators and other electrical active implants. In such critical activities the occurrence of high frequency intermittency events can have a critical influence on the monitoring process. A critical feature for all the developments is the ability to perform electrical connections, and for this application the metals which can be used are restricted to materials not generally used for connectors. For the biological systems the electrical contact capability has to be established using metals which are known to be acceptable for other in-vivo applications, such as artificial hips. Serum and interstitial fluids have a concentration of chloride ions, which is about 1/3 of the concentration of brine and a seriously corrosive environment for metallic materials.

In an initial study, three metal alloys were considered for this application. Titanium (grade 5) or Ti-6Al-4V. Stainless steels (SS) predominate as materials for prosthetic devices, because they are relatively inexpensive and easy to machine. MP35N alloy is a nonmagnetic, nickel-cobalt-chromium-molybdenum alloy possessing a unique combination of ultrahigh tensile strength, good ductility and toughness, and excellent corrosion resistance. An important development for this application has been the application of a low current power supply (20mV), and the associated data processing, [16].

The experimental methodology presented is the basis for a new standard method which could be used in a broad range of applications. The system allows for the continuous monitoring of contact volt-drop and from this methods have been developed for the detection of high frequency intermittent events. Two methodologies for detecting the events were presented for both a 14V, 5V and a 20mV dry-circuit power supply.

The initial study of intermittency for the in-vivo in-body electronics applications has shown the importance of the connector design to the system performance.

VI. A NEW APPROACH TO THE EVALUATION OF WEAR

To investigate the methodology for the evaluation of wear 3D surface data is considered from test conducted on fretting in in-vivo systems. The data is measured using a TaiCaan Technologies 4000CL system. An example process is shown in Fig's 3-6. Fig 3 shows and example of a cylindrical connector surface, with a fretting wear area circled. To determine the dimension the wear area, the surface form is first removed using the BODDIES© software package designed for the purpose, [17]: after form fitting the wear area is replaced to give the data in Fig 4. From this the dimensions of the wear scar can be easily determined.

Table 1 shows the importance of the methodology when determining volumetric wear calculations. In Method A the form of the surface is removed, but the form removal is also applied to the wear region.

In Method B the wear region is selectively and manually removed before the form removal is applied. The wear region is replaced after the form removal, allowing the evaluation for the volumetric wear. In this case the form of the surface will be the true surface form. The resultant wear area allows improved evaluation of the volumetric wear, relative to a datum surface, shown in Fig.5. The volume wear is defined in table 1, as a volume above and below the surface.

In both Methods A and B the resultant volume will depend on the degree to which the surface is cropped. Thus the values in table 1 are only approximations. To enable a more robust evaluation of the wear will require a modified approach. Previous studies have developed a defect removal method, but this require a prior understanding of the wear geometry, [12]. Other methods involve using a free form line drawn around the area of interest, but this is essentially the same as the method used to cut off the data in Methods A and B.

Method C. The data resulting from method A is analysed to determine the 3D surface roughness (S_q) in the region out-side the wear area. For the sample shown this is 0.674µm. The S value is then used to determine the standard deviation of the surface roughness, and this is removed from the volumetric calculation. The resultant values in table 3 are thus much lower than those of A and B.

Method D uses the same S value to determine the cut of window in a viewer. This is an approximation, and allows the evaluation of the volume between the higher and lower cut-off, shown in brackets.

The results in Table 1 shown the high degree of variability that can be presented for the same surface. The most robust method is C, which uses pre-defined parameters to define the surface cut-off. This also implies that with a good form fit to the un-worn surface, the variability implicit in methods A and B by the user defined cut-off of area will be removed.

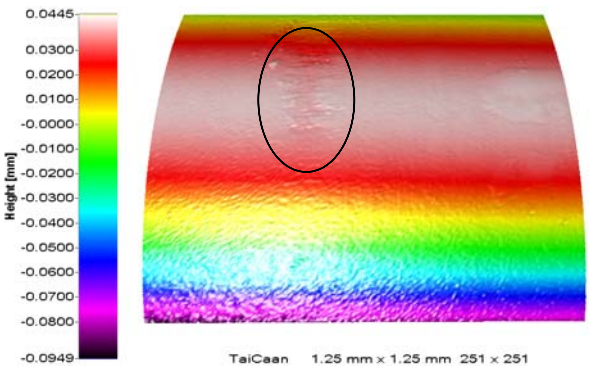

Fig.3 Raw data of the wear region on a cylindrical connector surface with wear area highlighted.

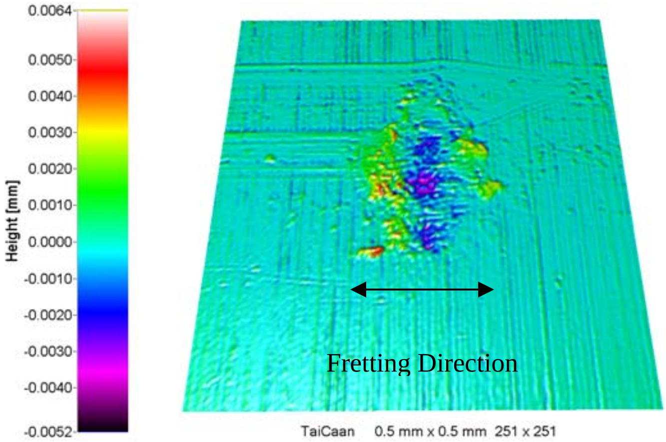

Fig.4 Wear area after form removal.

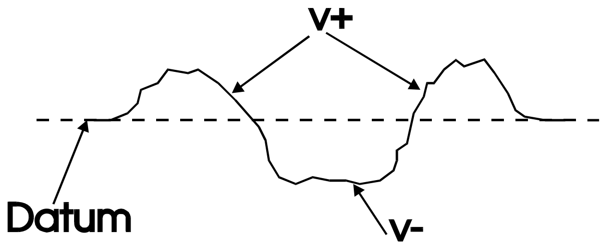

Fig5 Typical 2D section of data used to determine volume

	Volume below the datum surface, after form removal, (mm^3)	Volume above the datum surface, after form removal. (mm^3)
Method A	15.3 x10^{-5}	10.2 x10^{-5}
Method B	16.3 x10^{-5}	6.46 x10^{-5}
Method C	5.48 x10^{-5}	0.68x10^{-5}
Method D	8.56 x10^{-5}	1.7 x10^{-5} (13.0)

Table 1 The error in using the incorrect methodology for form removal in determining volumetric wear.

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