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Fretting corrosion in power contacts: Electrical and thermal analysis

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***Abstract*-Fretting corrosion phenomenon is known as the main cause of contact resistance increasing in signal contact. But for power connectors this undesirable phenomenon in embarked systems is more complex because high current induces high voltages and subsequent Joule overheating can be expected during vibration. Our study deals with contact similar of power connectors ones submitted to vibration amplitudes up to 25 micrometres at frequencies of a few 10Hz under a current ramp from 0.1 to 40A under 14VDC.**

The main measured parameters are the contact voltage during vibration up to a hundred thousand cycles. The average voltage by micro-voltmeter and its fluctuation during one cycle are acquired permanently by oscilloscope.

Thermal aspects are also investigated by the use of miniature thermocouples logged as close as possible to the contact zone. It was found that a limiting voltage is reached similar to the fritting voltage in a tarnished metal film reported by Holm. So contact resistances and the power brought by Joule effect are reduced and the temperature rise is limited. The main factors playing a role are current, contact materials and its susceptibility to wear and debris oxidation at the interface. This behaviour is confirmed by the SEM-EDX analysis of fretting zone at different steps of fretting.

Keywords: fretting-corrosion, fritting, contact resistance, contact voltage, contact temperature, automotive connectors.

I. Introduction

Due to repetitive micro-displacements, fretting phenomenon was defined as an electrical and mechanical degradation of the higher contact interface in telecommunications and more recently in power automotive connectors.

Communally the electrical degradation is quantified by the increase of contact resistance [1-3] deduced by contact voltage. To explain the voltage variations and non-linearity conduction reported in the literature [4] as shown in Fig. 1, the authors focused their investigation of the effect of current and power on various regions on the rate of fretting appearance and subsequent temperature.

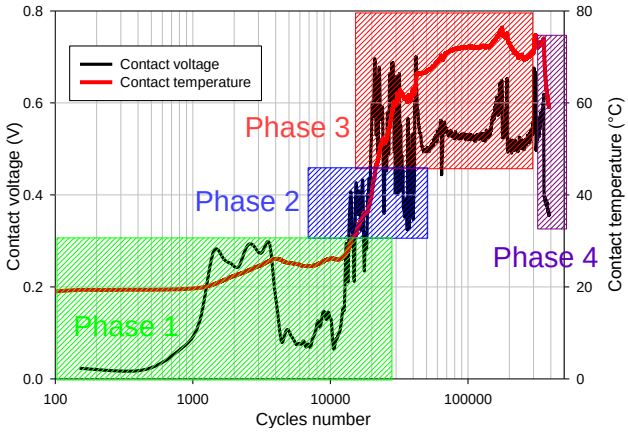

Fig.1. Evolution of contact voltage and temperature during fretting for 10A. Dashed area indicates the three phases of fretting.

Using the analysis of voltage and temperature in real time during fretting, we study the conjointly of both voltage and temperature evolution. Finally, we analyse the non-linearity and breakdown of aged samples by fretting with current ramp (0.1 to 40A) in the three phases of fretting [5].

II. Experimental Device and Procedure

A. Sample and Vibration Characteristics

The U-shaped samples are produced in our laboratory from cooper alloy of 0.8 mm thickness and coated by tin (2µm). Two contact parts are produced; the upper part with a spherical (CuSn3Zn9) shape of radius 2 and 3mm, and a plane part Fig. 2. In order to simulate actual operating conditions of the connectors, vibrations are imposed directly on the lower contact as shown in Fig .3. On one side the sample is firmly attached to a force sensor which is fixed to the ground while the lower part is fixed to the shaker. The vibrations are a typical sinus oscillation with a frequency of 50Hz and displacement amplitude of 2a = 50µm p-p (peak to peak). This movement is checked and measured on the sample with a displacement sensor (laser resolution of 0.1 microns).

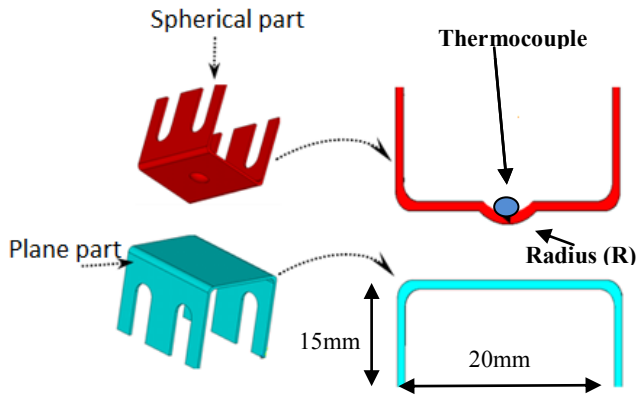

Fig.2. Sample geometry equipped with thermocouple for tests

B. Experimental Procedure

Using a micrometre intender, a displacement is made the upper part which ensures contact with the lower at 3N of contact force. The contact voltage is measured by a micro voltmeter (0.1 mV averaging contact voltage on one cycle). A current source with a compliance of 10 V supplies the sample in the current range from 1 to 40A. In addition, this current source has been used in the range 0.1A 40A to draw the characteristic of the contact voltage in the different phases of wear. A miniature thermocouple was placed as close as possible to the contact zone to measure the temperature (Fig. 2) and gives a thermal effect on the electrical degradation conjointly with the contact voltage. For faster voltage fluctuations during one cycle and position in the track of displacement we use a digital oscilloscope.

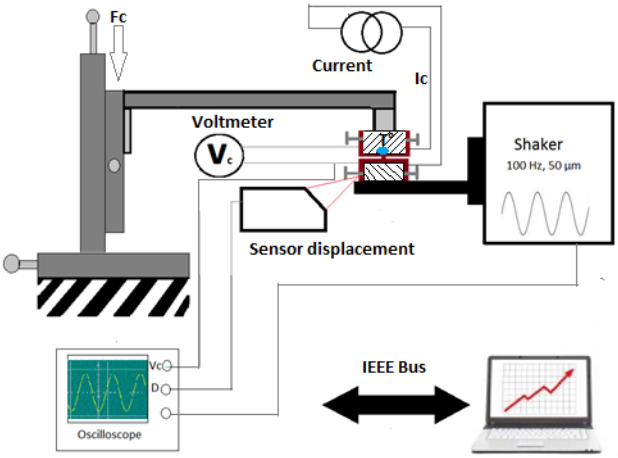

Fig.3. Fretting devices allowing displacement, voltage and temperature of contact measurements

III. Results

The main results deal with voltage analyses during sliding in the two directions of motion and its non-linearity in wide range of current versus aging phases as are shown in Fig. 4.

A. Influence of Current on Fretting-Corrosion

Voltage and temperature versus number of cycle are plotted for different currents levels from 1 A to 40A and for two radius of the spherical shape. As it is was expected the saturation voltage around few hundred millivolts appears earlier when the current is increased and seems to be followed by final phase with lower and stable voltage.

Also the size of the sample acts as an accelerator factor for fretting appearance: higher radius of 3mm shows a smaller number of cycles to initiate fretting and tends to higher voltage saturation than radius of 2mm. This is due to larger contact which could produce increasing wear and debris. Conjointly contact temperature is measured during fretting of sample at various current used in our test. We note that temperature remarkably follows the variation of contact voltage during fretting. So after the initial phase at ambient temperature it increase with some delay compared to voltage because the thermal inertia. Similar maximum of temperature was reached at the final stage of fretting corresponding to voltage evolution. No doubt this well correlation between temperature and voltage is due to the heating by Joule effect and subsequent power P=Vc Ic dissipated in the contact interface as related in the literature [5].

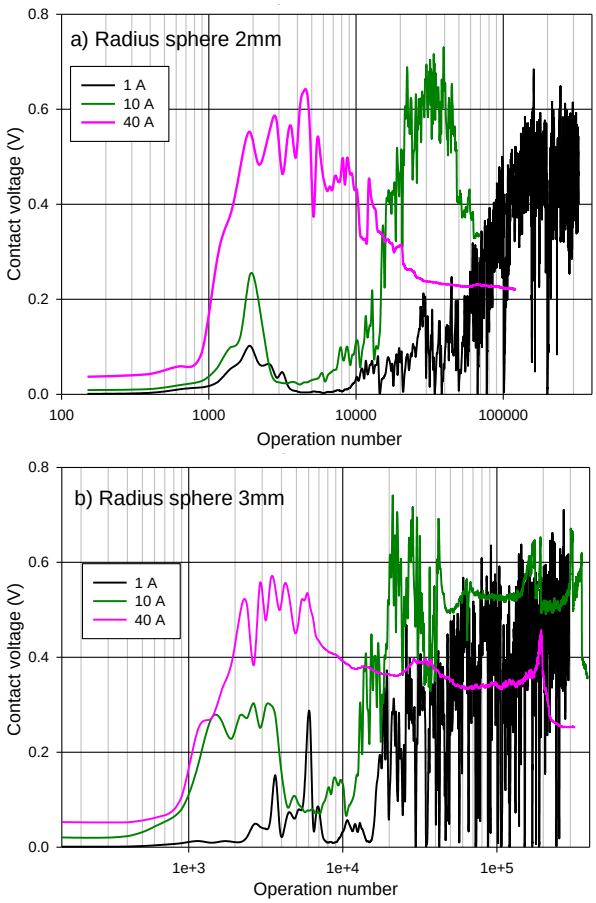

Fig.4. Contact voltage versus cycle number for three currents: a) Radius 2mm; b) Radius 3mm

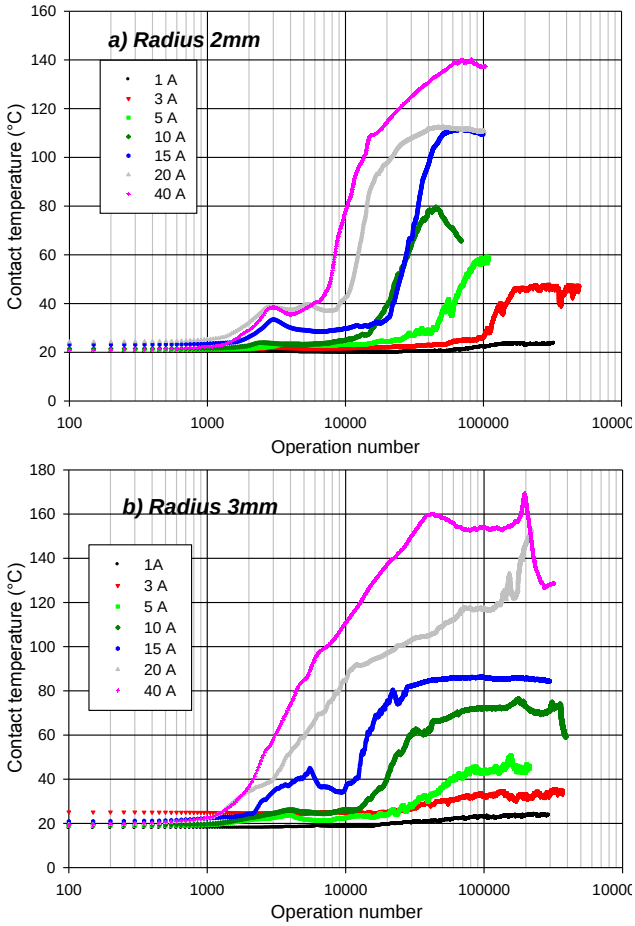

Fig.5. Contact temperature versus cycle number for three currents: a) Radius 2mm; b) Radius 3mm

As in low current level and for practical aim we calculated the number of operation needed to reach a certain value of voltage (instead of resistance) which is called as criteria of default. We can see in figure 6 the number of cycles N_c needed to reach a given voltage value (100,200,400,600mV) in the range of current 1 to 40A. It appears two behaviour regions:

- In the first region dashed in blue and limited to 10A, the relationship is $N_c=K_1/I$ where K_c depend on desired voltage for example for $K_{100mv}=8*10^4$ op.A^{-1}.

- Above 10A, the slope is increased and the relationship is $N_c=K_2/I^2$. This accentuation of these phenomena is due to the earlier appearance of the fretting phenomena accentuated by thermal and wear and this higher current value.

B. *Non-Linearity of Contact Condition*

The voltage saturation values in Fig. 4 seem to be close to a few hundred mV for a wide and large current domain. One can deduce that the non-linearity conduction in such interfaces is due to formation of debris and oxides.

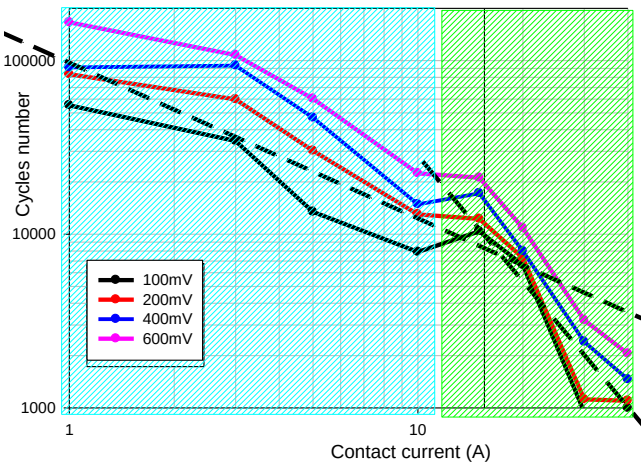

Fig.6. Cycle number versus current at different reached voltages (default criteria): dashed line indicate the power law ($N_c=K/I^n$)

This phenomenon is reported in the literature [5]. As processes of oxidation of the contact surface oxidation induce poor conduction and non-linearity of current flow in the contact. For this reasons, we applied a current ramp from 0.1A to 40A to contact simple aged by different numbers of fretting cycle as it is shown in Fig. 7. In the low number of cycle corresponding to the first phase of fretting we can remark that the contact voltage is proportional to the current. So the linearity is ensured and contact resistance remains constant Rc=Vc/Ic and close to the initial constriction value. This value can calculate by the slope of the curve V-I. At the higher number of cycles corresponding to the second and the third phase the contact voltage follow linear evolution up to certain value of current corresponding to the power of 0.3W for fretted sample at 3A and 3W fretted sample at 40A.

Also, the sample aged by fretting at 3A (lower current) diverges from linearity at low current applied and is more sensitive to electrical breakdown than the fretted sample at 40A (high current). During fretting observation of the voltage fluctuation during the cycle and along the displacement track are important with many peaks with various amplitudes. This aspect is reported in our paper [6] at low electrical level. But at the final stage the contact voltage is stabilised and remain constant.

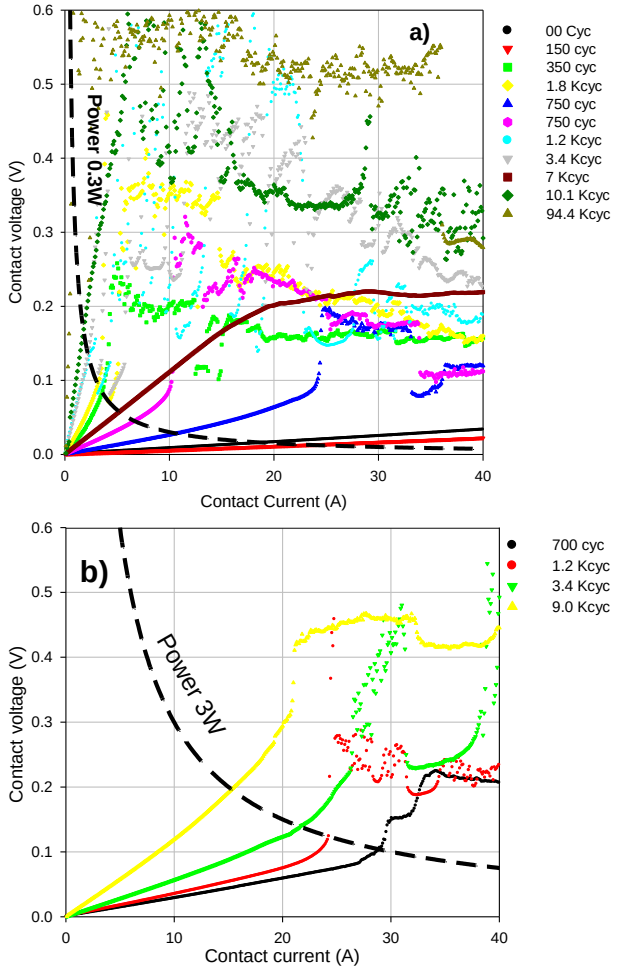

Fig.7. Contact voltage versus current for different stages of fretting: Dashed curves are constants power respectively 0.3W and 3W: a) Fretting at 3A; b) Fretting at 40A

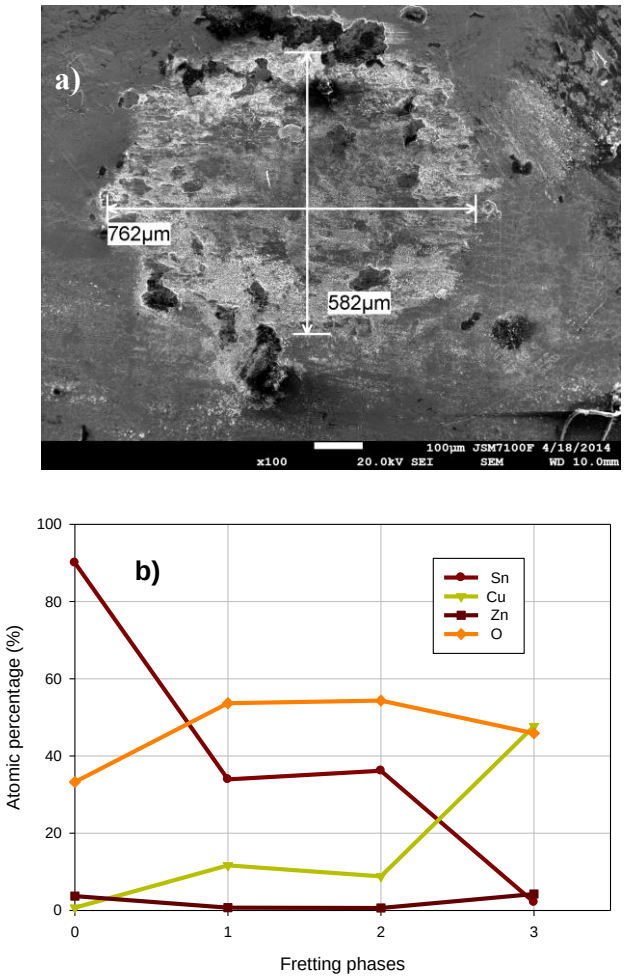

Fig.8. Fretting zone and microscopic analysis of elements Sn, Cu, Zn, O.
a) Fretting zone photography showing debris
b) Atomic percentage of elements at Phase 1, 2 and 3 (0 is no fretted zone)

C. *Contact Surface Analysis*

Regarding the evolution of voltage versus number of cycles we attempt to microscopic analysis (SEM-EDX) the elements percentage on contact surfaces at different phases of fretting. As shown in Fig. 8 the mains elements considered are the metallic coming from the subtract (Zn, Cu), coating (Sn) and Oxygen (oxidation level proof). It is clearly shown that the coating is removed progressively during the two firsts phases and disappears in the third phase where voltage is limited. In addition, during this third phase the elements of subtract appear and dominate the debris composition on the fretting surface. Finally, Oxygen concentrations on the surface are increased at the first phase of fretting and remained important in the following phases two and three. We assume that the oxygen is bonded to Sn forming SnO_2 at the initial phase, but at the final phases oxygen is bonded to cooper forming Cu_2O.

IV. Conclusion

In the present study we have to expand our knowledge about the fretting phenomena to higher current and power. As in low level, the fretting evolves in the three phases but an additional final stage of stable low voltage appears in the high current, this phenomenon caused by large wear and oxidized debris in the interface. The contact temperature evolution follows similar behavior than contact voltage. Obviously, the thermal heating by Joule effect is the main cause of this over heating up to 160°C at 40A. Due to the non-linearity conduction phenomenon the default criteria of the contact should be based on the voltage level instead of contact resistance. We found that two default domains of current intensity separated by 10A, in the first one, the number of cycles to reach the default is proportional to the reverse current intensity.

However this decrease is accentuated in the second region where the number of cycle is proportional to the reverse square of current. Probing this aged sample by fretting in a large current domain we found that the linearity conduction (Ohm law) is ensured at low current and limited by a power dissipation curve. The aged sample at high current (40A for example) seems to support a higher current and power before electrical breakdown by fritting voltage [7].

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