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Analysis of temporal and spatial contact voltage fluctuation during fretting in automotive connectors

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Abstract

Our study is focused on contact voltage fluctuations during fretting with small amplitudes of a few tens microns which generate damage of the contact of connectors. A contact composed by a pin and a curve female part are submitted to vibration cyclic of 25 μ m at 100Hz and supplied with current ramp from 0.1mA to 3A in two directions. With the help of fast devices, the voltage and position data acquisition are conjointly made with the common DC contact voltage during fretting. Some unexpected results state that voltage fluctuation occurs in the different stage of fretting and start at the beginning of test in the insertion direction and located at half of track. These small voltage fluctuations around few mV increased to few hundred millivolts and may reach few volt at ultimate phase of degradation with random distribution along the track. When the motion is stopped the ohmic conduction of such fretting interface is ensured only when the subsequent voltage stay below a sutured value depending on the degradation and current level. It is found that the common three phases of degradation have a different saturation voltage which appears at higher and higher current and induce voltage breakdown. Regarding that symmetric characterises is obtained in two the directions current ramp the semiconducting behaviour effect of oxide layers on debris particle is negligible. As voltage-current experimental data was well fitted to similar equation of granular material conduction we have deduced the fitting parameters (V_1 and I_0) of interface.

Keywords: fretting-corrosion, fritting, contact resistance, contact voltage, intermittence.

1 Introduction

Due to repetitive micro sliding, fretting phenomena has been defined as a subsequent electrical and mechanical degradation of the contact interface in telecommunication and more recently in automotive connectors. Electrical degradation is currently quantified by contact resistance increases [1,2,3]. Also intermittence and contact voltage fluctuation have been investigated and reported in the literature [4,5,6]. In order to explain voltage fluctuations mentioned in the literature [7] as shown in the figure 1 the authors have focused their on the three regions.

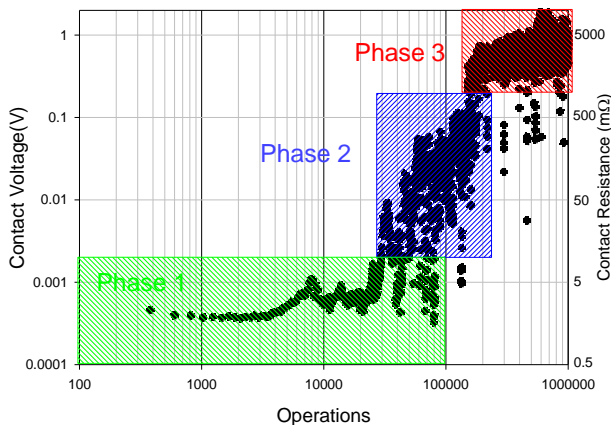


Figure 1 Evolution of contact voltage and resistance during fretting at 200 mA. Dashed area indicates the three phases of fretting.

Some considerations on electrical break down by fritting voltage phenomena [8] and non-linearity conduction [9] in the corroded interface or granular materials [10] are suggested to explain the origin of large low fluctuation.

Using the latest sensitive voltage analysis in real time we focus our interest on contact voltage fluctuations. As shown in Figure1 typical example the low level and near the constriction voltage (Phase1) are analysed [11]. In the second level corresponding to fretting appearance and finally at the saturated voltage [12]. This analysis is made fluctuation during cycle time and position in the track. To disclose the non-linearity between voltage and current we explore and plot voltage current characteristics in wide range current 100 μ A to 3A. This work is done on commercials tin coated connectors (Female part shape with plane lamella) and medium frequency 100Hz with amplitude 50 μ m P-P. The objective of this work is to extend the knowledge of contact voltage and its validity to define the contact resistance verses time and displacement inside the cycle. By this approach we aim to define the dynamic contact resistance and his dependency to the current flow level.

2 Experimental device and procedure

2.1 Vibration characteristics

The samples are extracted from a commercial automotive connector which is made in copper alloys coated with Nickel 2 μ m under layer and tin 2 μ m external coat. To

simulate real working conditions a particular vibration characteristics are imposed directly to the contact. As is shown in figure 2, one side (half side of the female part) is fixed firmly on force sensor and attached on the ground while the male part (the lamella) is attached to the shaker, working at frequency 100 Hz with amplitude of $2a=50\mu\text{m}$ (peak to peak) of sinus oscillations. This movement is controlled and measured by displacement sensor (by laser $0.1\mu\text{m}$ of resolution) focused.

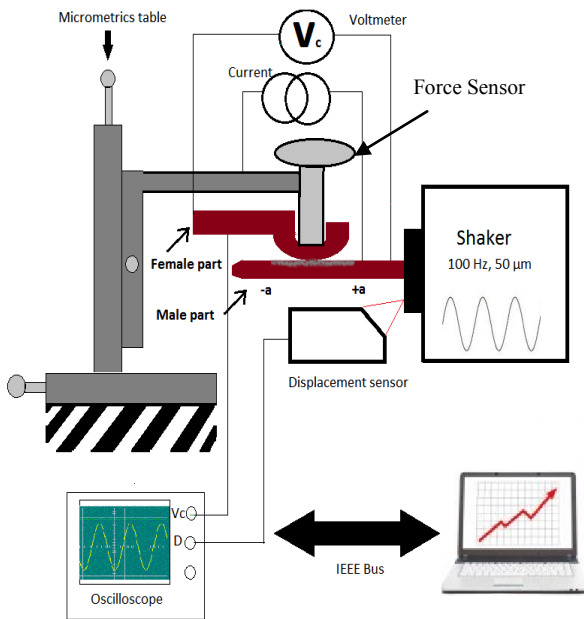


Figure 2 Fretting device and Voltage and displacement measurements

on the female and male parts. The contact force of 2N is applied by micro sliding and indentation of female part on lamella. The average fretting contact voltage is measured by a micro voltmeter ($0.1\mu\text{V}$ resolution averaged over 1 Power line cycle of 20ms i.e. 2 periods of oscillations of fretting 10ms) under 200mA delivered by current source with 10V Voltage compliance. Also, this current source was used in range $100\mu\text{A}$ to 3A to plot current Voltage characteristic at different phases of fretting. For faster fluctuation during the cycle as show in figure 3 a digital oscilloscope was used to acquire contact voltage fluctuations and displacement during one cycle (sampling period $20\mu\text{s}$) at different stages of fretting. So we can made analysis of the voltage on the two distinct direction of sliding: the insertion $-a$ to $+a$ and the extraction $+a$ to $-a$ of the lamella.

The samples are extracted from a commercial connector which is made in copper alloys coated with Nickel $2\mu\text{m}$ under layer and tin $2\mu\text{m}$ external coat.

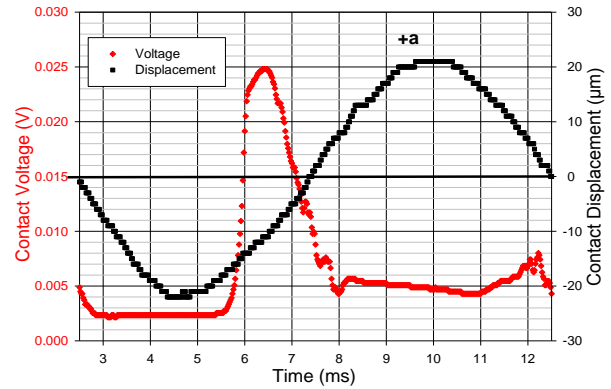


Figure 3 Contact voltage and contact displacement during one vibration cycle at 100Hz and $50\mu\text{m}$ p-p.

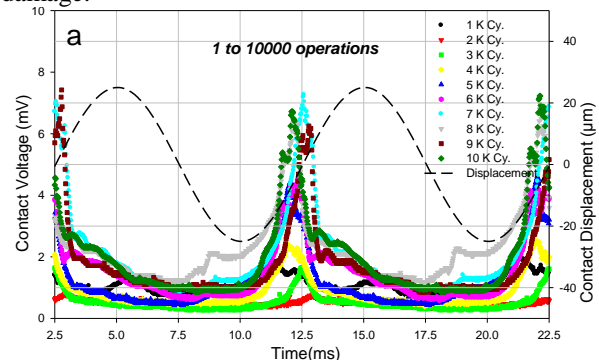
3 Results

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 figure 1.

3.1 Voltage fluctuations during fretting

Contact voltage are plotted for 2 successive cycles after each 1000 cycles during different stages of aging corresponding to the previous three phases described in the figure 1. These curves are shown in figures (4,5,6).

As we can see in figure 4a at earlier first phase of fretting corresponding to low voltage (0 to 10 mV) a mayor part of fluctuations take place at half period of duty cycles. However this low voltage remains constant during the second part of duty cycle. In addition we have examined the voltage fluctuation during displacement (figure 4b) in the twice directions i.e. from $(-a)$ to $(+a)$ directions of the displacement (insertion) and from the $(+a)$ to the $(-a)$ direction (extraction). Let's note that in the insertion direction a maximum voltage is observed at the left part of the track (comprised between 0 and $-a$, approximately $17\mu\text{m}$). Surprisingly this maximum voltage wasn't observed when the displacement is in the reversed direction (extraction). Subsequently contact voltage remains constant and keep contact resistance at its construction value. This behaviour is currently observed during the first phase of fretting approximately 10 000 cycles. One can assume that this behaviour is due to the unsymmetrical surface damage.



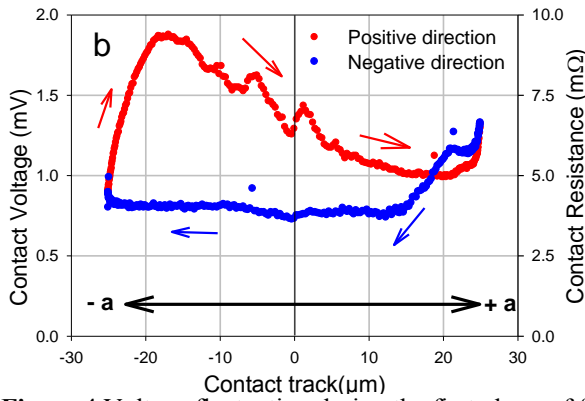


Figure 4 Voltage fluctuation during the first phase of fretting: a) fluctuation during time of two periods after different number of cycles, b) fluctuation during displacement after 1K cycle.

However, for further operations corresponding at the second phase (figure 1) this maximum voltage in the left side is remained and additional maximum appears in the second part of duty cycle as shown in figure 5a. This is confirmed by plotting the voltage during displacement in figure 5b. Also, we remark that the position in the fretting track and amplitude of this voltage fluctuation are changed during this second phase.

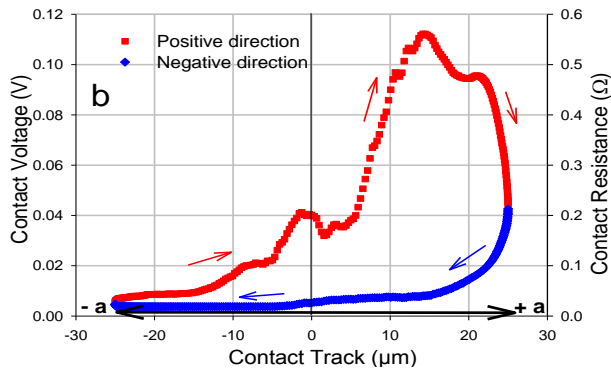
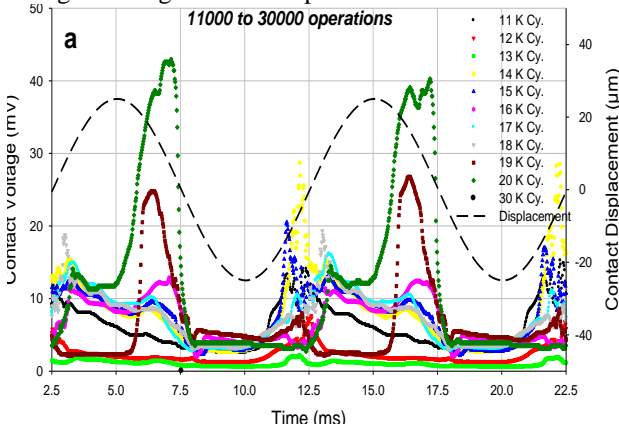


Figure 5 Voltage fluctuation during the second phase of fretting: a) fluctuation during time of two periods after different number of cycles, b) fluctuation during displacement after 20K cycle.

Finally, at the last phase of fretting the contact voltage become random but some stable voltage can be observed during a fraction of the duty cycle approximately during a quarter of cycle 2.5ms (figure 6a.b). In addition, this volt-

age can fall down to the low value close to the second phase value. Also, this random behaviour of contact voltage fluctuation and its limited value can be attributed to the breakdown of films by fritting phenomena reported by Holm [8]. This random behaviour at this advanced stage of fretting can be related to the sever degradation by wear and accumulation of debris and their sudden ejection.

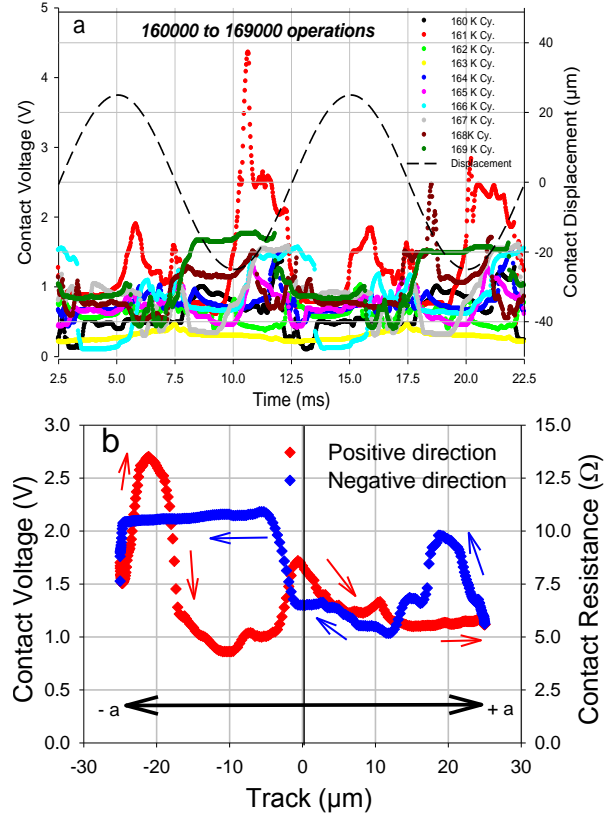


Figure 6 Voltage fluctuation during the third phase of fretting: a) fluctuation during time of two periods after different number of cycles, b) fluctuation during displacement after 168K cycle.

In fact, the origin of these fluctuations was assumed to the debris coming from the wear of the coating [10,11] and their oxidation [13]. However, the observed fluctuations of the first phase are mainly due to mechanical abrasion of the coating localised in the same position of the track while their appearances in the insertion motion can be attributed to the uniformity wear zone.

Lastly and principally in the second and third phases the production of the wear debris is accentuated and their oxidation is activated so the maximum voltage fluctuation is observed and each side of the centre of motion.

3.2 Contact voltage analysis after fretting

As reported in the literature the oxidation of contact surfaces induce poor conduction and non-linearity of current flow in the contact. As an example in the literature reported in literature for tarnished films [9], we believed that the similar phenomena can take place in this corroded debris in various phases of fretting. For this aim, we applied current ramp from 0.10mA to 1A at contact simple stopped at different phases of figure 1. In the first phase this result given in figure 7, we can remark that the con-

tact voltage is proportional to the current. So the linearity is ensured and contact resistance remain constant $R_c=V_c/I_c$ and close to the construction value. Its value is close to construction value of few mΩ with we can calculate by the slope of the curve V-I. At the second and the third phases the contact voltage follow linear evolution and remain proportional to the current where the slope is the contact resistance $R_c=V_c/I_c$. However, when this voltage reach certain value generally $> 100\text{mV}$ break down appears and contact voltage fluctuate around constant value. From this voltage level contact resistance is variable and could decrease with current enhancement as is shown in figure 8. This phenomena is accentuated and take place at lowest current of few tens mA and higher breaking voltage $>500\text{mV}$ namely in the phase 3.

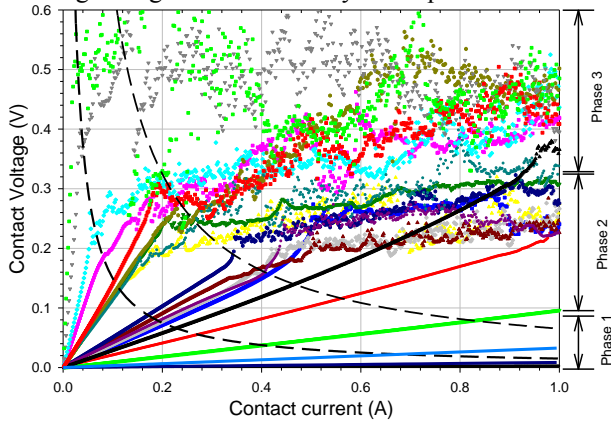


Figure 7 Current voltage characteristics at stopped motion at different stage of fretting. Dashed curves are power curves 5 and 25 mW.

Also, the breaking and the non-linearity domain can be limited by the maximum of power dissipation which can be supported by contact interface without damage. Two power curves corresponding 5mW and 25mW can limit this domain. These curves are marked by dashed line in figure 7. Also, beyond the maximum power of 25mW supported by the contact it is found that power of 0.15W breakdown and non-linearity appears all the time. In this work we have confronted the breaking voltage value of such interface resulting from the fretting to the previous theory of HOLM [8]. It is clearly that breaking voltage is comprised in the range of 170mV to 700mV; this is corresponding to fretting A and B.

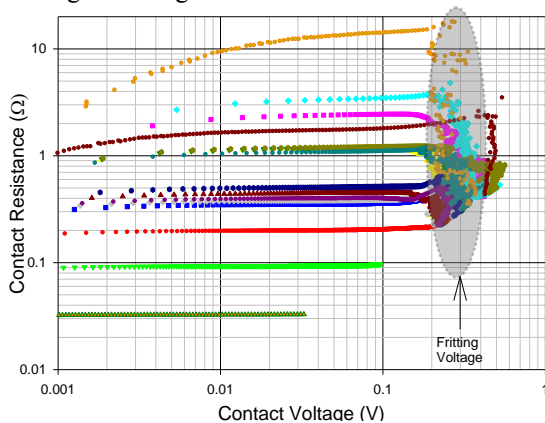


Figure 8 Contact resistance versus contact voltage from different stage of fretting.

3.3 Contact voltage analysis after fretting

In order to examine the semi-conducting and non-linearity phenomena we apply the current ramp in the two directions: from -1A to 1A alternatively $(I+\Delta I)$ and $(I-\Delta I)$ with logarithmic step ΔI . The corresponding plots are given in figure 9 corresponding to contact degradation stopped at different phases of fretting. As the main remarks that the curves are symmetric and no-rectifying effect coming to semi-conducting of oxide layers on tin and copper and nickel debris.

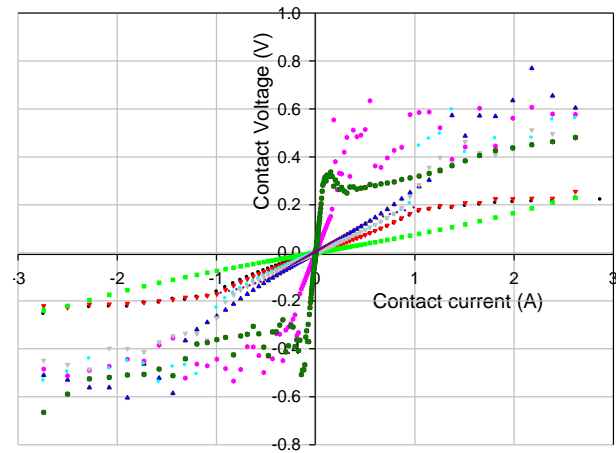


Figure 9 Contact voltage versus contact current for positive and negative current at stopped motion for different stage of fretting.

In addition, some attempt by fitting experimental result (figure 10) data (I-V) to the well-known equation of contact voltage V_c versus current I_c in granular materials [10]:

$V_c = V_l (1 - e^{-\frac{I_c}{I_0}})$ Where $V_l=0.371\text{ mV}$ is voltage saturation (breaking voltage) and $I_0=1.633\text{A}$ is relate the current slop. A similar fitted curve is obtained for negative ramp $V_l=0.278$ and $I_l=1.344\text{A}$. Furthermore, by derivation of the upper equation we deduce the dynamic contact

resistance R_d law versus current I_c : $R_d = R_0 e^{-\frac{I_c}{I_0}}$ Where R_0 is V_l/I_0 . This mean that contact resistance decrease exponentially with the applied current I_c .

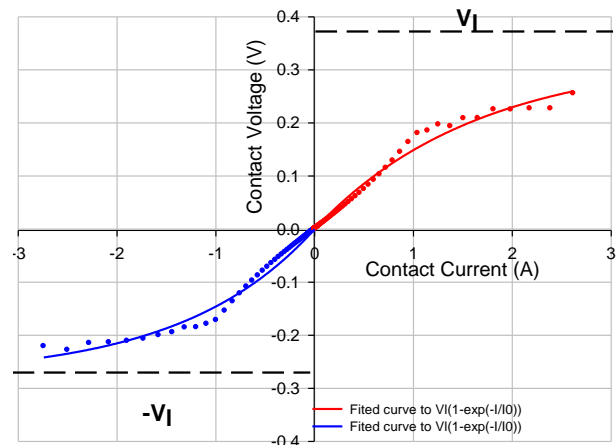


Figure 10 Contact voltages versus contact current: Solid lines are the fitted curves to experimental data.

4 Conclusion

The present study aims to expand our knowledge about the phenomena of fretting carrying an interest of fluctuating voltages of contacts in conjunction with mean voltages widely used as a control of degradation of electrical conduction of contacts.

Indeed, the voltage fluctuations appear from the beginning of vibration only in a part of the track and preferentially in the direction of insertion. By consequence these fluctuations generate in these parts of the track contacts resistances higher resistance value compared to the value of the constriction resistance. This result demonstrates the existence of localized mechanical degradation of the track of a non-uniform manner. It is only in the next phases of fretting that these fluctuations reinforce and change place of occurrence in the track to become random and very important along a portion of the track friction : it is the effect of wear and debris accumulated in the conduction and ejected periodically that can explain this behavior.

These voltage fluctuations disappear at each stop of the vibration, giving way to a stable voltage with different values depending on the state of chemical and mechanical interface degradation. The linearity of the conduction is kept to a certain current level from which a phenomena of electrical breakdown appears and is accompanied accompanied by voltage limitation as described by Holm "Fritting voltage". This phenomenon of saturation and non-linearity is similar to that of the conduction in the granular material of which the texture is similar to that of the wear debris in the interface [10]. In conclusion the study of fluctuations and saturation voltage as the current increases and the state of degradation gets worse, constitute a useful and appropriate tool for characterizing the conduction contacts during fretting.

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