U.P.B. Sci. Bull., Series C, Vol. 71, Iss. 2, 2009 ISSN 1454-234x

MECHANICAL WEAR OF AUTOMOTIVE CONNECTORS DURING VIBRATION TESTS

Rochdi EL ABDI[1], Noureddine BENJEMAA[2]

Impactul vibrațiilor asupra contactorilor a fost studiat în literatura de specialitate dar, nici un studiu nu a furnizat o relație de legătură clară şi simplă între evoluția rezistenței electrice şi mărimea uzurii.

Obiectivul principal al acestui studiu este de a stabili o corelație între uzură, comportamentul electric şi tensiunile mecanice generate de vibrații. Testele au fost realizate pe un contactor auto acoperit cu mai multe tipuri de starturi. Analiza comportamentului electric se bazează pe măsurarea rezistenței electrice. Această mărime este influențată de uzura stratului şi a substratului care este cuantificată prin pierderea de masă. De asemenea, este analizată forma uzurii. Contactorul este format dintr-o plăcuță ce poate glisa între opt resorturi, câte patru pe fiecare față. Sunt utilizate trei tipuri de acoperiri din aur, cositor şi argint, de 2 µm grosime.

Două niveluri de forțe sunt utilizate la înaltă frecvență de 100 Hz pentru a impune trei amplitudini de vibrație de 10 şi 100 µm. În plus, o frecvență joasă de 1 Hz este produsă de un micromotor de translație (pentru o amplitudine de10 şi 100 µm).

Partea « mamă » este montată pe tija vibratoare iar partea « tată » este fixată pe o masă micrometrică. Rezistența de contact este obținută cu ajutorul unei surse de curent (1 mA) ce utilizează o complianță Vcc de 20 mV (voltaj limită).

Rezultatele arată o corelație semnificativă între rezistența electrică.

Impact fretting of connectors was studied in the literature, but none of these studies is completely satisfactory for finding the relation between the electrical contact and wear rate.

The main objective of this work is to find and establish a correlation between wear, electrical behaviour and vibration stress. The work is made on automotive connector with various coatings. The electrical behaviour measured by contact resistance and wear by mass loss are correlated. In addition, the wear shape is analyzed. The connector includes four spring lamellas in each side and the pin has flat shape. Three coatings are used with 2 µm of thickness and made in tin, silver or gold.

Two levels of stress are used at high frequency of 100 Hz corresponding to do amplitude of 10 µm and 100 µm on the shaker. In addition, low frequency of 1 Hz is used by micro motor sliding (for 10 µm and 100 µm).

The female part is mounted on the shaker while the male part is fixed on micro-metric tables. The contact resistance is made with a current source (1 mA) using compliance Vcc of 20 mV (voltage limit).

[1] Prof., Laboratory of Applied Mechanics – Larmaur Fre Cnrs 2717- Rennes1 University, France, relabdi@univ-rennes1.fr
[2] Assistant Prof., PALMS Laboratory – Equipe Contacts Electriques, Rennes1 University, France

Results show that the correlation between the electrical contact resistance and wear is significant. The effects of motion parameters, test duration and different coatings were studied.

Keywords: connector, fretting, wear, electrical resistance, corrosion

1. Introduction

Fretting corrosion is the most important failure mechanism for tin plated contacts and has been discussed in many publications [l- 5].
Result of the fretting action, fretting corrosion is a building up of corrosion products, usually oxides of the contact material [6]. Fretting and fretting corrosion have been highlighted as mechanisms of degeneration in electrical connector contacts [7]. This phenomenon is a complex process involving the interaction of various physical phenomena between two contact surfaces (friction, wear, adhesion, transfer, etc.), and the chemical reactions which occur on the surface and in the subsurface layers. It is associated with small amplitude oscillatory movement, which may occur between two contact surfaces when subjected to vibrations [8- 13].

The main objective of this study is to find and to establish a correlation between wear, electrical behavior and vibration stresses. This work is made on automotive connector with different coatings.

The electrical behavior measured by contact resistance and wear by mass loss are correlated. On the other hand, different analyses using microscope observations are done. In addition the wear shape is analyzed.

2. Test condition apparatus and protocol

2.1 Test condition

The studied connector includes four spring lamellas in each side and the pin has flat shape (width 2.8 mm) (Fig. 1). Three coatings are used with 2 µm of thickness and made in tin, silver or silver under gold.

Two levels of stress are used at high frequency of 100 Hz corresponding to do two amplitudes 10 µm and 100 µm on the shaker. In addition, to cheek the frequency effect, a low frequency of 1 Hz is used by a sliding micro-motor which make a horizontal movement (resolution of 0.1 µm).

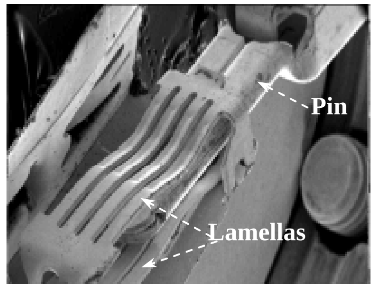


Fig. 1. Studied connector with eight spring lamellas

2.2. Test apparatus

The female part (spring lamella) is mounted on the shaker in case of high frequency (Fig. 2a) and on micro-motor in case of low frequency (Fig. 2b), while the male part (pin) is fixed on micro- metric tables in order to make a better alignment between the two parts.

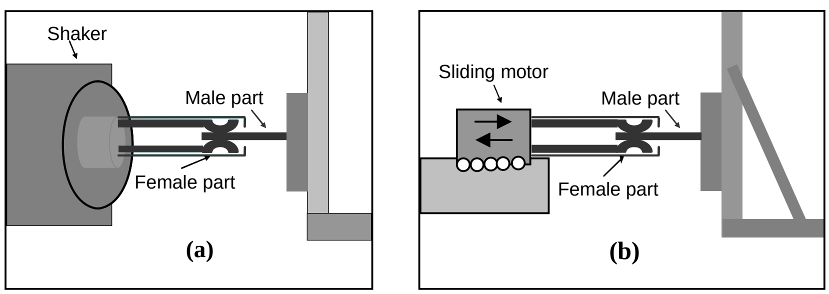


Fig. 2. Test apparatus vibration: (a) high frequency, (b) low frequency

The contact resistance is made with a current source (1 mA) using compliance Vcc of 20 mV (voltage limit). So, at this constant current the value of resistance is calculated by the contact voltage measured by micro voltmeter with a resolution of 0.1 μV. The integration period of the micro voltmeter is 40 ms. Thus, the contact voltage is the mean value during this period and its measurement is repeated each second without any synchronization between the measurement time and the shaker position.

2.3. Test protocol

The procedure of the test for the high and the low frequencies is the following:

*before the test, the connector is cleaned during 5 min by alcohol in an ultrasonic bath in order to remove the lubricant and all the external deposits. Then, the connector is dried,
*thereafter, the connector is mounted on the shaker and the vibration tests are starting. Simultaneously, the contact resistance is continuously measured at each second,
*finally and after the test, the two parts of the connector are cleaned in order to remove the particles caused by the wear and to determine the mass loss. After the tests, the eroded volume and the dimensions of the wear track (length, depth and width) are calculated with the help of a new method based on the eroded surface scanning.

3. Relative movement

In order to control the programmed connector movement and to be sure that the test apparatus is rigidified, possible relative movement and the shift of the center of the movement are examined. Two lasers are positioned on micrometric table. The first one measures the female part movement which is fixed on the shaker and the second one measures the residual movement of the male part (Fig. 3) which is normally nil.

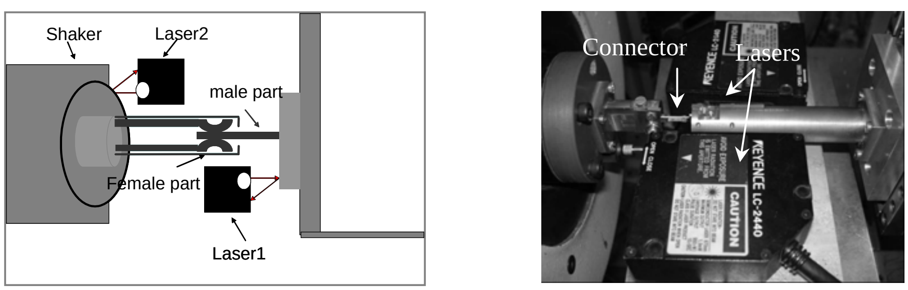
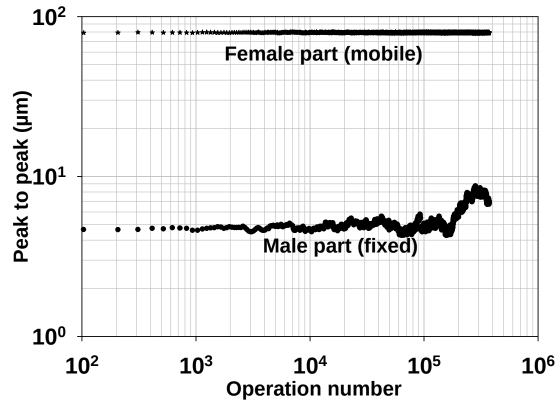


Fig. 3. Test apparatus to measure the relative movement (laser technique)

With laser technique, the amplitude of the female part (mobile) keeps amplitude near 100 μm during the entire test (which is the programmed amplitude for the shaker). At the beginning of the test, the male part (fixed part) has low amplitude (5 μm) (Fig. 4a). Passing 10^5 operations, this amplitude increases and stabilizes around 10 μm. This increasing can be explained by the sample fatigue and by the effect of some little movements of the spring inside the socket. Also, the shift of the center of the movement is analyzed. The center of the movement moves from -50 μm to 50 μm and passes through 0 μm. This center for the female part and the male part has a small shifting (2 μm) and stabilizes during the test (Fig. 4b). The relative movement is neglected and the test apparatus is validated.



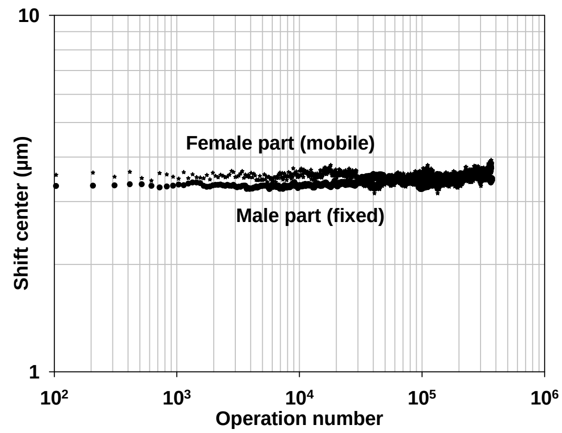


Fig. 4a. Amplitude of the two parts of the connector at 100 µm (laser technique)

Fig. 4b. Amplitude derivation of the two parts of the connector at 100 µm (laser technique)

4. Experimental results for contact resistance

4.1. Contact resistance at high frequency (100 Hz) (Amplitude = 100 µm)

The contact resistance versus operation number is represented in Fig. 5. The contact resistance has nominal values at the beginning of the test. Then, this resistance sharply increases with the increasing of the operation number. It reaches higher value and stabilizes around a maximum value of 20 Ohm.

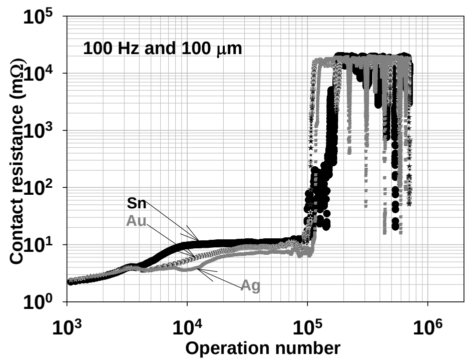
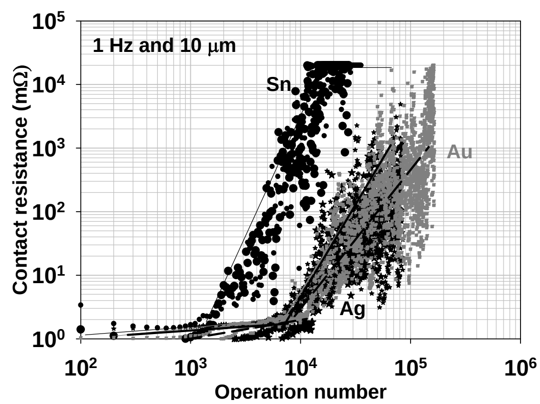


Fig. 5. Contact resistance versus operation number for tin, silver and gold under high frequency

The increasing of the contact resistance firstly appears for the tin then for silver and gold. This confirms the poor quality of tin compared to noble metal reported in the literature. However, the operation number seems to be much higher in this fast sliding movement. In fact, the oxidation of debris produced by abrasion maybe not completely finished. For this reason same tests must be done on lower fretting frequency.

4.2. Contact resistance at low frequency (1Hz) (amplitude of 10 and 100 µm)

Fig. 6 shows that after 10^3 operations the contact resistance increases and fluctuates between higher and lower values for each coating (Au, Ag and Sn) (Fig. 6a). For an amplitude of 100 µm (Fig. 6b), the increasing slope is lower than the one of an amplitude of 10 µm. For vibration amplitude of 10 µm, the eroded particles stay blocked between the pin and the spring (oxidation). But in the case of 100 µm, these particles are ejected out and the contact surface is cleaned. For lower amplitude, the contact resistance increasing is high; the amplitude is too small to generate the fretting phenomena at the same number of operations than for the high vibration amplitude.



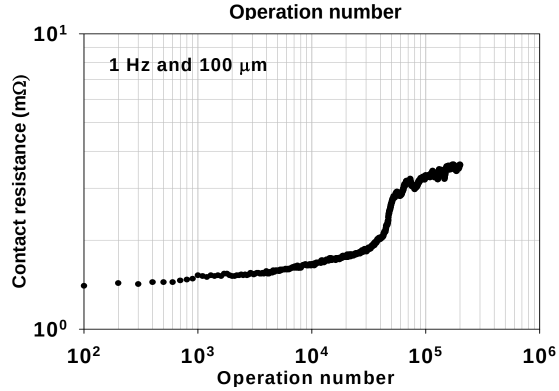


Fig. 6a. Contact resistance for tin, silver and gold for 1 Hz and 10 μm

Fig. 6b. Contact resistance for tin, silver and gold for 1 Hz and 100 μm

Thus at low frequency and high vibration amplitude, the contact resistance increasing is low (Fig. 6b). In fact, the oscillation period is 100 times lower than the other one for high frequency (Fig. 5). So, the oxidation process of the wear zone is more efficiency. On the other hand, the coating effect is conforming at the well-known behavior.
The effect of amplitude is the reverse direction (Figs. 6a and 6b).

5. Wear and mass loss technique

5.1. Track sizes

After the vibration test, eight tracks are present in each part of the pin (Fig. 7). Using a scanning profile-meter, the length (l), the depth (d) and the width (w) of the track are measured.

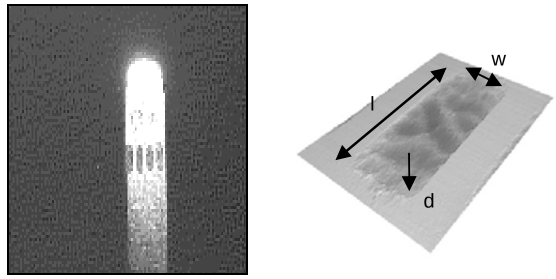


Fig. 7. Example of the pin track and its dimensions

The length increases with the increasing of the operations number. The contact zone length at the initial stage is about 300µm.

At the end of the test, the length of track is 5 times the contact area radius. The depth also increases according to the operation number, but the slope is higher compared to the length one. The width increases versus increasing operation number and rapidly stabilizes at 0.5 mm (width of the lamella). A new method based on the eroded surface scanning is used in order to obtain the track dimensions and the track volume (Fig. 8).

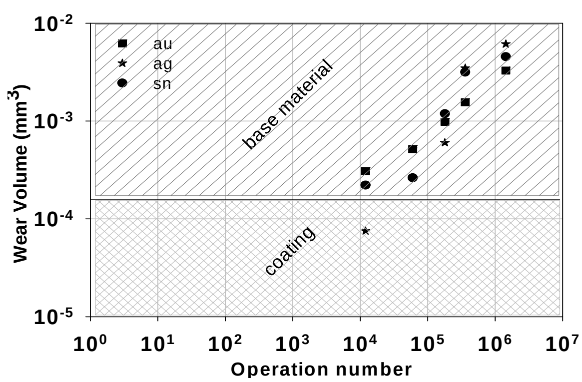


Fig. 8. Eroded volume of the pin track (100 Hz, 100 µm)

The eroded volume is calculated using the sample sizes obtained after tests under a frequency of 100 Hz and amplitude equal to 100 µm. The eroded volume increases with the operation number, the depth is higher then coating thickness (coating thickness equal to 2 µm): the coating is out only after 10^4 operations (Fig. 8). The effect of the coating is neglected: the conditions of the test are severe.

On the other hand, the spring and the pin have been weighed using a microbalance before and after the vibration tests. Fig. 9 shows that the spring mass loss is higher than the pin mass loss (tree time more). This can be explained that in the spring the contact surface is more localized than in the pin. As the pin mass loss is weak compared to the spring, the next tests are focalized only on the spring mass loss.

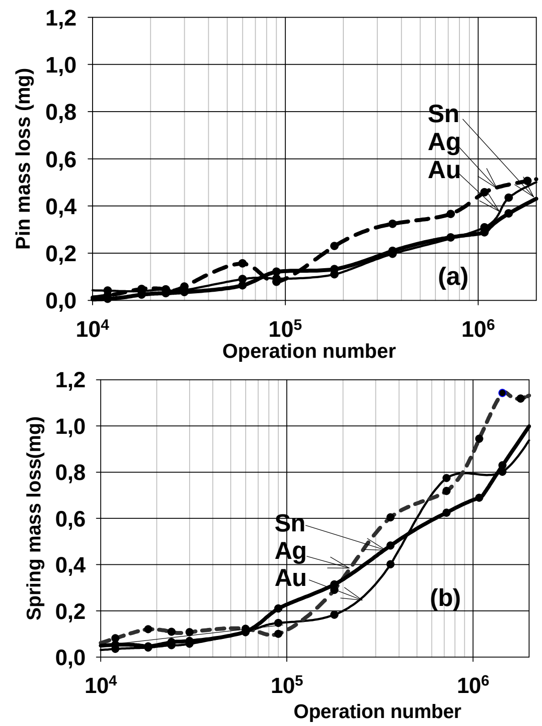


Fig. 9. Pin and spring mass loss versus operation number at high frequency

5.2 Correlation between wear and electrical behavior at high frequency

Two regimes of wear are clearly shown in Fig. 10:

* a very low wear during a stable contact resistance (for operation number less than 10^4),

* a higher wear corresponding to the high increasing contact resistance. The transition from the 1st regime to the 2nd one is well correlated to the electrical behavior and depends on the coating.

Lower mass loss and nominal contact resistance coincide during the first period. The end of this first period corresponds to the coating consumption (Fig. 10).

During the second phase (operation number higher than 10^4), the spring mass loss and contact resistance increase sharply. This takes place on copper base materials “oxide particles’’.

The coating effect on wear is less significant than on contact resistance. The same conclusions were obtained when the pin mass loss is analyzed.

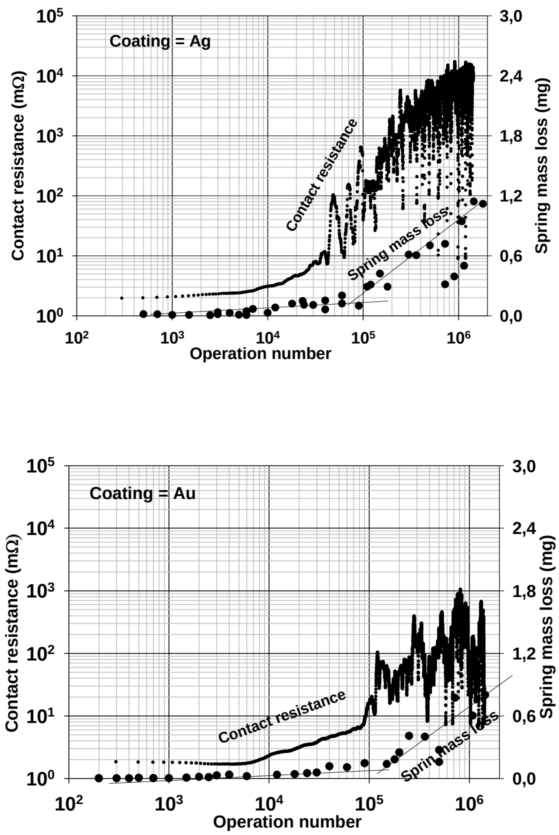


Fig. 10. Contact resistance and spring mass loss versus operation number at high frequency for different coatings (100 Hz and 100 μm)

5.3. Correlation between wear and electrical behavior at low frequency (1Hz)

To show the frequency effect, measurements under vibration of 1Hz are made. The results are shown in Fig.11. As in the case of high frequency, the contact resistance and the mass loss increase after some operation number. This phenomena is appears early in the case of the low frequency.

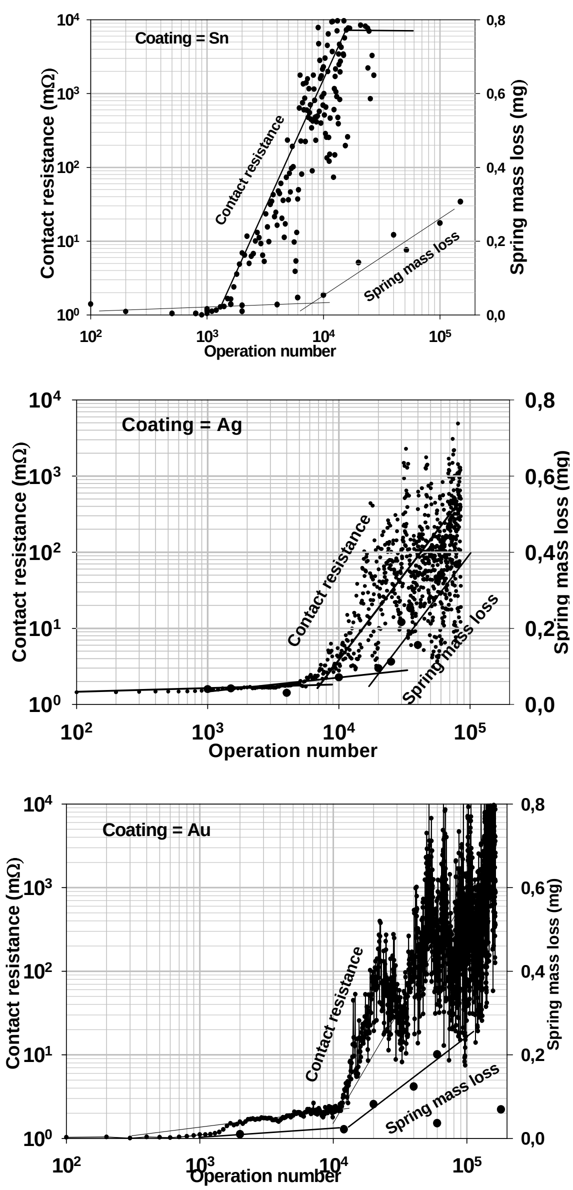


Fig. 11. Mass loss by weighing and contact resistance versus operations number at low frequency

Finally, the low frequency induces more contact zone oxidation for tin coating; the increasing of the contact resistance is early shown. On the other hand, the oxidation of Ag coating particles is less than the one of tin coating particles.

6. Microscopic analysis of the tracks

6.1. Samples cleaned after test

Some studies are done by microscope analysis on different coatings and at different times. For example, results on springs with tin coating are presented after a vibration time of 2 min, 30 min, 1 hour and 4 hours (Fig. 12).
On the spring surface, the track size increases with the vibration period. The coating (tin) is out even after 2 min. The substrate (copper) is appeared and the oxygen is present on the track. The oxygen participates to the copper oxidation and to the tin particle oxidation. This can explain the increasing of the contact resistance. The same results are obtained with the other coatings.

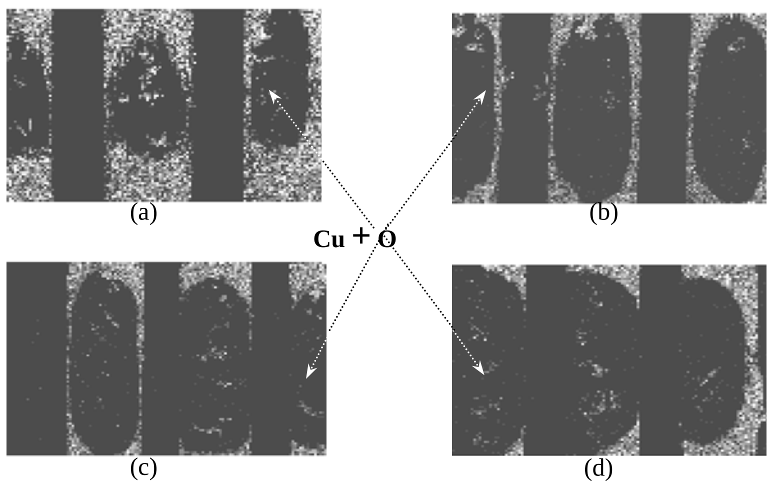


Fig. 12. Chemical compositions in tracks at (a) 2 min, (b) 30 min, (c) 1 hour and (d) 4 hours (Tin coating)
(Frequency =100 Hz; Vibration amplitude = 100 μm)

6.2. Chemical elements on the eroded tracks

After the vibration tests, the spring surface is analyzed in order to obtain the chemical elements on the eroded track. The coating is removed and copper of substrate lamella appears. Fig. 13 shows the removed particles from the contact zone and different points where the measurement will be done. Fig. 14 gives the percentage of the chemical elements.

On certain measurement zones (zones 2 and 5), the tin coating completely disappeared. In other zones (zones 1 and 6), tin is always present. Thus, wear is not uniform on the contact surface between the spring and the pin. The oxidation action appears when tin coating is very worn (zones 2 and 5) and this oxidation is conversely proportional to the tin percentage.

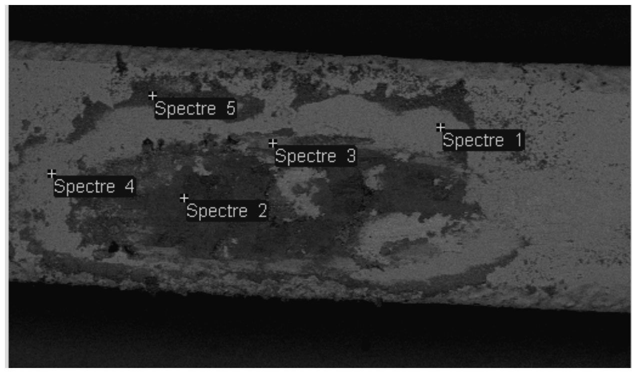


Fig. 13. Removed particles

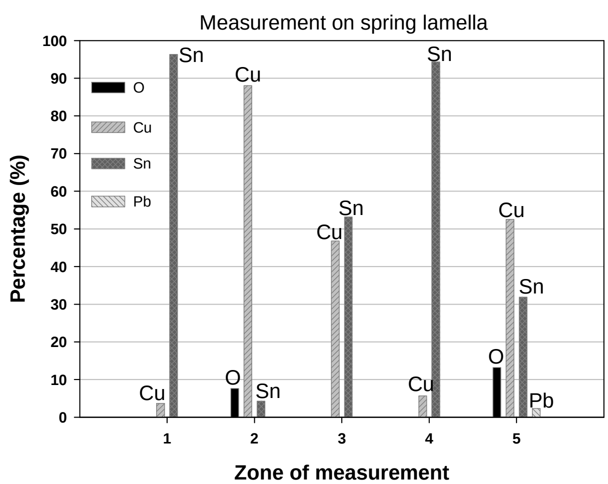


Fig. 14. Chemical compositions in track after 2 min (Tin coating, 100 Hz and 100mm of amplitude) for different zones shown in Fig. 13

7. Conclusion

The electrical behavior degradation is well correlated to the wear with two periods and the first period corresponds to the coating consumption. Low frequency (long period) is favorable to the fretting phenomena and enable oxidation process.

Noble material coating seems to delay the fretting. The amplitude of vibration needs minimum value to enable fretting (absorbent spring elasticity).

Finally, the war is not uniform on the contact zone.

Acknowledgment

This work supported from the European Commission "Growth" Program, Research Project AUTOCON: “Integrated Wiring and Interconnecting of Electrical and Electronic Components for Intelligent Systems”- G1RD-CT01.

R E F E R E N C E S

[l] *J. Horn, B. Egenolf*, ‘‘Shape Optimization of Connector Contacts for Reduced Wear and Reduced Insertion Force”, AMP Journal of Technology, **Vol. 2**; November 1992, pp. 42-46.
[2] *P. van Dijk, F.van Meijl*, ‘‘Contact Problems Due to Fretting and Their Solutions” AMP Journal of Technology **Vol. 5**; June 1996, pp. 14-18.
[3] *I. Buresh, P. Rehbein, D. Klaffke*, ‘‘Possibilities of Fretting Corrosion Model Testing for Contact Surfaces of automotive Connectors”, Proc. 2nd World Tribology Congress. Ed. F. Franek, W. J. Bartz, A. Pauschitz, Sept. 2001, pp. 413-416.
[4] *P. van Dijk*, ‘‘Some Effects of Lubricants and Corrosion in Inhibitors on Electrical Contact”, Proc 16th ICEC Conf. Loughborough, Sept. 92, pp .67-71.
[5] *P. van Dijk, F. van Meijl*, ‘‘Design Solution for Fretting Corrosion”, Proc 42nd IEEE Holm Conference on Electrical Contacts, 1996, pp.375-382.
[6] *M. Antler*, ‘‘ Electrical Effects of Fretting Connector Contact Material”, Wear, **Vol. 106**, No.l-3, Nov. 1985, pp. 5-33.
[7] *M. Braunovic*, ‘‘Effect of Fretting on the Contact Resistance of Aluminum with Different Contact Materials”, Proc. 24 Holm Conf., 1978, pp. 81-86.
[8] *I. Sevim and I. B. Eryurek*, ‘‘Effect of Abrasive Particle Size on Wear Resistance in Steels”, Materials & Design, **Vol. 27**, Issue 3, 2006, pp. 173-181.
[9] *S. Buytoz, M. Ulutan and M. M. Yildirim*, ‘‘Dry Sliding Wear Behavior of TIG Welding Clad WC Composite Coatings”, Applied Surface Science, **Vol. 252**, Issue 5, 15 December 2005, pp. 1313-1323.
[10] *I. R. McColl, J. Ding, S. B. Leen*, ‘‘Finite Element Simulation and Experimental Validation of Fretting Wear”, Wear, **Vol. 256**, Issues 11-12, June 2004, pp. 1114-1127.
[11] *Y. S. Zhang, Z. Han, K. Wang, K. Lu*, ‘‘Friction and Wear Behaviors of Nanocrystalline Surface Layer of Pure Copper”, Wear, Vol. 260; Issues9-10, 2006, pp. 942-948.
[12] *M. Izciler, M. Tabur,* ‘‘Abrasive Wear Behavior of Different Case Depth Gas Carburized AISI 8620 Gear Steel”, Wear, **Vol. 260**, Issues 1-2, January 2006, pp. 90-98.
[13] *K. Elleuch, S. Fouvry*, ‘‘Wear Analysis of A357 Aluminum Alloy under Fretting”, Wear, **Vol. 253**, Issues 5-6, September 2002, pp. 662-672.