



HAL
open science

Study of vibration transfer in automotive connectors for understanding of fretting corrosion damage

Mack Mavuni Nzamba, Erwann Carvou, Grégory Lalet

► **To cite this version:**

Mack Mavuni Nzamba, Erwann Carvou, Grégory Lalet. Study of vibration transfer in automotive connectors for understanding of fretting corrosion damage. ICEC, ICEC, Jun 2021, Conférence online, Switzerland. hal-04208221

HAL Id: hal-04208221

<https://hal.science/hal-04208221>

Submitted on 20 Sep 2023

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Study of vibration transfer in automotive connectors for understanding of fretting corrosion damage

M. Mavuni^{1,2}, E. Carvou¹, G. Lalet²

¹Université de Rennes1, France
Institut de Physique de Rennes UMR CNRS 6251
35042 Rennes cedex – France

² APTIV, France
Z.I. des Longs Réages - BP50025 | 28231 Epernon Cedex | France
* E-mail : mack.mavuni-nzamba@univ-rennes1.fr

Abstract-- Fretting corrosion damage is caused by a relative motion of contact pairs surfaces subjected to external mechanical vibrations. Indeed, global mechanical excitation on a whole connector may cause relative displacement on contact area and then to fretting degradation. This work experimentally investigates the global relative motion in 1-way automotive connectors with many components (11 parts). Therefore, a methodology is presented, that allows to study the whole connector movement in order to analyze the relative influence on connector components. To understand the fretting degradation at the actual contact interface, a test bench and a methodology were set up to perform these relative motion measurements using a 3D laser vibrometer. We first focus to understand induced motion through different connector components from wires to male and female terminals as well as male and female holdings motions caused by vibrations. Then the whole connector relative movements were deduced from the measured displacements in three-dimensions, on components such as housing, terminals and wire. Furthermore, the experiment results were compared with the frequency response, obtained from modal analysis modeling. So, from the previous comparison, the specific damaged frequencies domains were detected. Finally, the relative displacements of the electrical contact zone are deduced and if effectively fretting corrosion may appear.

Keywords: Fretting corrosion, automotive connectors, vibration, modal analysis, modeling

1. Introduction

The automotive environment in which electrical connectors are located is characterized by high vibrations that can reach acceleration up to 80 g within the range from 5 Hz to 2 kHz frequency [1]. The vibration induced by automotive environment is transferred on different connectors [2], particularly on

the wire and housing and then transferred to the terminals. This leads to relative micro displacements at the interface of male and female parts, inducing fretting-corrosion which strongly, influence its electrical conductance and then voltage fluctuation. Therefore, an increase in contact resistance is considered as an indication of the electrical contact failure [3].

To achieve a reliable device, electrical connector must meet certain vibration specifications requirements to ensure continuous conduction without being damaged by fretting corrosion [1], [4].

To minimize the relative displacement on electrical interface and so fretting corrosion, designers develop electrical connectors consisting of many components, with different mechanical properties. In fact, each component is meticulously chosen as it plays a specific role. For example, the female inner casing component, that has loaded female terminal for limiting his movement, the silicone component for damping and absorbing vibration-induced, or the lock spring for mechanical interlock of connectors etc. [5]. Unfortunately, these connectors are not exempted from failure.

The occurrence of fretting corrosion is difficult to predict. Many investigations have been done in order to determine a threshold fretting damage [6-9]. Bouzera [8],[10] concluded that the fretting is indeed worst when the relative displacement between the terminals, at contact point, reach a certain threshold value. Fu, et al. [11] found that the relative displacement measured at the contact interface, increasing when the vibration amplitude increases. Park, et al. [12] review and summarize previous work on fretting corrosion in electrical contacts. They summarize and list the most important parameters for fretting corrosion. Besides, the motion of cables also may have an effect on the electrical contact during vibration test since it can induce additional stresses for such vibration test [13].

In 2017, Carvou and al. [2] proposed a new methodology for measuring relative displacement, inside a connector, by using a non-contact 3D laser vibrometer. This approach allows a better

understanding of dynamical behavior of electrical connector under vibration. They found that relative motions depend not only on the vibration of excitation, but also on the way these movements are mechanically transferred. Thus, proper instrumentation and testing methods are also inevitable for obtaining fretting corrosion conditions in experimental test [14].

This paper presents development of this previous investigation that consider the transfer of vibrations, at three dimensions, into the automotive connectors and cable which leads on fretting corrosion.

To be sure, after attempting to design a mechanically stable connector, of its reliability, it is necessary to validate new designs by making qualification tests aimed to detecting if the connector is susceptible to present fretting corrosion during his lifetime.

Combining various experimental test and modal analysis modeling, we will attempt to answer two fundamental questions:

- How exactly is the vibration transferred on the contact zone, in three dimensions, for a given vibration excitation?
- Which frequency domain will cause the maximum relative displacement between contact surfaces?

A test bench was designed to measure the motions at various points of connector components and wire. Then, absolute and relative displacements were deduced at different frequencies. Furthermore, the experimental results were compared with the frequency response obtained from modal analysis modeling. Finally, specific damaged frequencies domains were determined.

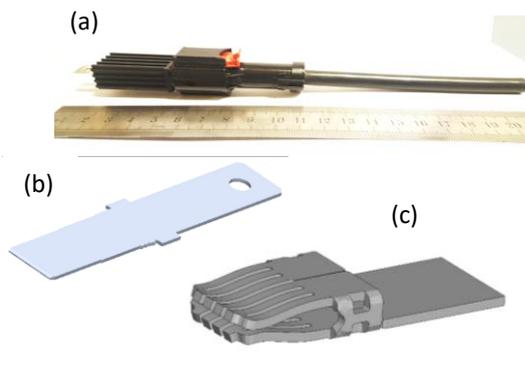


Figure 1: (a) Automotive connector, (b) Pin, (c) Socket

1.1. The sample connector

The connectors to be tested are a 1-way automotive connectors manufactured by Aptiv. This connector consists of 11 parts were the main ones are insulating housings, contact pair (pin and socket) and spring lock (see Fig. 1). The female part consists of twelve contact

points symmetrically distributed (Fig.1c). The wire, with 35mm² of cross-section, is connected to the female part by ultrasonic welding.

The connector surface is plated with silver and the substrat connector material is copper, on which an electrolytic nickel interlayered was deposited in order to limit copper diffusion. Many works report that a connector with silver plating coatings could make the fretting corrosion less significant [15], [16]. The table below provides more details about connector characteristics.

Table 1: Material and dimensional proprieties of model components

parts	Thickness	Density (kg.m ⁻³)	E(GPa)
Pin housing	-	1470	2.7 - 9.2
Female housing	-	1470	2.7 - 9.2
Male terminal	1 mm	8819	125 - 130
Female terminal	0.5mm	8819	125 - 130
Cable (145mm)	-	4157	4 - 56
Seals	-	1000	1 - 3

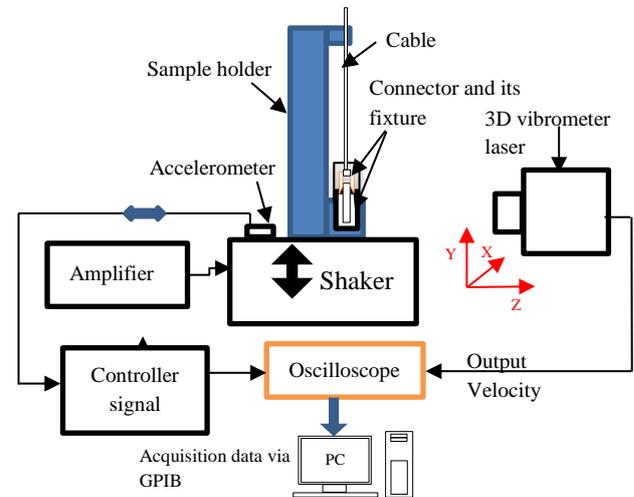


Figure 2: Schematic diagram of the test bench (lateral view).

2. Experimental set up

In order to study the effects of vibration on the connector, a vibration bench test was built and set up with the aim of to be as close as possible of automotive vibrations environments conditions. The input vibration excitation is produced by using a LDS V555 shaker driven by an accelerometer. A schematic diagram of the experimental test setup is shown in Fig. 2. A sample holder, on which the connector is mounted,

was specially designed and afterwards it is rigidly fixed on shaker head which is displayed in Fig. 3. The connector fixed on sample holder is in testing equipped with a male and female housing and a cable length of 145mm. the male housing was fixed to limit his movement in two directions perpendicular to electrical contact insertion. Furthermore, the cable was clamped. By doing so, the connector system will be able to follow the motion of the shaker head.



Figure 3: Fixture and vibration direction (front view)

This fixation configuration is required by the automotive manufacturer in accordance to standard tests described in [1] and [4]. The excitation direction is axial (Y-axis), is chosen parallel to the direction of the electrical contact insertion as illustrated in Fig [3]. The parts inside the housing are accessible by making holes, small enough in order to avoid modification of the mechanical properties of the connector [10]. Series of tests were done in order to investigate mechanical behavior of this automotive connectors subjected to axial vibration excitation. A LabVIEW acquisition data program has been developed on a computer to collect data from oscilloscope via GPIB bus.

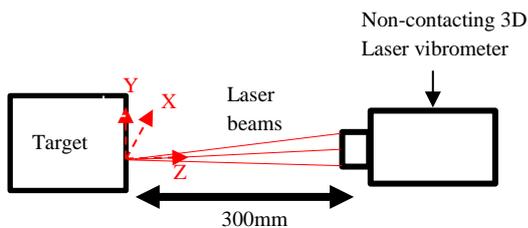


Figure 4: Principle of measurement geometry by using CLV-3D laser vibrometer

3. Measurement of displacements

The displacement measurements of the different samples are carried out using a Polytec 3D-Laser vibrometer by reflecting laser beam on a specified target surface. This equipment allows measuring simultaneously, at a single-point targeted, all three velocity components on a vibrating structure (Fig.4). The output is an analog voltage signal, which are proportional to the velocity amplitude of the target [10]. Fig. 5 shows the measuring locations of the male and female parts through holes. The displacement measurements of the different parts are deduced by integrating the velocity measured by the vibrometer.

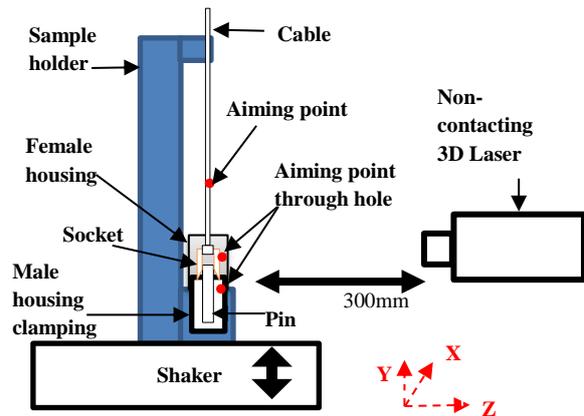


Figure 5: Located measuring displacement through the holes (red dots)

For an axial vibration applied i.e. in the direction of the insertion of the connector (aka the Y-axis), the absolute displacements of the sample holder, female housing, female terminal, male terminal and the cable were measured in 3-axis. We assume that the sample holder movement amplitude is the reference movement with the respect to the movement amplitude of the other components.

4. Measured relative displacement

The fretting corrosion damage is governed by the relative displacement of the contact pairs. Ideally, the relative displacement between two contact points should be measured simultaneously but this requires duplicating expensive equipment (one 3D laser vibrometer per piece). Our experimental set-up consists of only one 3D laser vibrometer. This causes a phase's problem between two measurement points. To solve this issue, we used the signal phase of the accelerometer as reference time and we corrected our signal accordingly:

- i. By subtracting the reference phase from the phase of the measured signal
- ii. Then we will hence extract from previous measurements the relative displacements of the

male part with respect to the female part as described by Carvou et al. [2], Fu et al.[11].

5. Modeling and simulation of the frequency response of the connector system

a. Modal analysis

A modeling and simulation, with finite element analysis (FEA), for modal analysis, has been conducted on the connector (include the cable) in order to identify the terminal natural frequencies and its vibration modes. We assume that if one of these natural frequencies is close to the car engine frequencies, then there is a potential risk for the connector integrity [17]. Modal analysis is run with frequencies sweep from 5Hz to 2 kHz, by using LS-DYNA Software. The modeling and FE simulation approach proposed in this paper is shown in Fig.6.

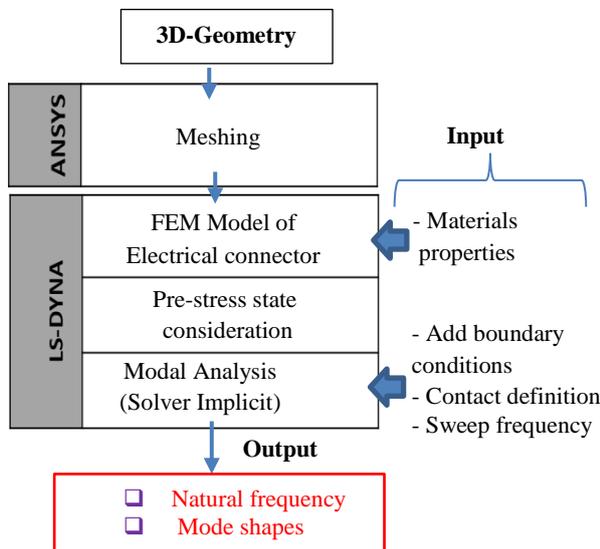


Figure 6: FEA Simulation process of modal analysis of electrical connector

The material properties (such as Young's modulus E , and density) were given in Table 1. The connector is meshed using the hexahedral elements. The mesh is refined around the terminals contact interface.

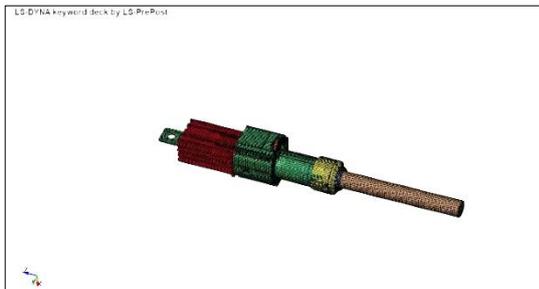


Figure 7: Views of connector with its finite element mesh

6. Results and Discussion

Using the test configuration described above, a series of experiments and modal analysis simulation were performed to investigate the dynamic behavior of the automotive connector subjected to axial vibration input. First, for characterizing experimentally the response of the sample during a vibration test, sine sweep is a fast and useful method for determining eigen or dominating frequencies of the connector [18]. We measured the transfer function of different components to determining resonant peak and vibration modes, seen in Fig.8. The transfer function of the connector sample is determined by comparing the output response at the component to the input vibration amplitude from the shaker head.

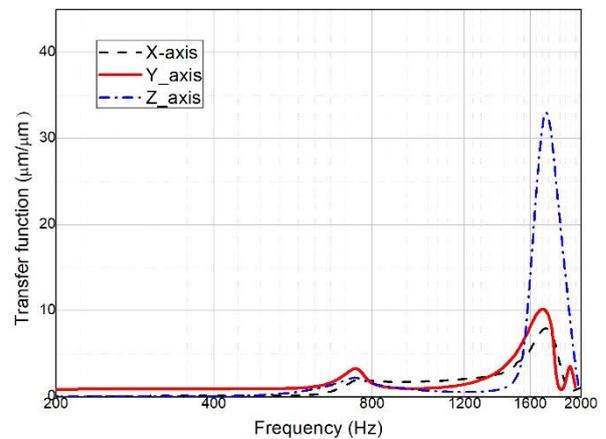


Figure 8.a: Experimental results showing the transfer function for the Female housing

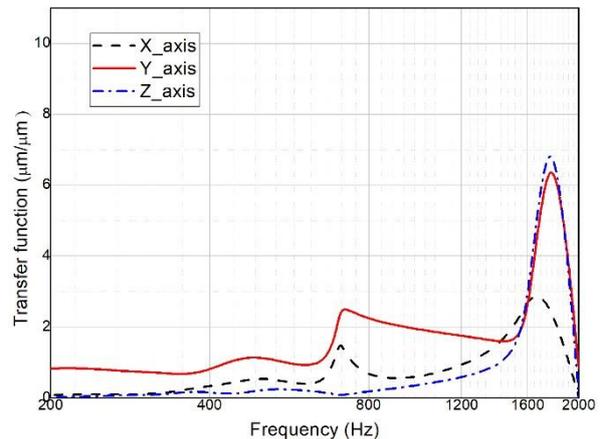


Figure 8.b: Experimental results showing the transfer function for the Male housing

A sine sweep applied on the connector/cable system produce a motion that will be transferred on electrical contact. The frequencies of he applied vibration ranges from 5 Hz to 2 kHz with a fixed acceleration $1g$ (9.8 m/s^2) and the sweep rate is 0.1 oct/min. Figure 8.a and 8.b show the transfer function that were obtained, in

three axis, for different vibration amplitude for the female and male housing, respectively. We can observe that for the low frequency domain, the transfer function value is 1 in the vibration direction (aka Y) because the input amplitude is equal to the output amplitude. However, the transfer function value is around 0 for the perpendicular axis (X and Z axes) to the vibration direction. It is logical because the input amplitude in vibration direction is to larger than the output amplitude in X and Z axes. The value of transfer function has a significant change at the frequencies between 1600 Hz and 1800 Hz. For the female housing, two natural frequencies have been detected (Fig.8.a). At 1650 Hz according Y and Z axes, and at 1770 Hz according X-axis. Regarding the male housing, two natural frequencies were detected at 1700 Hz for the X and Y axes and at 1650 Hz for X-axis (fig. 8.a).

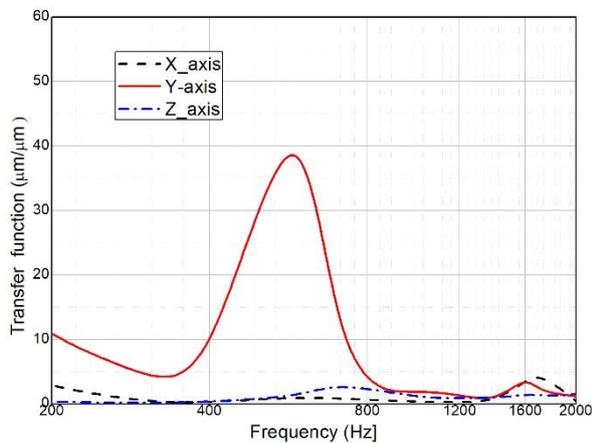


Figure 9.a: Experimental results showing the transfer function for the Female terminal

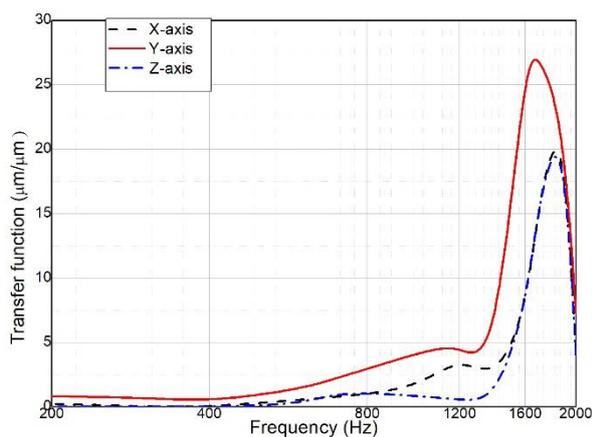


Figure 9.b: Experimental results showing the transfer function for the Male terminal

Experimental results of transfer function measured on the terminals is illustrated in Figure 9.a and 9.b. For the female terminal (socket), the peak became more pronounced at approximately 600 Hz in the insertion

direction of the connector (Y-axis) (fig 9.a). In fact, around 1600 Hz the peak is lower in Z and X axes. Regarding the male terminals (Pin), the natural frequencies were detected at 1650 Hz in Y-axis and at approximately 1770 Hz for Z and X axes.

FEA simulation of modal analysis was carried out with as boundaries conditions the same experimental fixing. LS-DYNA software was used with an implicit solver assuming that the problem was linear static. From simulation, two modes were extracted between 5 Hz and 2 kHz to identify natural frequencies of the connector system. The table provides three modes from simulation and experiment results.

Table 2: Identified natural frequencies between 5 Hz and 2 kHz

Mode shapes	Natural Frequencies Hz	
	experimental	Simulation
1	1650	1568
2	1770	1754
3	1600	-

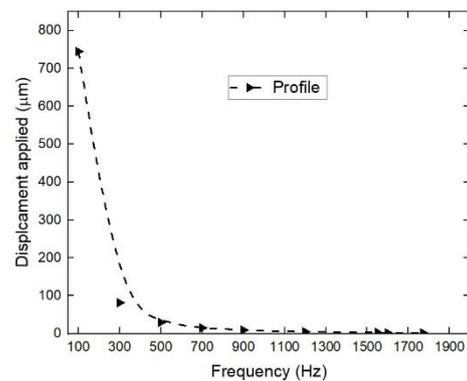


Figure 10: A standard vibration profile

Thus, two natural frequencies were compute from modal analysis simulation, at 1568 Hz for Mode 1 (Z-axis) and at 1754 Hz for Mode 2 (X-axis). We can observe a low difference between the results, of natural frequencies, obtained from experimental and simulation. Two reasons allow explaining this. First, it can be related to the difference between the mass of real connector and the 3D model's mass used in simulation. Furthermore, it can may due to the contact parameters define between each component in FEA simulation.

A. Effect of vibration with fixed acceleration with varying amplitudes and frequencies

During this test, the vibration acceleration is fixed at 15G. The objective of this type of test was to highlight the most damaging domain for this connector. A

standard vibration 15G profile (fig.10) is used to scan ranges of frequency with varying amplitude in order to determine the mechanical response of the system. The vibration excitation was applied in inserting connector direction (aka Y-axis). The figure 11.a, 11.b and 11.c show the absolute displacement, measuring in three axes, for different connector components.

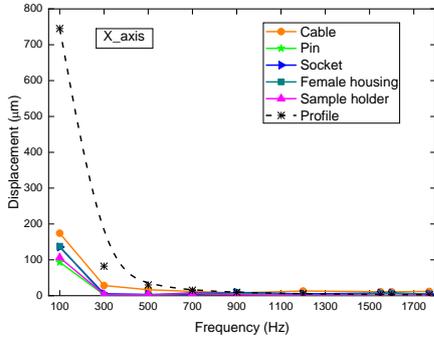


Figure 11.a: Spectrum of the absolute displacement in X-axis

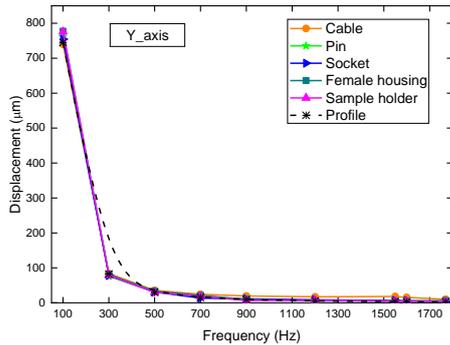


Figure 11.b: Spectrum of the absolute displacement in Y-axis

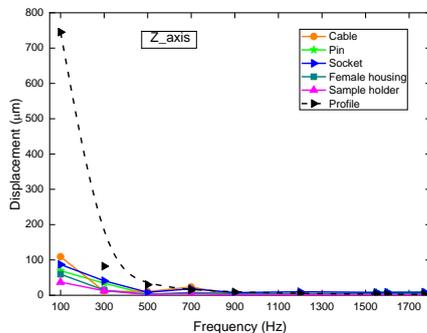


Figure 11.c: Spectrum of the absolute displacement in Z-axis

The absolute displacement measurements of the different samples are deduced by integrating the velocity measured by the 3D vibrometer. As shown in

Figure 11.a, 11.b and 11.c, all the components present the same shape of the curve that the vibration profile, in three axes. For vibration in X-axis (Fig.11.a), the cable presents the most displacement amplitude, and then the vibration is transferred from the cable to the socket. The pin follows the sample holder's motion. Regarding vibrations in the direction of insertion (aka Y-axis), the Figure 11.b shows that the connector system follows exactly the vibration profile with the same input displacement amplitude. For vibration in Z-axis, displacements follow each other in a rough way, seen in fig.11.c.

The relative displacement of the contact interface induced by engine vibration is one of the most significant causes for the fretting corrosion phenomenon. We will thus extract from previous measurements the relative displacements of the male part with respect to the female part. The results are presented in figure 12 for the three axes, X, Y and Z.

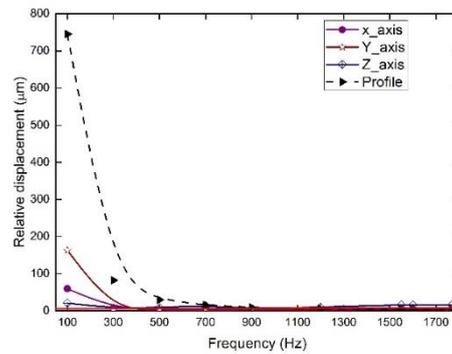


Figure 12: Spectrum of the relative displacement

For the three axes, X, Y and Z, the relative displacements between pin/socket are relatively important in low frequency domain (between 100 Hz and 300 Hz) for the highest applied amplitude. However, the relative motion measuring at high frequency domain are relatively small for X and Y axes. For Z-axis, we can see that the relative motion is around 18µm greater than the fretting damage threshold [9]. We therefore see that the measurements of the relative motion between the connector components allow us to determine the vibration conditions for which relative motion of contact zone is greater than 5µm and then when fretting is, for example to avoid a frequency range when using connectors [10], [7].

To summarize, the methodology and the vibration amplitude used in this paper for this type of connectors, made it possible to determine the frequency domains of vibration to avoid. First the low frequencies, due to their very large vibration amplitude. But also the high frequencies, which have been identified as the natural frequencies for these types of connectors. Outside these

domains, whatever the amplitude of vibration, there is a good probability that relative displacement at the contact interface of Pin / socket will remain less than 5µm. Subsequently, it will be difficult to be able to trigger the fretting corrosion mechanisms.

7. Conclusions

This study shows how the vibration is transferred to the different connector parts. It may thereby induce motion and fretting damage to the contact interface. The main results are as follows.

- 1) An experimental methodology has been proposed, allowing for in-situ measurement through a 1-way connector under range of vibration. This methodology is generalizable for another type of connector.
- 2) For the transfer function, the peak of natural frequencies was only found at the high frequency domain, in the three axes X, Y and Z. The transfer function values were smaller at the low frequency domain.
- 3) The simulation results are correlated with the experimental behavior of the connector parts. Two mode shapes were detected between the results obtained with the FEA simulation of modal analysis and experimental test. A slight difference was observed between the results of natural frequency obtained in simulation and experiment test.
- 4) Hence, the important conclusion is that fretting corrosion may appear in both low frequency and high frequency domains.

Future work will include

- Establish a correlation between previous results and the contact resistance changes under the most dominating frequencies
- Investigation of fretting corrosion in low frequency and high frequency domains, over long operating time.
- Investigate relative motion by using FEA simulation of vibration for validating the model

REFERENCES

- [1] LV 214-3 Motor Vehicle Connectors; Test Sequences, 2010.
- [2] E. Carvou, J. Labbé, L. L. Marrec, C. Plouzeau and F. L. Strat, "A Phenomenological Model of Vibrations Transfer in Connectors for Fretting Corrosion Phenomena," 2018 IEEE Holm Conference on Electrical Contacts, Albuquerque, NM, 2018, pp. 381-386.
- [3] S. E. Mossouess et al., "Analysis of temporal and spatial contact voltage fluctuation during fretting in automotive connectors," ICEC 2014; The 27th International Conference on Electrical Contacts, Dresden, Germany, 2014, pp. 1-5.
- [4] PSA Peugeot-Citroën, "connectors general requirements," Standard B217050.
- [5] Performance specification for automotive electrical connector systems SAE/USCAR, February 2013.
- [6] H. Yang and G. Flowers, "Threshold of Axial Vibration Induced Fretting in Electrical Connectors," 2013 IEEE 59th Holm Conference on Electrical Contacts (Holm 2013), Newport, RI, 2013, pp. 1-10.
- [7] G. T. Flowers, Fei Xie, M. Bozack and R. D. Malucci, "Vibration thresholds for fretting corrosion in electrical connectors," Proceedings of the Forty-Eighth IEEE Holm Conference on Electrical Contacts, Orlando, FL, USA, 2002, pp. 133-139.
- [8] A. Bouzera fiabilité de la connectique sous sollicitation de vibrations mécanique. PhD thesis, Université de Rennes 1, 2012.
- [9] A. Bouzera, E. Carvou, N. Ben Jemaa, R. El Abdi, L. Tristani, and E.M. Zindine. Minium fretting amplitude in medium force for connector coated material and pure material. 56th IEEE Holm Conference on Electrical Contacts, pages 101–107, 2010.
- [10] J Labbé, Détection et étude de microdéplacement des contacts sous contrainte vibratoire et leurs conséquences sur les matériaux et revêtements des connecteurs automobiles, Phd thesis, Rennes, 2017.
- [11] R. Fu et al., "Vibration-Induced Changes in the Contact Resistance of High Power Electrical Connectors for Hybrid Vehicles," in IEEE Transactions on Components, Packaging and Manufacturing Technology, vol. 2, no. 2, pp. 185-193, Feb. 2012.
- [12] Y. W. Park, J. P. Jung, and K. Y. Lee, "Overview of fretting corrosion in electrical connectors," Int. J. Automot. Technol., vol. 7, no. 1, pp. 75–82, 2006.
- [13] A. Bouzera, E. Carvou, Influence of cable vibrations on connectors used in automotive application, Journal of Electrical and Electronics Engineering.
- [14] Clarence W. de Silva, Vibration and Shock Handbook, 2005.
- [15] J. F. Bruel, P. Smirou, and A. Carballeira, "Gas environment effect on the fretting corrosion behavior of contact materials," in Proc. 14th Int. Conf. Electr. Contacts, 1988, pp. 219–223.
- [16] F. Hubner-Obenland and J. Minuth, "A new test equipment for high dynamic real-time measuring of contact resistances," in Proc. 45th IEEE.
- [17] Yahya, O. and Miled, H., "Modeling of the Impact of Ultrasonic Welding of Harness on the Terminals Integrity," SAE Technical Paper 2014-01-0224, 2014.

- [18] Yashan Xing and Weilong XuSignal, “Analysis of Fretting Damages on Electrical Connector Systems,” Karlskrona, June 2017.