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Vibration effect on electrical resistance fluctuations in electrical connectors

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A B S T R A C T

Proper functioning of electrical connectors used in high oscillation is of great importance. Vibrations in connector pins cause stress and electrical resistance variations in the contact surface. In the present paper, the impacts of vibrational loads on electrical connectors is being modeled using the finite element method, and the electrical resistance oscillations of the connectors will be examined. Ultimately, the parameters affecting the electrical resistance oscillations of contacts will be determined and their relations with oscillations in electrical resistance are specified as well.

1. Introduction

In the majority of electrical devices, signal transmission is done via contacts as the direct carriers of signals. In fact, they send signals from the input end to the output end or to the terminal of electrical connectors. Given the important roles played by contactors in connectors, their failure results in very sever damages to the parent or the greater product. Therefore, in order to study and optimize pins and socket contacts, their design is of paramount importance in improving the reliability of electrical connectors (Bin et al., 2007). In this regard, however, there are a number of factors that raise concerns over the issue, among which are heat and vibration factors, both having the ability to make abrasion. This abrasion will result in variations of the resistance and current of the system. In this respect, an extensive body of research has been carried out in order to assess the heat cycle, which can lead to abrasion (Whitley & Bock, 1974; Lee et al., 1988; Antler, 1984; Malucci, 1996). Flowers et al. (2005), for instance, examined the effect of mechanical stresses on wear performance of electrical connections, which has been rarely dealt with in the literature. Flowers and coworkers (2004) studied single-frequency excitation effects as well as contacts wear performance under both excitations of stochastic and single-frequency excitations. Ultimately, they attempted to present a model based on the laboratory data. In the same research, Hsu et al. (2000) showed how the optimal spring shape of a connector contact can be found.

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In the present work, the Insert process will be modeled, which includes inserting a PCB in the contact springs of a connector with an analysis of the finite element. Moreover, the maximum inserted force and the normal force to be applied on the contact will be calculated and the effects of various parameters will be discussed. Afterwards, different dimensions of the contact springs are parameterized and optimized, and the required Insert force is minimized, while the contact normal force remains at a certain amount.

It is noteworthy here that all removable electrical contacts need some force to hold together the male and female halves while coupling. When the connector is closed, the contact normal force provides such a force that produces the contact interface and keeps the contact interface stable against mechanical disturbances throughout its working life. In addition, the minimum contact resistance of a connector is dependent on the normal force. When the two surfaces come together, the contact area reduces in size and the current passing through the interface will be limited to this restricted area, which in turn will increase the resistance. This resistance can be expressed as follows:

$$R_c = \frac{\rho}{d} \approx \rho\sqrt{H/F_n}, \tag{1}$$

where R_c is the limited resistance, ρ is the wire resistance, H is the material hardness and F_n is the normal force. From this equation, Wager (1971) showed that in order to decrease the limited resistance, contact normal force is to be increased.

Yet another similar case, where proper functioning of electrical connections is of high importance, is that of aerospace industry. In fact, pin and socket contacts are among the key parts of the electrical connector in aerospace electronic components. Moreover, the contacts also work as the main carriers of signals in electronic devices, sending signals from input to the output terminal of the electrical connector. Therefore, the reliability of pin and socket contacts can have direct impacts on signal transmission. In this respect, Bin et al. (2007) have tried to improve the reliability of aerospace electrical connectors. In line with the above-mentioned studies, the present paper is aimed at a computer simulation analysis on the performance data of contacts using the simulation system coded by PCL language of MSC Software. The simulation results are subsequently validated using the experimental ones.

In order to perform a simulation analysis of electric connections and predict their dynamic behavior, one of the important issues to be taken into consideration is that of forecasting variations in electrical resistivity. To impose the initial pre-press effect on modal analysis, the contact location is modeled using the springs whose parameters need to be extracted. To determine the connection parameters of the interference fit kind, Schmitz et al. (2007) used contact elements of ANSYS finite element software to perform the analysis.

2. System model

In order to evaluate resistance fluctuations in electrical connections, a simple pin connector is modeled using FEM, on which the desired excitations are subsequently applied. Fig. 1 illustrates this modeled connector schematically.

In electrical connections, there is always a pre-press between the male and female parts to avoid separation. In order to create this pre-press in the designed contact, a negative tolerance is thus established with a separation force of 18N in the connection.

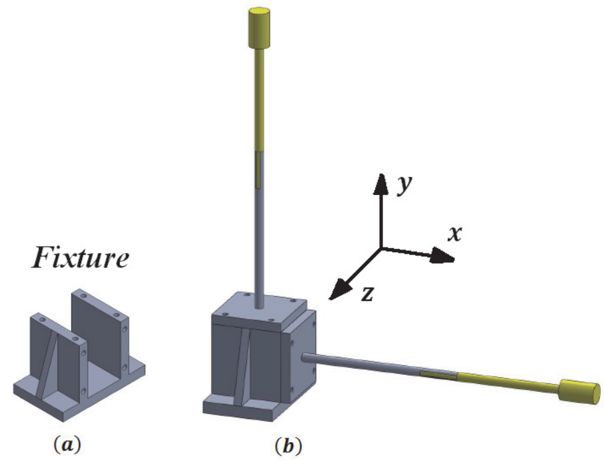

Fig. 1. The modeled connection (a) Test fixture (b) connections during test in x and y directions

3. Modal Analysis of the connections

Excitation frequency is regarded as one of the factors which can have great effects on fluctuations in electrical resistance. It is estimated that the impacts of excitation frequency on resistance fluctuations is dependent upon the dynamic behavior of the system. Hence, first a modal analysis of the system is being presented. In order to investigate the role of pre-stress impact in the modal analysis, the contact location is first modeled using the springs whose parameters are to be extracted. Thus, in order to determine the interferential coincidence connection parameters, the finite element method is being employed. Once the connection parameters are elicited using frequency sweep methods, the connection will be excited in both y and x directions and therefore, the frequency responses can be obtained, as represented in Fig. 2 and Fig. 3.

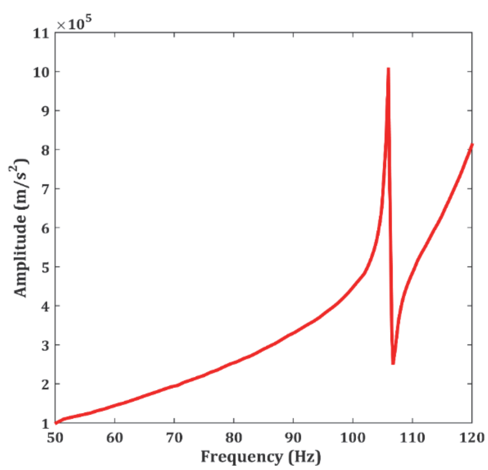

Fig. 2. Frequency response of the system under excitation in *y* direction

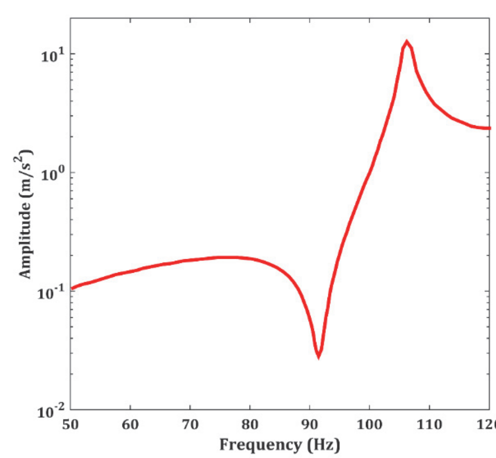

Fig. 3. Frequency response of the system under excitation in *x* direction

4. Results

Fluctuations in electrical resistance are under the influence of various parameters, including the excitation frequency and amplitude, and initial pre-press, whose effects on electrical resistance fluctuations have been addressed in the present study. A detailed description of the findings is being provided in the following sections.

4.1. The effects of excitation frequency on electrical resistance fluctuations

Using FEM, the connection in question was modeled and the effects of excitation frequency on electrical resistance fluctuations were examined separately for different directions.

4.1.1. Vibrations in y direction

For evaluating the effects of vibrations frequency on electrical resistance fluctuations, the connection was firstly excited in the y direction at different frequencies and the electrical resistance fluctuations were measured. To determine the contact normal force, first the fluctuations in the contact normal force needed to be calculated. To this end, the contact pressure fluctuations were first calculated in 25 points across the contact surface.

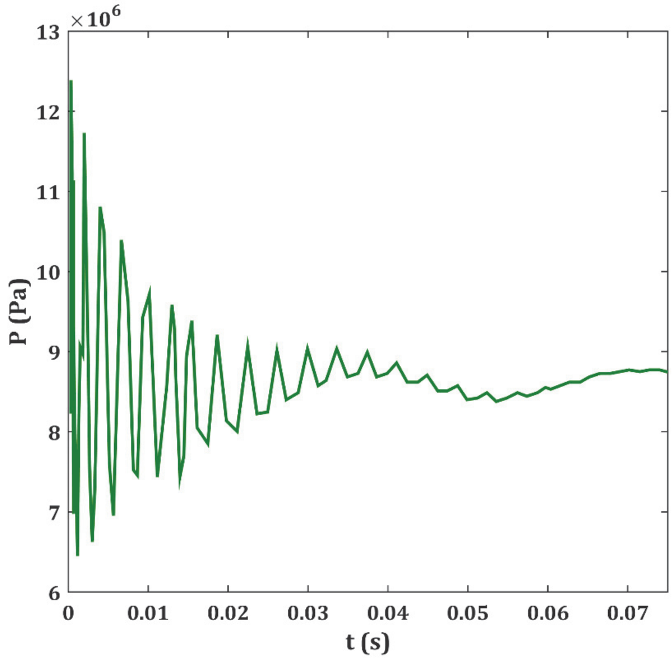

Fig. 4. Contact pressure fluctuations at a point of connection at frequency of 40 Hz with excitation amplitude of 3g

Fig. 4 having determined the contact pressure fluctuations at the 25 different points, at a given frequency, using equation (1), one has:

$$\frac{R}{R_0} \propto \sqrt{\frac{F_{n_0}}{F_n}} = \sqrt{\frac{P_o}{P}}. \quad (2)$$

According to Eq. (2), P_0 is to be set beforehand, for which a value of 276 KPa was obtained using the finite elements method. It is noteworthy that in Eq. (2), the parameter P is the mean contact pressure value, which was obtained through averaging the surface pressures in the aforementioned 25 points.

Using Eq. (2), the electrical resistance fluctuations are plotted for different frequencies. Fig. 5 and Fig. 6 represent the electrical resistance fluctuations plots for frequencies of 40 and 50 HZ respectively. Similarly, the electrical resistance fluctuations were obtained for other frequencies and using the maximum resistance fluctuations in each frequency, the electrical resistance fluctuations graphs were drawn vs. vibration frequencies in Fig. 7.

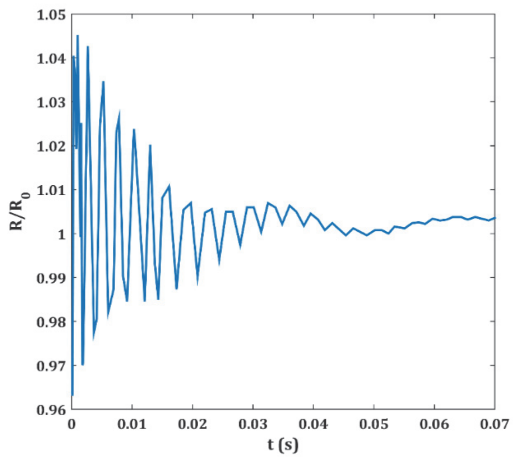

Fig. 5. Electrical resistance fluctuations at the frequency of 40 Hz with excitation amplitude of 3g

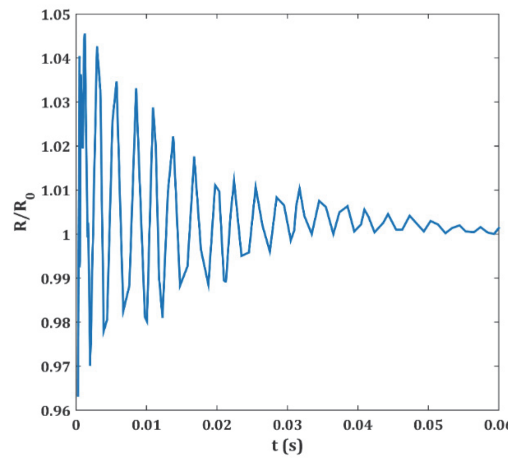

Fig. 6. Electrical resistance fluctuations at the frequency of 50 Hz with excitation amplitude of 3g

As can be observed in Fig. 7, the graph for the maximum electrical resistance fluctuations in the frequency domain is a good fit in the contact frequency response (Fig. 2). Therefore, one may come up with the conclusion that the maximum electrical resistance fluctuations can be estimated in the frequency domain, using the dynamic behavior of the connection.

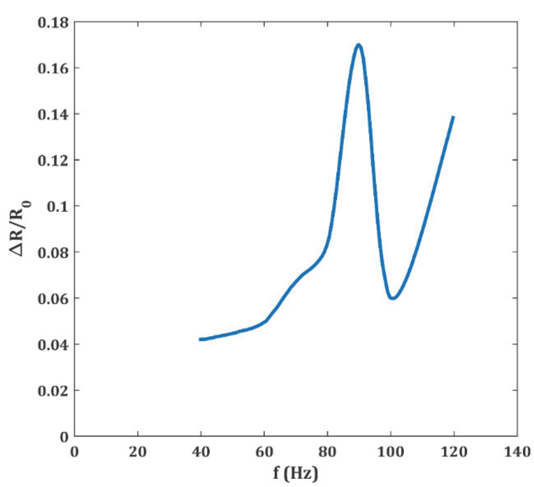

Fig. 7. Variations of maximum electrical resistance fluctuations in frequency domain with excitation amplitude of 3g in the *y* direction

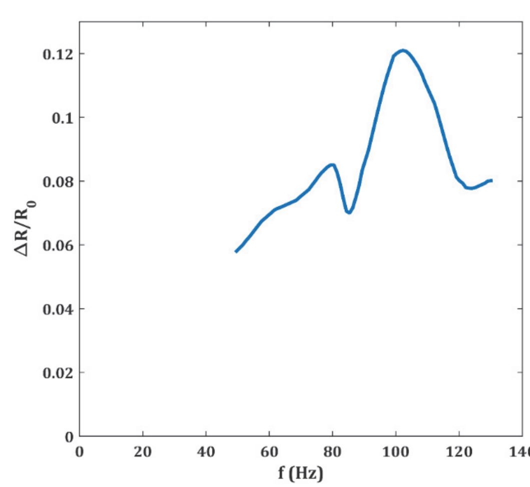

Fig. 8. Variations of maximum electrical resistance fluctuations in the frequency domain with excitation amplitude of g in the *x* direction

4.1.2. Vibrations in x direction

For studying the effect of fluctuations in the electrical resistance, while the connection is exposed to vibrations in x direction, the connection is excited in different frequencies, and the contact pressure fluctuations is investigated in different areas. Taking into consideration the fluctuations obtained from the contact pressure across different points of the connection, the fluctuations in electrical resistance were also obtained for each frequency. Subsequently, using the maximum resistance fluctuations at each frequency, the maximum changes in the electrical resistance fluctuations versus vibration frequency were plotted on a graph, as shown in Fig. 8.

4.2. The effect of initial stress on electrical resistance fluctuations of the connection

The amount of pre-stress of the connection is regarded as another parameter affecting the electrical resistance fluctuations. In fact, variations in the amount of pre-stress result in changes in the connection parameters. As mentioned before, the contact location is modeled with the help of springs in a way that any change in the amount of pre-stress results in changes in the spring constant of the contact area. As the contact parameters vary, it can be concluded that the dynamic behavior of the system will also change accordingly. Therefore it is expected that, as changes occur in the pre-stress amount, fluctuations in the electrical resistance will also vary. Having this in mind, we attempted to examine the changes in the electrical resistance fluctuations by increasing the amount of the applied pre-stress. Firstly, the modal analysis of the connection was conducted in the x direction and then the frequency response of the connection was plotted as presented in Fig. 9.

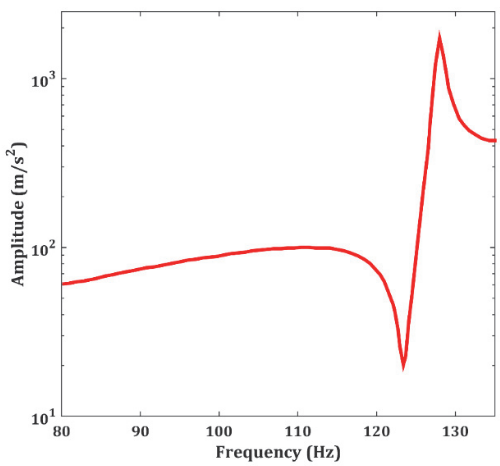

Fig. 9. Frequency response of the system with excitation in x direction

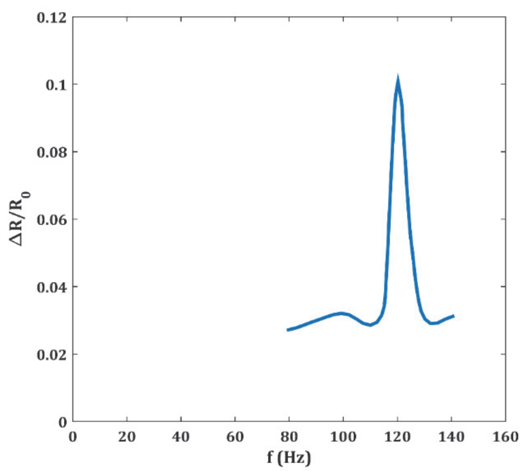

Fig. 10. Variations of maximum electrical resistance fluctuations in the frequency domain with excitation amplitude of g and in the x direction

Subsequently, the connection was excited in different frequencies and the fluctuations in the electrical resistance across the contacts were also achieved. Having substituted the mean contact pressure in Eq. (2), we could arrive at the fluctuations in the electrical resistance at different frequencies. Using the maximum electrical resistance fluctuations in each frequency, the maximum changes in the fluctuations in the electrical resistance were plotted versus vibration frequency, as illustrated in Fig. 10. From this figure, one can see that the maximum electrical resistance fluctuations plot owns an appropriate fit in the frequency response of the connection (according to Fig. 9). A comparison of the modal analysis plots reveals that as the amount of pre-stress enlarges, the natural frequency values will increase as well. Hence, the maximum electrical resistance fluctuations are expected to occur at higher frequencies. On the other hand, it is observed that when the pre-stress increases, the slip is decreased, which in turn reduces the maximum electrical resistance fluctuations.

4.3. The effect of excitation amplitude on the fluctuations in electrical resistance

In addition to the two above-mentioned parameters, the excitation amplitude of the connection is another parameter affecting the electrical resistance fluctuations. As for the purpose of this study, in order to evaluate the effect of vibration amplitude on fluctuations of electrical resistance, the connection was excited at the frequency of 60 Hz in several amplitudes and the electrical resistivity fluctuations were obtained accordingly. The changes in the maximum electrical resistance fluctuations versus acceleration excitation amplitudes are plotted on a graph, as displayed in Fig. 11.

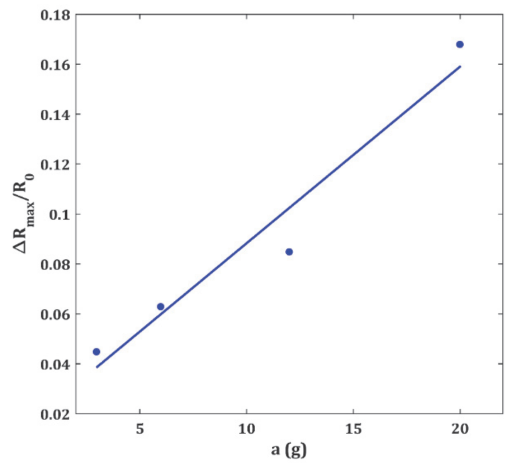

Fig. 11. Maximum electrical resistance fluctuations at frequency of 60 Hz and different excitation domains

In Fig. 11 one can see that increasing the excitation acceleration amplitude will result in a rather linear increase in the maximum variations of electrical resistance, for which the approximated line equation can be expressed as:

$$\Delta R_{max}/R_0 = 10^{-4} \times (7a + 181) \tag{3}$$

where a is the excitation acceleration amplitude.

5. Conclusion

In the present work, the FEM was employed to estimate the electrical resistivity fluctuations, followed by an investigation of the impacts of various parameters on electrical resistivity fluctuations. In this respect, the first parameter studied, was the excitation frequency. The findings revealed that changes in the maximum resistance fluctuations in the frequency domain tend to show a similar behavior to the frequency response of the devices. A modal analysis was subsequently performed on the connection, and thus the maximum electrical resistivity fluctuations were predicted.

The second parameter examined, was the initial pre-press value. The results indicated that with an increase in the amount of the pre-stress, the natural frequency values will raise as well. Therefore, the maximum electrical resistance fluctuations are expected to occur at higher frequencies. On the other hand, it was observed that by increasing the pre-stress, the slip is decreased, which in turn reduces the maximum fluctuations in the electrical resistance. The third parameter investigated in the present study was the excitation acceleration amplitude. It can be concluded from the results that with changes in the excitation acceleration amplitude, the maximum fluctuations of electrical resistance vary rather linearly.

The method presented in this work can be of great application in predicting the noise in electrical connections. In addition, various parameters can be examined in terms of their potential effects on the electrical resistance fluctuations and appropriate designs can be proposed for the connections, given their functioning location.

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