Performance Simulation of Automotive Connector Considering Coupled Electromagnetic Force and Fretting Vibration

Jun Hong[1], Wei Wang[1], Baotong Li[1], Guoqing Yang[1], Shuhong Wang[2]
[1]Faculty of Mechanical Engineering, Xi'an Jiaotong University, 28 West Xianning Rd, Xi'an 710049, China
2Faculty of Electrical Engineering, Xi'an Jiaotong University, 28 West Xianning Rd, Xi'an 710049, China
E-mail: jhong@mail.xjtu.edu.cn

Abstract — This paper presents the simulation analysis for the performance of automotive connectors. In the cases of different contact surfaces, the influence of the connector fretting is simulated. The current, equivalent resistance and the electromagnetic force are calculated by using finite element method. A cantilever model is built to analyze the mechanical kinetic characteristics of connector under the fretting operation. Excited by the imposed mechanical force and electromagnetic force, the preloaded force which keeps the reliable contact of the connector is discussed.

I. INTRODUCTION

With the development of automotive industry, the number of connectors of electrical and electronics systems used in a vehicle has increased to over 400 with 3000 terminals [1]. For the reliability of the automotive connectors, many researchers focus on the improvement of the mechanical and electrical characteristics of the connectors considering the temperature, humidity and vibration. J. L. Queffelec, et al., studied the contact resistance in both the insertion phase and during vibration motion by experiments [2]. In [3], the influence of conducting polymers on contact resistance was investigated by experiments.

In this paper, the electromagnetic and mechanic characteristics of an automotive connector are analyzed. The electromagnetic force and the resistance of the connector are calculated by using 3-dimensional finite element method taking the contact surfaces modification. A cantilever beam model is constructed for the kinetic analysis of the connector. The dynamic function which describes the model is solved by using numerical method. The effects of preloaded force are discussed.

II. CONNECTOR MODEL

In this paper, the electromagnetic and mechanic performances are theoretically simulated for a typical automotive connector, as shown in Fig. 1. The simplified model is illustrated in Fig. 2.

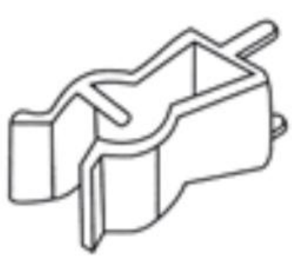

Fig. 1. An automotive connector

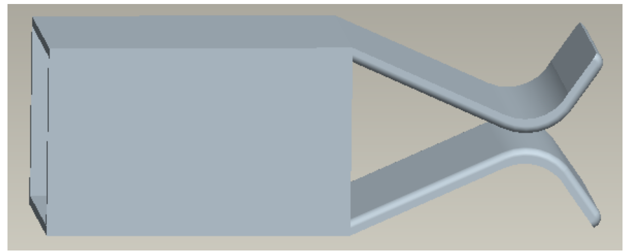

Fig. 2. Simplified socket of the automotive connector

A plate pin is inserted into the socket to provide an electrical pathway when connected, and can be disconnected according to requirement. The preloaded force needs to be imposed enough on the socket to ensure the perfect contact of socket and pin. However, over preloaded force might lead to the increased friction as well as the increased temperature between socket and pin. As the temperature rises, the thermal stress may damage the connectors. In this paper, the fretting vibration considering electromagnetic force and friction of socket and pin is simulated.

III. ELECTROMAGNETIC CHARACTERISTICS ANALYSIS OF AUTOMOTIVE CONNECTOR

The thermal shock, humidity, water and gaseous pollutants, vibration, and mechanical shocks may degrade the connectors [1]. The contact resistance of connector may be increased due to the environment during the real operation. Increased contact resistance may lead to failure in electrical connection system and abnormal operation.

The 3-dimensional finite element (FE) method is applied for voltage-driven magnetic field of automotive connector. In order to be equivalent to the influence of contact resistance, different contact areas are adopted.

In the first case, the contact area between upper socket and pin is the same as that between lower socket and pin. Fig. 3 depicts the FE meshing. The distributions of current, magnetic field and Lorentz force are shown in Figs. 4 to 6, respectively.

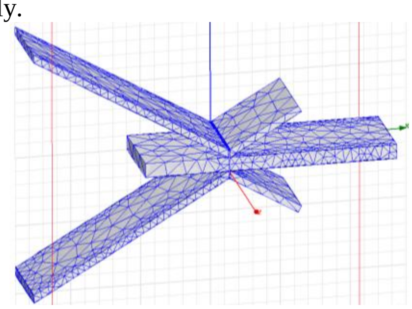

Fig. 3. FE meshing in the first case

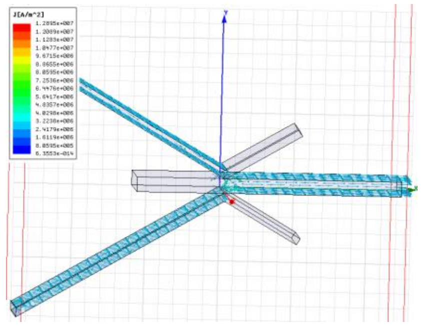

Fig. 4. Current flowing through connector in the first case

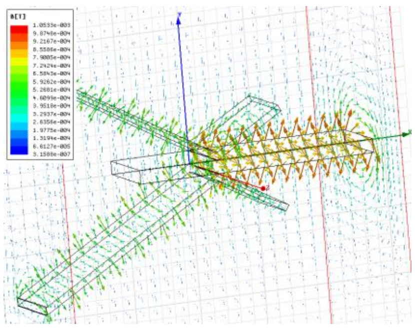

Fig. 5. Magnetic field distribution in the first case

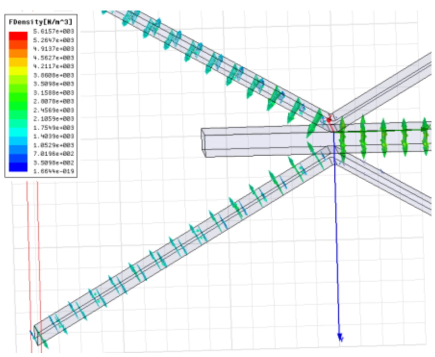

Fig. 6. Lorentz force distribution in the first case (Unit of force: N/m^{-3})

In Fig. 6, the electromagnetic force of socket results in a crimp force on the pin.

In the second case, the contact interface area between the pin and upper socket is different from that between the pin and lower socket. The Lorentz force distribution in this case is pictured in Fig. 7. As the contact resistance changes due to environment corrosion and mechanic corrosion, the current and electromagnetic force may be decreased. Sometimes the resistance at each contact interface is different; this deduces an unbalanced cramp force on the pin.

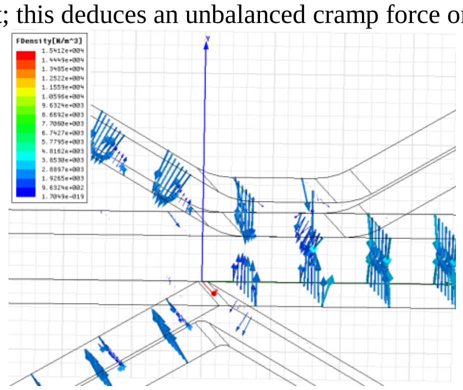

Fig. 7. Lorentz force distribution in the second case

IV. FRETTING VIBRATION MODELING

The unbalanced electromagnetic force and external fretting force results in the deformation of both socket and pin. As shown in Fig. 8, the socket and pin are regarded as three contacted cantilever beams.

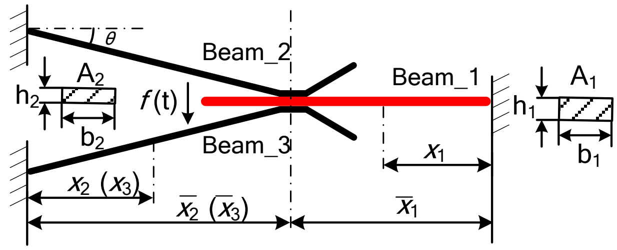

Fig. 8. Cantilever beam model

The kinetic characteristics can be analyzed as

$$\begin{cases} E_1 I_1 \dfrac{\partial^4 w(x_1,t)}{\partial x_1^{\,4}} + m_1 \dfrac{\partial^2 w(x_1,t)}{\partial t^2} + C_1 \dfrac{\partial w(x_1,t)}{\partial t} \\ \quad = f(t)\cdot \dfrac{3E_1I_1}{(\bar{x}_1)^3} \Big/ \left(\dfrac{3E_1I_1}{(\bar{x}_1)^3} + \dfrac{6E_2I_2\cos^2(\theta)}{(\bar{x}_2)^3} \right) \\ E_2 I_2 \dfrac{\partial^4 w(x_2,t)}{\partial x_2^{\,4}} + m_2 \dfrac{\partial^2 w(x_2,t)}{\partial t^2} + C_2 \dfrac{\partial w(x_2,t)}{\partial t} \\ \quad = \left(\dfrac{\delta}{2} + f(t) \Big/ \left(\dfrac{3E_1I_1}{(\bar{x}_1)^3} + \dfrac{6E_2I_2\cos^2(\theta)}{(\bar{x}_2)^3} \right) \right) \cdot \dfrac{3E_2I_2\cos^2(\theta)}{(\bar{x}_2)^3} \\ E_3 I_3 \dfrac{\partial^4 w(x_3,t)}{\partial x_3^{\,4}} + m_3 \dfrac{\partial^2 w(x_3,t)}{\partial t^2} + C_3 \dfrac{\partial w(x_3,t)}{\partial t} \\ \quad = \left(\dfrac{\delta}{2} - f(t) \Big/ \left(\dfrac{3E_1I_1}{(\bar{x}_1)^3} + \dfrac{6E_3I_3\cos^2(\theta)}{(\bar{x}_2)^3} \right) \right) \cdot \dfrac{3E_3I_3\cos^2(\theta)}{(\bar{x}_2)^3} \end{cases}$$

where x_1, x_2 , x_3 are the coordinates of beam_1, beam_2 and beam_3, respectively. $\bar{x}_1$, $\bar{x}_2$, $\bar{x}_3$ are the equivalent length of the beam_1, beam_2 and beam_3, respectively (as shown in Fig. 8); t is the time variable; $w(x, t)$ is the unknown deformation of the beam; m is the mass of unit length of the beam ($m = \rho A = \rho b h : \rho$ is the density of the material, h and b is the height and width of the beam respectively, and A is the sectional area of the beam) , C is the damping coefficient of the beam, E is the elastic modulus of the material and I is polar moment of inertia. $f(t)$ consists of electromagnetic force and fretting external force. δ is the preloaded displacement, which is used to describe the influence of preloaded force.

The kinetic characteristics including deformation and the discussion of preloaded force will be presented in the full paper.

V. REFERENCES

[1] J. Swingler, J. W. McBride, and C. Maul, "Degradation of road tested automotive connector," *IEEE Trans. on Components and Packaging Technologies*, vol. 23, no. 1, pp. 157-164, 2008.

[2] J.L. Queffelec, J. N. Ben and D. Travers, "Materials and contact shape studies for automobile connector development," *The Proceedings* of *15th International Conf. on Electric Contacts*, Aug. 20-24, pp. 225-231, 1990

[3] J. Swingler, "Enhancing connector reliability by using conducting polymer materials to minimise contact fretting," *Materials and Design*, vol. 30, pp. 3935–3942, 2009.