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Review paper

Effect of normal forces on fretting corrosion of tin-coated electrical contacts

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ABSTRACT

Electrical connectors have been extensively used as the electrical connecting component in various electronic systems. The performance of the electrical connector directly affects the performance of an entire system. Fretting corrosion is generally recognized as an essential failure mechanism for an electrical contact. Major factors affecting the fretting corrosion include current magnitude, normal contact force, displacement amplitude, relative humidity, frequency, and temperature. In order to investigate the effect of normal forces on fretting corrosion behavior, normal forces were fixed at 1 N, 1.25 N, 1.5 N, 2 N, 2.5 N for various displacement amplitudes. Riders and flats made of 0.3 mm-thick brass sheet were coated with tin. The change of the electrical resistance was measured by applying constant current and displacement amplitudes to the upper sphere contact specimen, fixing the flat specimen. The normal force (F) shows a linear relationship with the threshold displacement amplitude (δ_{th}). When the displacement amplitude increases with increasing normal force, the plating layer was severely worn due to contact pressure. Dimples were found on the surfaces of the central part of the specimens showing infinite lifetime, suggesting that a soft metal-to-metal contact formed just before separation of the mated specimens at the end of the test. Specimens with an infinite lifetime tested under partial slip condition showed a relatively low oxygen concentration on the center of the wear surface. It is very important to design an electrical connector contact to maintain partial slip by using the information on the normal force and displacement amplitude in order to achieve infinite lifetime.

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1. Introduction

Mechanical vibration and thermal expansion and contraction cause micro-displacements between pairs of contact surfaces of automobile connector. When the contact surfaces have oscillatory displacement at small sliding amplitude (smaller than 100 μm), electrical insulating oxidation products are continuously generated at the contact surfaces and cause fretting corrosion. When fretting corrosion occurs, signal data values output from various electronic control sensors of the vehicle may be distorted, resulting in malfunction of the electronic devices.

Major factors involved in fretting corrosion include current magnitude, normal contact force, displacement amplitude, relative humidity, frequency, temperature, environment gas, etc. [1–6]. Many studies

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have been performed to understand the factors contributing to fretting corrosion lifetimes of electrical connectors. For examples, Fouvry et al. [1] proposed a method to predict the electrical endurance of silver-coated contacts. They formalized the endurance, using a power law function of the mean friction energy density dissipated during a fretting cycle taking into account the normal force, friction coefficient and sliding amplitude. Pascucci [2] et al. proposed a theoretical model for fretting corrosion degradation of non-noble metal coated contacts. They formulated a theoretical model to estimate the resistance rise and oxide accumulation during fretting cycles, adopting a continuum method based on a consideration of a macroscopic description of fretting-oxidation induced evolutions of resistance and metal fraction. Chalandon et al. [3] conducted constant–displacement-amplitude tests to determine the effect of a nickel layer on the performance of electrical tin coated contacts. They reported that there is no influence of the nickel layer on the electrical endurance during gross slip. The application of the nickel layer was reported to cause the maintaining of a high tin tin friction coefficient and to extend the partial slip domain, resulting in an increase of the reliability of the electrical contact. Song et al. [4] investigated the effect of temperature on fretting corrosion of gold-coated contacts. They performed fretting test in the temperature range of 25 °C–125 °C by fixing the displacement amplitude at 25 μm. They reported that the role of gold coating is soften and lubricate the contact surface, resulting in the maintaining of a low contact resistance and in reducing failure rate at higher temperature. At elevated temperatures, however, the formed copper oxide particles deteriorate the contact resistance by wearing the substrate copper alloy material. Lee et al. [5] investigated the effect of temperature on fretting corrosion of lubricated tin-coated contacts. They performed a fretting test in the temperature range of 27 °C–155 °C by fixing a normal force of 0.5 N and displacement amplitude of 90 μm. They reported that, at room temperature, the lubrication is very effective and the contact resistance remains stable. However, at elevated temperatures the performance of lubricated contact is poor due to the higher wear rate of tin coating and also due to evaporation of the lubricant. Vincent et al. [6] investigated the fretting sliding transition from partial slip to gross slip for electrical contacts with noble and non-noble material coatings. They reported that if the displacement amplitude becomes higher than the transition value, the generalized gross slip condition activates debris formation over the whole contact surface, resulting in unstable electrical resistance for non-noble material coatings. Noble material coatings can only extend the lifetime of the electrical contacts. Wearing-out of the substrate coating material caused high and unstable electrical resistance. Vincent et al. [6] also reported that the sliding transition can conveniently be predicted if the cyclic hardening behavior of the mating material and the friction law of the tribo-system can be correctly identified.

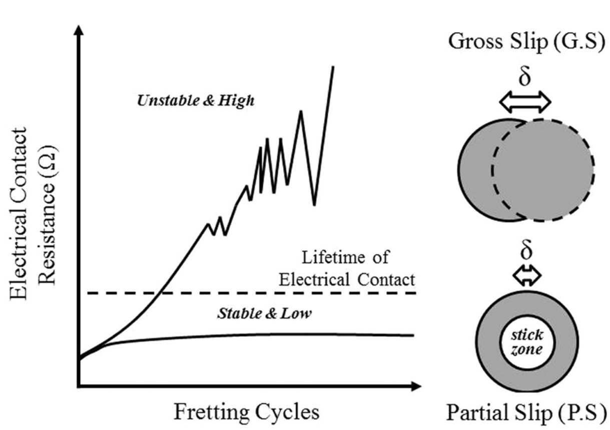

Fig. 1. Illustration of the influence of the sliding regime on the finite and infinite behavior of electric connectors.

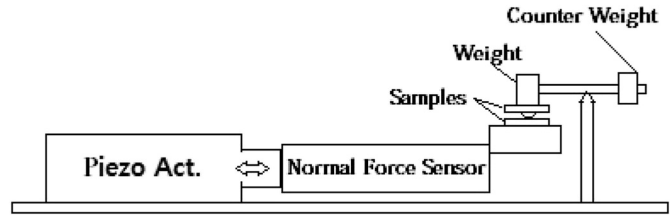

Fig. 2. Fretting test system.

When two objects come into contact, a micrometer-level sliding motion can occur. For a pair of contact surfaces in spherical form and a plane contact, the sliding regime can be divided according to the displacement amplitude into partial slip and gross slip [7], as shown in Fig. 1. When the displacement amplitude is small, partial slip causes an annular slip area on the outer periphery and a stick zone in the center area where slip does not occur. On the other hand, when the sliding displacement is relatively large, the stick zone disappears and gross slip occurs. Generally, when a partial slip occurs on an electrical contact, an oxide film is formed in the area where the slip occurs. The stick zone in the center has metal-to-metal contact. Therefore, as shown in Fig. 1, the electrical resistance is very low, so that it is possible to achieve an infinite lifetime of the electrical connector terminal. In contrast, when a gross slip occurs, slip occurs over the entire contact area and oxide debris is created in the entire area. As a result, the electrical resistance rapidly increases with the number of cycles, as shown in Fig. 1.

It is desirable to design an electrical connector contact to maintain partial slip in order to guarantee its electrical lifetime. The main factors affecting partial slip are normal force and displacement amplitude. Generally, as the normal force increases, the displacement amplitude required for partial slip increases. The purpose of this study is to investigate the effect of the normal force on the electrical resistance through fretting experiment under various displacement amplitude conditions for tin-plated brass connectors. For this purpose, the displacement amplitude required to achieve infinite lifetime at each normal force will be derived. The aim of this study is to provide basic information on the design of the connector in terms of its durability.

2. Experimental procedures

In this study, we designed and built a system for the fretting test. The experimental setup is shown in Fig. 2. The system is composed of a displacement generation system, a normal force measuring system, a system for transferring a dead weight to the test specimen, and holders for fixing the specimens.

The specimens used for the fretting test were brass plate of 0.3 mm thickness plated with tin. In order to improve the adhesion of the tin plating, tin was electroplated to a thickness of 10 μm after plating the brass very thinly with copper. The upper sphere contact specimen and the lower flat specimen were fixed to the holders. The fretting test was conducted at a frequency of 0.05 Hz. A constant current-resistance measurement method was used to measure the changing electrical contact resistance during the fretting test. As shown in Fig. 3, by supplying a constant current of 0.1 A across the specimen, the voltage was measured

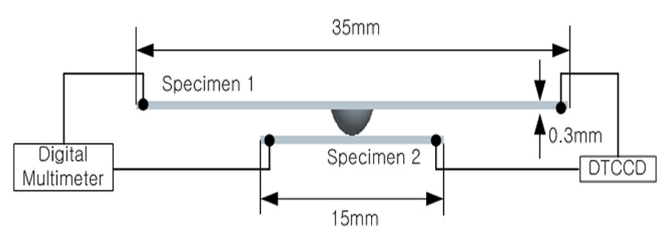

Fig. 3. Schematic of measurement for contact resistance.

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