

Effects of Oil Film Thickness and Lubricant Conductivity on Electrical Erosion in EV Traction Motor Bearings

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In recent years, e-Axles for electric vehicles (EVs) have been required to achieve further downsizing to improve power density and vehicle packaging. As a result, drive motors are increasingly operated at higher rotational speeds, raising concerns regarding electrical erosion damage in motor bearings caused by shaft currents. Electrical erosion occurs when the lubricating oil film between the bearing raceway and rolling element undergoes dielectric breakdown, generating discharge heat that locally melts and damages the metal surface.

Although oil-film thickness is known to be an important factor in suppressing electrical erosion, the electrical conductivity of lubricants also varies depending on their composition. In this study, the effects of oil-film thickness and lubricant volume resistivity on bearing electrical erosion were evaluated under different electrical conditions, with the aim of providing guidelines for developing e-Axle lubricants with improved resistance to electrical erosion.

Electrical erosion can be broadly classified into two modes: the “circulating-current mode,” caused by induced voltage resulting from magnetic circuit imbalance, and the “discharge-current mode,” caused by common-mode voltage associated with inverter operation. In both modes, damage occurs when electrical energy is converted into Joule heat, resulting in localized melting of the metal surface.

The electrical resistance of the oil film is determined by the oil’s volume resistivity, oil-film thickness, and contact area, and increases with increasing film thickness. Under constant-current conditions, a thicker oil film increases Joule heat and consequently aggravates damage. In contrast, under constant-voltage conditions, a thinner oil film increases Joule heat and aggravates damage. Thus, the effect of oil-film thickness is expected to differ depending on the electrical erosion mode.

Electrical erosion was reproduced using a ball-on-disk test machine by applying voltage or current to the ball. Several lubricants with different volume resistivities were used, and the oil-film thickness was controlled by adjusting the viscosity, contact pressure, and sliding speed. Damage on the disk surface was quantified as damage volume by measuring the cross-sectional profile of the damaged area and integrating it around the circumferential direction.

Under conditions in which the oil-film thickness was kept constant, increasing the applied voltage or current increased the Joule heat and, consequently, the damage volume.

Under constant-current conditions, the damage volume increased with increasing oil-film thickness. Conversely, under constant-voltage conditions, the damage volume increased as the oil-film thickness decreased. In both conditions, no clear difference in damage volume was observed among lubricants with different volume resistivities when the oil-film thickness was the same.

Within the evaluated range, oil-film thickness rather than lubricant volume resistivity was found to be the dominant factor governing electrical erosion damage. Accordingly, reducing the oil-film thickness with a low-viscosity lubricant is effective in the circulating-current mode, whereas increasing the oil-film thickness with a high-viscosity lubricant is effective in the discharge-current mode.

However, in the discharge-current mode, common-mode voltage may generate electromagnetic noise and cause system malfunctions. Therefore, hardware measures, such as shaft-grounding brushes, are also required. In the circulating-current mode, the use of a low-viscosity lubricant may simplify insulation measures, such as the application of ceramic rolling elements, when the leakage current is relatively small.

The limited effect of volume resistivity also indicates that an increase in extreme-pressure additives associated with lubricant viscosity reduction does not significantly increase the risk of electrical erosion, despite changes in electrical conductivity.

Damage volume showed a strong correlation with the generated Joule heat. For suppressing electrical erosion, reducing the oil-film thickness through the use of a low-viscosity lubricant is effective in the circulating-current mode, whereas increasing the oil-film thickness through the use of a high-viscosity lubricant is effective in the discharge-current mode. The results further show that lubricant viscosity, or oil-film thickness, is the dominant factor affecting electrical erosion damage, while the effect of volume resistivity is limited.