Prevention of Electrical Pitting on Rolling Bearings by Electrically Conductive Grease

Junichi SUZUMURA
Lubricating Materials Laboratory, Materials Technology Division

This paper describes a fundamental study of the preventive measures against electrical pitting on rolling bearings by using electrically conductive lubricating grease. In order to evaluate the ability to prevent the electrical pitting on rolling bearings of several types of grease into which conductive nanometer-scaled carbon particles, or “nanocarbon” particles, have been dispersed, bearing rotation tests were conducted when an electric current was turned on. It was concluded that the electrically conductive grease has the ability to prevent electrical pitting, or “ridge marks”, if the electric current density at the points of rolling contact is lowered.

Keywords: electrical pitting on rolling bearings, electrically conductive grease, nanocarbon

1. Introduction

The electrical pitting of rolling bearings is one type of metal surface damage attributable to the electric current flowing through the thin insulating oil film in bearings. For traction motor bearings, electrical pitting is one of the factors leading their premature replacement because of increased bearing vibration and ambient noise due to the roughness on the rolling surface and deterioration of the lubricant incurred by metal particles generated by electrical pitting. This causes pitting and washboard-like markings, or “ridge marks”, which are both characteristic of electrical pitting. There are two approaches to preventing electrical pitting: “bearing insulation” and “bearing conduction”. Insulated bearings with their outer ring coated in an insulating ceramic or polyphenylene-sulfide (PPS) have been introduced for traction motor bearings, based on the “bearing insulation” principle [1]. Other solutions based on the “bearing conduction” approach also exist. For bearings in solarization units in copy machines and laser printers, which are built into the electric circuit, electric discharges are prevented by using electrically conductive greases because of the low volume resistivity of thin oil films [2, 3]. In general, electrically conductive greases have low volume resistivity of less than $10^5 \, \Omega \cdot \text{cm}$ because of the dispersion of electrically conductive particles such as metal, graphite or carbon material particles.

This paper focuses on the applicability of electrically conductive greases as a means to prevent electrical pitting in traction motor rolling bearings with a view to reducing maintenance costs and improving traction motor safety, although tests did not extend on trials on a railway vehicle. Several types of grease were selected in which nanometer-scaled carbon materials, i.e. nanocarbons, were dispersed as the electrically conductive material. Small bearing rotation tests were conducted where electric current was passed continuously through the test bearings in order to estimate their performance in terms of resistance to electrical pitting. Tests also examined the influence of the grease’s composition, i.e. the types of base oil and types and quantities of nanocarbons, on the occurrence of electrical pitting. Some typical nanocarbons were used, such as ‘fullerenes’ which have carbon atoms arranged and bonded to each other like a soccer ball and, ‘graphenes’ which are composed of sheet molecules bonded in a hexagonal net, ‘carbon-nanotubes’ (CNT) which are composed of a graphene sheet rolled up in a cylinder of a nanometer-scaled diameter and form a hollow and tubular molecule, and ‘carbon-blacks’ (CB) which have a spherical form. These new materials have become a subject of great attention because of their excellent properties, such as mechanical characteristics, electrical conductivity and heat conductivity.

2. Experiments

Figure 1 shows the experimental apparatus of the small bearing rotation test conducted with a live electric current. The test greases as shown in chapter 3 were filled into the test ball bearing (deep-groove radial bearing of the bearing number 6206) with a space-area ratio of 33 percent. The test bearing set into the housing was rotated at a speed of 1000 min$^{-1}$ under a radial load of 180 N.

The direct electric current flows from the outer ring to the inner ring via the housing which borders the outer ring and the rotating shaft which borders the inner ring. According to previous studies, ridge-marking was expected to appear at the minus pole when a direct current flowed into the bearing [4]. This means that under these test conditions, ridge-marking could occur at the rolling surface of the inner ring. It is known at the same time, that electrical pitting does not occur when the electrical current density in the rolling contact area is less than 1 A/mm$^2$ [5, 6, 7]. In this test, the electrical current was set at the constant value of 6 A because this electrical current density is large enough to generate ridge-marking in the case of conventional grease, i.e. non-conductive grease.

Radial vibration acceleration, which increased when the electrical pitting occurred on the test bearing, was measured by a pick-up fixed to the housing. The appearance and degree of electrical pitting were estimated by visual inspection of the outer ring, ball, and inner ring, and by surface roughness measurement of the inner ring, and
Conductive grease for office equipment

Penetration

Non-Conductive
Poly

Conductive grease for office equipment

Lithium

Mineral oil

Ester

Half the CB used in grease C.

CNT

220

Lithium

CB

Mineral oil

Ester

Half the CB of grease B.

211

Non-conductive grease for traction motor

430

4. Results and discussions

4.1 Prevention of electrical pitting by conductive greases

Greases A and B were evaluated through small bearing rotation tests for electric currents kept active for 25, 50 and 100 hours. These tests were used to establish the effects of grease conductivity on electrical pitting, depending on whether it was conductive grease or non-conductive grease.

4.1.1 Appearance and vibration measurement of test bearings

For non-conductive grease A, the inner ring rolling surface was colored 25 hours after the start of rolling, and ridge-marking appeared 50 and 88 hours after rolling began. The waves in the surface roughness curve lines, as showed in Fig. 3, were caused by ridge-marking. As shown in Fig. 4, the fluctuation in vibrations of the test bearings increased abruptly from 50 hours onward. With conductive grease B, however, ridge-marking and waves in the surface roughness curve lines did not appear even when the grease was tested for 100 hours, and the fluctuation in vibrations did not increase during the test time. This leads to the assumption that ridge-marking may be prevented by using conductive grease.

Table 1  Summary of the test greases

| Grease | Base oil       | Thickener   | Conductive material | Penetration (310) | Volume resistivity (Ω・cm) | Base oil viscosity at 40℃ (mm/s) | Comment                                      |
|--------|----------------|-------------|---------------------|-------------------|-----------------------------|----------------------------------|------------------------------------------|
| A      | Mineral oil    | Lithium     | complex             | Non               | more than 1.0 × 10⁷         | 101                              | Non-conductive grease for traction motor bearings. |
| B      | Poly α olefin  | CB          | CB                  | 259               | 6.7 × 10⁷                   | 30.5                             | Conductive grease for office equipment bearings. |
| C      | Ester          | CB          | CB                  | 220               | 4.1 × 10⁷                   | 33.2                             | Conductive grease for office equipment bearings. |
| D      | Fluorine oil   | CB          | CB                  | 224               | 5.5 × 10⁷                   | 400                              | Conductive grease for specific use. |
| E      | Poly α olefin  | CB          | CB                  | 430               | 1.7 × 10⁷                   | 30.5                             | Half the CB of grease B. |
| F      | Ester          | CB          | CB                  | 430               | 1.7 × 10⁷                   | 33.2                             | Half the CB used in grease C. |
| G      | Mineral oil    | Lithium     | complex             | CNT               | 5.6 × 10⁴                   | 101                              | CNT dispersed into grease A. |

Fig. 1  Experimental apparatus of the small bearing rotation test

Measurement of iron density in the grease, which is considered to be generated by electrical pitting.

3. Sample greases

Table 1 gives a summary of tests on seven greases i.e. greases A to G. Grease A was universally adopted as the non-conductive grease for traction motor bearings. Greases B, C and D were conductive greases with CB dispersed into their different types of base oil. CB are nanometer-sized spherical carbon particles varying in size from a few nanometers to few hundred nanometers. The conductive grease contained dispersed carbon-blacks varying size from 30 to 70 nanometers accounting for approximately 10% of the material weight. These particles also act as a thickener which keeps the grease in a semisolid lubricant state. Greases E and F were conductive greases containing only half the CB of greases B and C. Therefore, the volume resistivity of greases E and F was larger than in greases B and C. Grease G was a conductive grease produced by dispersing the conductive material CNT into grease A.
4.1.2 FFT analysis of voltage variance

Figure 5 shows the voltage variance in the 100 hour test. The voltage amplitude of grease A is larger than that of grease B, and increases as the test progresses. The voltage variance shows the effect of the electric resistance and the channel in the test bearing because the electric current of 6 A constantly flows through the bearings without the effect of the electrical characteristics of test greases under this test condition. Therefore, the difference of the voltage variance shows the difference in the electrical condition inside the bearings between non-conductive grease and conductive grease. The electrical condition inside the bearings were estimated by comparing the frequency components of the voltage variance which was obtained by Fast Fourier Transform (FFT) analysis and the frequency components connected with the bearing rotation, i.e., the rotating frequency of the cage or inner ring and the rotating or orbital frequency of the ball.
flows with the period of the rotating frequency of the inner ring, because ridge-marking appeared across the whole rolling surface of the inner ring. Therefore, it is considered that in the case of non-conductive grease, an electric channel forms through the thin insulating oil film in the rolling contact area, between the ball and the inner ring.

The voltage variance for grease B, however displayed no significant peaks in the 25 and 50 hour tests. A peak did occur of 13.56 Hz in the 100 hour test, however, its period was not influenced by the bearing rotation. This result indicates that the electrical channel of conductive grease is not influenced by the bearing rotation and there are other several channels in addition to the rolling contact area.

Figure 7 shows the electrical channel model for the non-conductive and conductive greases. It is considered that the conductive grease can prevent ridge-marking because the electric current density in the rolling contact area, in the case of conductive grease where the arc or spark would occur, is lower than with non-conductive grease for the same current value flowing through the bearings, and this is due to the formation of electrical channels.

### 4.2 Effect of grease composition on electrical pitting

Test greases C to G, shown in Table 1, were also evaluated through small bearing rotation tests with an electric current kept active for 50 hours, in addition to greases A and B. The tests aimed to determine the influence of the grease composition, i.e., the type of base oil and the type and amount of nanocarbon, on electrical pitting. The generation of electrical pitting and its level were evaluated through visual examination of the inner ring and measurements to determine the iron density in the grease.

Figure 8 shows the inner ring rolling surface of the test bearings. Table 2 shows the iron density of each test grease. Ridge-marking occurred with greases D and G. The test on grease D was aborted after 88 hours for safety reasons because of the extreme increase in bearing vibration.
Ridge-marking only occurred with grease D, despite the fact that greases B, C and D are all conductive greases with carbon-black dispersed as conductive materials. This suggests that the characteristics of the base oil have an effect on electrical pitting. In this case, the viscosity and volume resistivity of the base oil of grease D were higher than in the base oils used for greases B and C.

It was found that the iron density of grease B was higher than in grease C, although ridge-marking did not occur in either. Test greases B and C were evaluated through small bearing rotation tests where electric current was not active for 50 hours, in order to consider whether the difference of iron densities was caused by the electric current or not. Results demonstrated that iron powder is mainly generated by electric current because almost no iron component was measured in any of the test greases when tested with non-active electric currents, as shown in Table 2. This result indicates therefore that other types of surface wear, different from ridge-marking, may occur when the electric current flows in the bearing for grease B. Figure 9 shows the close-up of the inner ring rolling surface. For grease B, partial wear, circled by a dashed white line in Fig. 9, was found, but there was no visually recognizable wear for grease C. Although this wear mechanism is not clear, the lubricating performance of the grease may have an effect on this electrical wear.

For greases E and F, which contained only half the amount of carbon-black as greases B and C, and consequently had a relatively high volume resistivity, no ridge-marking occurred. This suggests that ridge-marking could be prevented by using greases B and C, even if their volume resistivity reached 1700 Ω·cm for grease B and 170 Ω·cm for grease C, which are equal to that of greases E and F. However, results also showed that the iron densities of greases E and F were greater than those for greases B and C, indicating that high volume resistivity and/or increased grease penetration, i.e., grease softening due to the reduction of carbon-black, may accelerate the electrical wear as shown above.

Ridge-marking occurred with grease G, which was produced by dispersing CNT into grease A. It can be inferred from this that the higher volume resistivity of grease G had an effect on ridge-mark occurrence.

### Table 2: Iron densities of the test greases

| Grease | Electrical current | Iron density (%) |
|--------|--------------------|------------------|
| A      | Active             | 0.10             |
| B      | Active             | 0.42             |
| C      | Active             | 0.08             |
| D      | Active             | 0.09             |
| E      | Active             | 0.89             |
| F      | Active             | 0.53             |
| G      | Active             | 0.31             |
| B      | Non-active         | 0.00             |
| C      | Non-active         | 0.00             |

5. Conclusions

This paper proposes a method to prevent electrical pitting from bearing conduction, using conductive greases. The mechanisms involved in preventing electrical pitting through use of conductive greases and the effect of the grease composition on the electrical pitting were studied, leading to the following findings:

1. Ridge-marking can be prevented by using conductive grease which has an appropriate composition.
2. Conductive grease can prevent ridge-marking because the electric current density of the rolling contact area is lowered due to the formation of electrical channels.
3. The types of base oil may have an effect on ridge-marking occurrence and on electrical wear.
4. Of all the test greases, conductive greases with an ester base oil were most effective in preventing ridge-marking.
5. Ridge-marking can be prevented by using some types of grease even if their volume resistivity reaches 1700 Ω·cm.
6. The conductive grease with dispersed CNT could not...
prevent ridge-marking occurrence in tests regarding the type and amount of the CNT.

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Author

Junichi SUZUMURA
Assistant Senior Researcher, Lubricating Materials Laboratory, Materials Technology Division
Research Areas: Tribology of lubricating oil and grease