Measurement of Acoustic Emission and Vibration of Rolling Bearings with an Artificial Defect

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In this study, we measured the acoustic emission (AE) and vibration of rolling bearings with an artificial defect on the raceway surface, investigated the detective capacity of AE method for such surface defect, and compared it with that taken from the vibration measurement.

From the measurement results, we concluded that it was possible to detect a raceway surface defect in rolling bearings by measuring AE, and that the detective capacity of the AE method for the surface defect was the same level as that of the vibration measurement within the range of present measurement.

Keywords : Rolling bearing, Acoustic emission, AE, Vibration, Surface defect, Defect frequency

1. Introduction

Rolling bearings, which support rotating axles and shafts of machines, are one of the most important machinery elements. A rolling bearing consists of an inner ring, outer ring, cage and a number of rolling elements. In railway vehicles, they are used to support axles, shafts of main motors and running gears and other parts.

In the rolling bearings for railway vehicles, raceway surface damages, referred to as indentations or electrical pitting, frequently occur. Indentations are generated by foreign particles and debris which intrude into the rolling bearings, and electrical pitting by the current which flows through them. Damaged bearings are found and put out of service in the periodical overhaul of vehicle equipment. It will be very profitable and labor-saving to detect raceway surface damages of rolling bearings without overhaul of the vehicle equipment.

Normal and damaged rolling bearings vibrate when they rotate. There has been much research on the vibration measurement of rolling bearings which have damages on the raceway surface, and show that such measurement is useful for the diagnosis of damages^{1)~4)}. We assumed that the measurement of the acoustic emission (AE) from rolling bearings was also useful for the same purpose if the AE occurred at normal and damaged bearings during operation. However, the AE measurement of rolling bearings with raceway surface damages has not sufficiently been studied⁵⁾.

In this study, we measured and evaluated the AE and vibration of rolling bearings with an artificial defect on the raceway surface.

2. Experiment

We measured the AE and vibration of rolling bearings with an artificial defect on the inner ring raceway surface. For the measurement, we used a radial type bearing test machine. Fig. 1 shows an outline of the bearing test machine and the positions of an AE and a vibration sensor. We used a deep groove ball bearing 6206 and a cylindrical roller bearing NU206 as the test bearings. There were nine and thirteen rolling elements in the deep

Fig. 1 Bearing test machine

Shape of Artificial Defect : Hole

Diameters of Artificial Defects : $D=0.1, 0.2, 0.5, 1.0, 1.5$ (mm)
Depth of Artificial Defects : 0.1 (mm)

Fig. 2 Dimensions of artificial defects in ball bearing

Shape of Artificial Defect : Rectangular Slit

Width of Artificial Defects : $W=0.1, 0.2, 0.5$ (mm)
Length of Artificial Defects : $L=4, 8$ (mm)
Depth of Artificial Defects : 0.1 (mm)

Fig. 3 Dimensions of artificial defects in roller bearing

groove ball bearing 6206 and cylindrical roller bearing NU206, respectively, and their bore diameters were 30mm, and the outside diameters were 62mm. A radial load (980N or 1960N) was applied to the test bearing, and its inner ring rotated at 1074rpm. The test bearings were lubricated with grease. The AE sensor was attached to the front of the housing, and the vibration sensor to the side of the housing.

Fig. 2 and 3 show the dimensions of artificial defects on the inner ring raceway surface of the test bearings. The artificial defects were produced by the electron discharge method (EDM). One test bearing has one artificial defect at the center of the inner ring raceway surface. We measured the AE and vibration of a normal ball bearing, five ball bearings with artificial defects, a normal roller bearing and six roller bearings with artificial defects under two bearing load (980N or 1960N) conditions.

Fig. 4 shows the block diagram of the AE and vibration measurement system. The AE sensor detected the AE signals which was generated at the rotating test bearings. The AE signals passed through a pre-amplifier, bandpass filter, main amplifier and envelope detector. Then, we recorded the enveloped AE signals on a data recorder. The measuring and processing conditions of the

Fig. 4 Block diagram of AE and vibration measurement system

AE are as follows. The pre-amplifier gain was 40 dB; the bandpass frequency range was from 20 to 200 kHz; the main amplifier gain was 0 dB; the time constant of envelope processing in the envelope detector was 1 msec. We analyzed the spectrum of the enveloped AE signals which was recorded on the data recorder using a fast Fourier transform (FFT) analyzer. The vibration signals detected by the vibration sensor were passed through an amplifier. We recorded the vibration signals on the data recorder. In the vibration observation, the vibration signals were passed through a bandpass filter (with a bandpass frequency range from 1 to 10 kHz) and envelope detector when the recorded vibration signals were played back. We analyzed the spectrum of the enveloped vibration signals by the method similar to that applied to the spectrum analysis of the enveloped AE signals.

3. Defect frequency in rolling bearings

For rolling bearings with surface defects, it is possible to calculate the defect frequency as a defect detection parameter. These defect frequencies have often been used for the diagnosis of rolling bearings by a vibration measurement. The defect frequencies are as follows⁴⁾.

Inner ring defect frequency:

$$F_i = \frac{F_r}{2} \left(1 + \frac{d}{D} \cos \alpha \right) z, \quad (1)$$

Outer ring defect frequency:

$$F_o = \frac{F_r}{2} \left(1 - \frac{d}{D} \cos \alpha \right) z, \quad (2)$$

Rolling elements defect frequency:

$$F_b = \frac{F_r D}{d} \left(1 - \left(\frac{d}{D} \right)^2 \cos^2 \alpha \right), \quad (3)$$

where,

F_r : Rotation frequency of shaft or inner ring (Hz),
 D : Pitch circle diameter of rolling bearing (mm),

d : Diameter of rolling elements,
 α : Contact angle of rolling bearing (deg)
 z : Number of rolling elements.

In this study, the rotation frequency is 17.9Hz (1074rpm). Then, the inner ring defect frequency for the deep groove ball bearing is 97.1Hz, and that for the cylindrical roller bearing is 124.9Hz.

4. Results and discussion

Fig. 5 shows the typical AE envelope spectrum. We can see peaks marked as the inner ring defect frequency (F_i), rotation frequency (F_r) and F_r modulation frequency of F_r (F_i-F_r, F_i+F_r). These marked peaks show the presence of inner ring defects in the bearings.

Fig. 6 shows the relationship between the magnitude of F_i components and the diameters of artificial defects in ball bearings. In Fig.6, the horizontal axis shows the diameters of artificial defects in ball bearings and the plots of zero on the horizontal axis shows the magnitude

of F_i components of normal ball bearings without defects.

In the AE measurement for ball bearings, the magnitudes of F_i components of the ball bearings with the defect diameters of 0.1mm and 0.2mm were nearly equal to those of normal ball bearings. The magnitudes of F_i components of the defect diameters of 0.5mm and over were larger than the magnitude of F_i components of normal ball bearings, and their magnitude of F_i components increased with the defect diameter. And also in the same diameter of the artificial defect, their magnitude of F_i components increased with the bearing load. In the vibration measurement for ball bearings, the magnitudes of F_i components of ball bearings with the defect diameters of 0.1mm and 0.2mm were nearly equal to those of normal ball bearings. The magnitudes of F_i components of the defect diameters 0.5mm and over were larger than those of normal bearings, and their magnitude of F_i components increased with the defect diameter except one plot (980N, 1.5mm). And also in the same diameter of the artificial defect, their magnitude of F_i components increased with the bearing load.

Fig. 5 Typical case of the AE envelope spectrum

Fig. 6 Measurement results of ball bearings

Fig. 7 Measurement results of roller bearings

Fig. 7 shows the relationship between the magnitude of F_i components and the widths of artificial defects in roller bearings. In Fig.7, the horizontal axis shows the widths of artificial defects in roller bearings, and the plots of zero on the horizontal axis shows the magnitude of F_i components of normal roller bearings without defects.

In the AE measurement of roller bearings, the magnitudes of F_i components of all test bearings with an artificial defect were larger than those of normal roller bearings, and their magnitudes of F_i components increased with the defect size. In the vibration measurement for the roller bearings, the magnitudes of F_i components of all test bearings with an artificial defect were larger than those of normal roller bearings, and their magnitude of F_i components increased with the defect size except one plot (980N, L=4mm, W=0.5mm).

From the results mentioned above, it seems that the AE which had the inner ring defect frequencies were generated from the rolling bearings with the artificial defect on the inner ring. Therefore, we assumed that we can detect the raceway surface damages in rolling bearings by measuring the AE. Moreover, it was estimate of that the detective capacity of AE method for the surface defect was at the same level as the vibration.

We have measured the AE emitted from rolling bearings which have various shapes of raceway surface defect, to obtain systematic data on the relationship between the surface defects and AE signals.

5. Conclusions

From the measurement results, we concluded that it was possible to detect the raceway surface defect in roll-

ing bearings by measuring AE, and that the detective capacity of the AE method for surface defect was at the same level as that of vibration within the range of present measurement.

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