Damage Diagnosis of Low Speed Rotating Bearings by AE Measurement

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Abstract:

Equipment diagnosis and condition monitoring techniques using vibration method have been established and widely used as diagnosis methods for rolling bearings used for rotary machines, etc. However, applying vibration method to slow-speed rolling bearings at 100 rpm or less is difficult, and alternative diagnostic methods are not widely known at present. Hence, we focused on acoustic emission (AE) as one of the effective methods for monitoring slow-speed rolling bearing condition, and introduce development of quantitative diagnosing method that enables us to diagnose damage state of slow-speed rolling bearing and application examples of the developed diagnosing technique while solving conventional issues with AE diagnosis.

1. Introduction

Equipment diagnosis and condition monitoring techniques employing the vibration method have been established and are widely used as diagnostic methods for rolling bearings, which have long been used in large numbers in rotary machines. However, because a certain bearing rotation speed is necessary for bearing diagnosis by the vibration method, application to low speed rotating bearings with speeds of less than 100 rpm is difficult, but no alternative diagnostic method has been established at present.

Effective condition monitoring techniques for low speed rotating bearings include temperature monitoring, analysis of foreign matter in lubricating oil and acoustic emission (AE). Among these methods, AE is considered to offer the highest sensitivity for the initial-stage failure condition, and the measurement operation is also easy. Therefore, focusing on AE, this report describes the development of a diagnostic technique that enables quantitative diagnosis of the damage condition of low speed rotating bearings while also solving the problems of conventional AE diagnosis, and presents an example of its application.

2. Development of New Technique for Bearing Diagnosis by AE

2.1 Problems of Conventional AE Diagnosis

AE is a technique in which the elastic energy which is accumulated internally is emitted as an elastic wave when deformation or fracture occurs. Because AE has high sensitivity for crack growth in the parts that make up bearings and for abrasion, wear, etc. of metal surfaces, it is applied to low speed rotating bearings and sliding bearings. At present, however, it has not been established as a diagnostic tool. As reasons for this, the limitations of measurement equipment hardware and ambiguity of diagnostic parameters may be mentioned. The former issue has been solved by the development of more compact and higher performance components in recent years, while the latter can be solved by adopting the AE parameter which was newly developed in this work.

Because acoustic emissions include information on phenomena which are sources of equipment trouble, it is necessary to extract the information in AE quantitatively in the form of parameters in order to use AE in equipment diagnosis. The AE parameters used until now include the amplitude and frequency spectra, duration, difference in arrival time, cumulative energy, hit count rate and others, and it is known that these parameters reflect different types of information.

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However, the correlation between the information obtained from these parameters and various bearing conditions has not been clarified. Qualitatively, it can be conjectured that AE parameters will have larger values as damage progresses, but because these parameters differ due to the diversity of types of bearings and changes in operating conditions, no general relationships have been found, and instantaneous understanding is difficult. Therefore, a new parameter for AE diagnosis was developed, bearing in mind the points of easy instantaneous understanding, automatic determination of threshold values based only on measured data and the ability to evaluate the conditions of bearings.

2.2 Development of New AE Parameter

AE generally has a frequency band of several 10s of kHz to several MHz, but when the time required for one revolution is long, that is, from several seconds to several minutes, as in the case of low speed rotating bearings, the amount of measured data necessary for continuous event monitoring becomes enormous. Therefore, the general practice in this case is conversion to a low frequency by demodulation of the AE waveform envelope.

Figure 1 shows an example of an AE signal waveform of a normal roller bearing, and **Fig. 2** shows the AE signal waveform from a damaged roller bearing in which flaking has occurred at the raceway surface. Here, the vertical broken lines in the figures show the time for one shaft revolution. As shown in Fig. 2, when damage has occurred in a bearing, large amplitude AE occur cyclically accompanying shaft revolution. From this result, it is thought that the peak amplitude can be used as an AE parameter for diagnostic purposes, but control is difficult if the influence of the width of amplitude fluctuations in changes in rotation speed and the noise level are considered. Therefore, in order to develop a more general parameter while continuing to use amplitude information, the differences in the AE waveform that should be observed under normal conditions and the AE waveforms observed under damage conditions were quantified as a parameter.

The amplitude distribution of the AE waveform in Fig. 1 is shown in **Fig. 3**. The *y*-axis shows the logarithm after normalizing the frequency of occurrence by the maximum frequency. From this, it can be understood that the amplitude distribution of the AE waveform of the normal bearing can be approximated by a normal distribution. Similarly, the amplitude distribution of the AE waveform in Fig. 2 is shown in **Fig. 4**. As can be understood from Fig. 4, this amplitude distribution is asymmetrical because it contains AE that originated from damage, and in comparison with Fig. 3, the frequency of occurrence of the high amplitude side has increased. However, the portion around the most frequent amplitude can be approximated by a normal distribution, in the same way as in Fig. 3. Thus, it can be understood that this distribution contains both a high amplitude AE component, and an AE

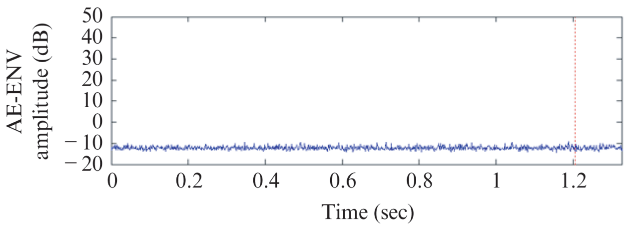

Fig. 1 AE waveform example of bearing (50 rpm)

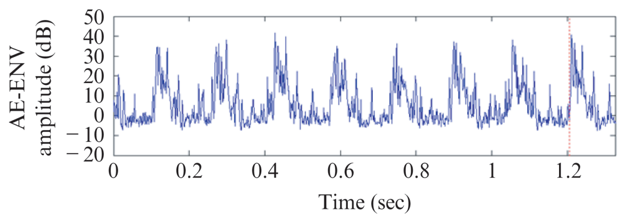

Fig. 2 AE waveform example of damaged bearing (50 rpm)

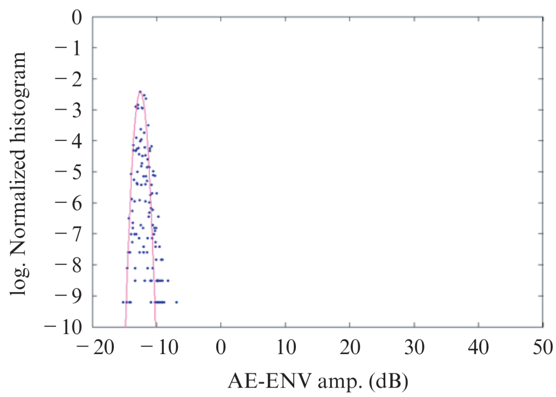

Fig. 3 Amplitude distribution of AE waveform in Fig. 1

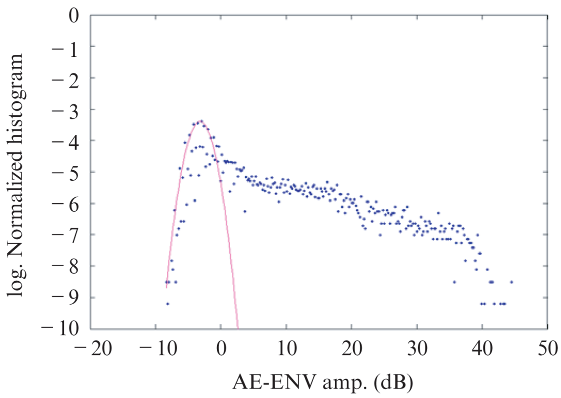

Fig. 4 Amplitude distribution of AE waveform in Fig. 2

component of base noise like that of the normal bearing.

Therefore, irrespective of the damage condition of the bearings, the amplitude distribution on the low amplitude side from the most frequent amplitude band was approximated by a normal distribution, and that, half of the distribution is symmetrically folded to the other side at the most frequent amplitude was regarded as the amplitude distribution of the AE waveform under a normal condition. These distributions are shown by the solid lines in Fig. 3 and Fig. 4. The area that deviates from this equivalent distribution under a normal condition was then extracted and quantified, and this parameter was termed the E_area.

As an advantage of this parameter, it is not necessary to consider the noise levels detected in individual measurements because the distribution under a normal condition is estimated automatically from the data itself measured at the time of measurement. Furthermore, as a distinctive feature, this is an easily-understood parameter, as it is not influenced by the diversity of bearing types or by changes in operating conditions. The possibility of detecting bearing anomalies in actual equipment by using this new parameter E_area was verified, as described in the following chapter.

3. Verification of New Parameter E_area Using Actual Equipment

3.1 Verification Method Using Actual Equipment

In order to verify the parameter E_area described above, AE measurements of low speed roller bearings in actual equipment were carried out using a general-purpose AE measurement device. An outline of the object equipment is presented below.

· By bearing type: Self-aligning roller bearing (automatic greasing type)
· Bearing (inner ring) rotational speed: 30 to 130 rpm

The general-purpose AE measurement device used in verification of E_area was based on the AE insulation deterioration diagnosis instrument AE-210 manufactured by JFE Advantech Co., Ltd., which was used in combination with a datalogger that enabled long-term waveform recording.

Envelope demodulation of the measured waveforms recorded in the logger was conducted by searching for the maximum value, being re-sampled to become a constant number of data points regardless of the rotational speed in digital processing, and E_area was calculated based on the above-mentioned calculation method.

As the result of a total of 363 measurements and an overhaul inspection, the following bearing damage was found:

(1) Remarkable damage of the inner and outer ring or rolling elements: 5 points
(2) Light spot damage of the raceway surface: 2 points

In addition, a bearing in which severe wear, just before damage, had occurred in the raceway surface loading region was also found.

3.2 Effectiveness Evaluation of E_area Using Actual Machine

The results of arrangement of the values of E_area obtained from the measured AE waveforms in descending order is shown in **Fig. 5**, and an enlarged figure of the high E_area part is shown in **Fig. 6**. In both figures, the results are divided into three types of bearing conditions, that is, bearings in use without replacement, bearings that displayed wear or were found to be normal, and bearings in which damage was confirmed, which were replaced immediately after the AE measurements. It may also be noted that Fig. 5 and Fig. 6 contain the results of multiple measurements of the same bearing at different points in time.

As is clear from these figures, E_area showed changes from near zero to around a maximum of 5 000. At the 13 points where the E_area at points

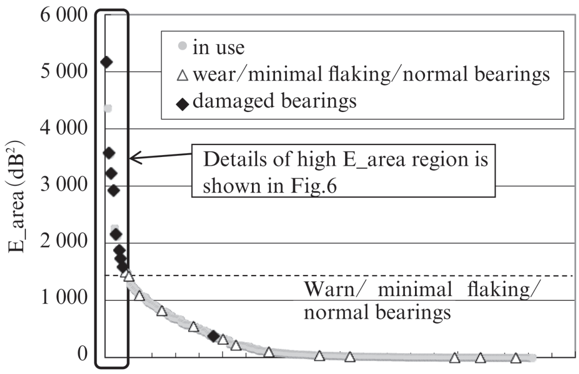

Fig. 5 Measurement result of E_area

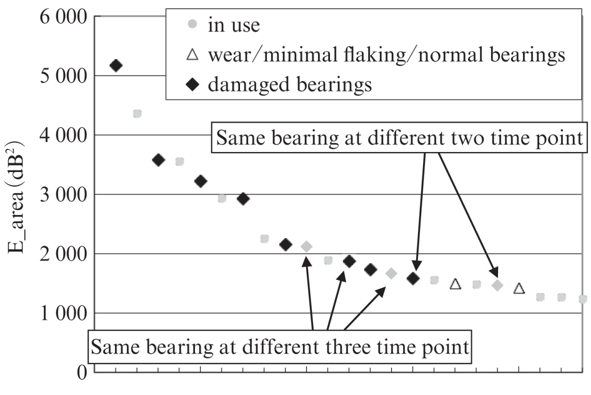

Fig. 6 Measurement result of high E_area

where bearings were replaced was lower than 1 500, wear could be seen, but there were no examples of flaking damage, with the exception of one point where minimal flaking was observed. At points with low E_area values of several 10s, no abnormality was found in the bearing.

On the other hand, at points where E_area was higher than 1 800, remarkable bearing damage had occurred in all cases. Based on this, even at the latest, the occurrence of AE due to contact between a damaged surface and rolling element, progress of flaking, etc., can be confirmed by the value of E_area.

Figure 6 shows the results of similar multiple measurements of the same bearing. Here, reproducibility could be confirmed, as no large changes were seen in the value of E_area itself. In addition, gradual deterioration of the bearing condition due to wear of the raceway surface, etc. could also be confirmed from the rise in the value of E_area.

3.3 Examples of Comparison of AE Measurement Results and Bearing Condition in Actual Machine Before/After Bearing Replacement

The following presents examples comparing the AE measurement results and the bearing condition before and after bearing replacement.

Figure 7 shows the measurement data for the AE waveform, amplitude distribution and FFT results for an E_area value of 2 931 when the shaft rotational speed at the time of the measurement was 50 rpm. Although the E_area value obtained before bearing replacement was extremely high, at about 3 000, E_area was reduced to 0 after replacement. **Photo 1** shows the result of observation of the removed bearing. Remarkable flaking could be seen on the outer ring raceway surface, and flaking could also be seen in the entire inner ring raceway surface and rolling element raceway surface.

Photo 1 Bearing damage example 1

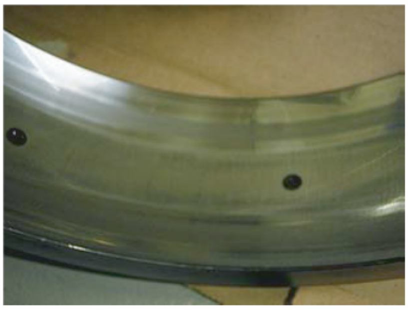

Photo 2 Bearing damage example 2 (65.7 rpm/E_area = 1 503)

Photo 2 is a photograph of a bearing with an E_area value of 1 503 before replacement, in which the shaft rotational speed at the time of the measurement was 65.7 rpm. After replacement, E_area was 8. As the result of a check of the removed bearing, remarkable wear marks could be seen on the outer ring raceway surface, inner ring raceway surface and rolling element raceway surface, but flaking or other damage was not observed. Thus, the condition of damage was light in comparison with that in Fig. 7, and good agreement with the tendency of the E_area value was found.

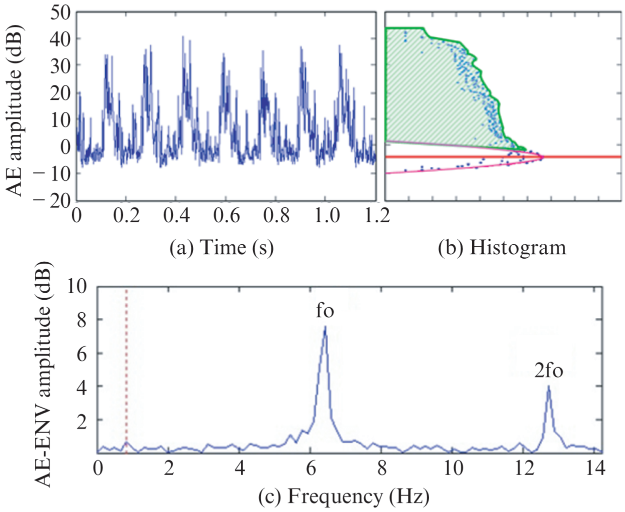

Fig. 7 Bearing damage example 1 Measurement data
(a) AE waveform (b) Amplitude distribution (c) FFT

4. Example of Application

Initially, JFE Steel used grease analysis in diagnosis of low speed rotating bearings at steel sheet production lines. **Figure 8** shows the transition of equipment down time due to bearing trouble and the E_area. It can be understood that equipment down time due to bearing trouble occurred periodically. Trouble gradually decreased after an AE diagnostic system was introduced in 2007, showing the effect of introduction of the AE diagnostic system in preventing trouble of low speed rotating bearings. Subsequently, JFE Advantech marketed a slow rotating bearing diagnosis instrument (MK-560), in which parameter sensitivity adjustment for E_area was added to the diagnostic instrument described in this paper, and that device was also intro-

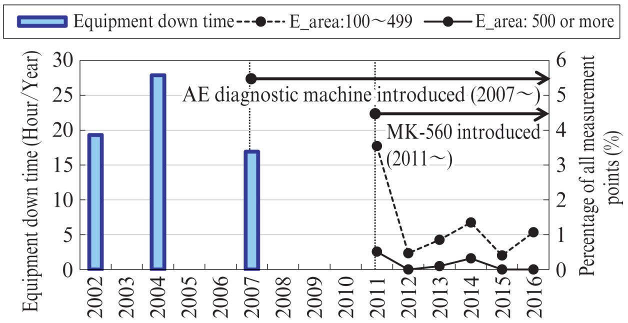

Fig. 8 Equipment down time and E_area transition

duced by JFE Steel in 2011. Judgment standards based on the E_area value were established as Danger (500 or more), Caution (100 to 499) and Normal (less than 100), and action is taken corresponding to these respective judgment levels.

As a result of the introduction of these instruments, equipment down time gradually decreased, and the percentage of abnormalities has also improved year by year. From the introduction of the MK-560 up to the present, no trouble originating from bearings has occurred, and zero equipment down time is currently continuing. In the future, together with continuing diagnosis, we also plan to expand the target equipment, including application of this technology to the drive systems of belt conveyors in the raw material transportation system.

5. Conclusions

A new AE parameter for condition monitoring of low speed rotating bearings was proposed based on AE measurement, which has high sensitivity to microscopic damage and sliding/wear and fast response, and its effectiveness was verified with actual equipment. As a result, the following conclusions were obtained.

(1) From the results of measurements of the new parameter E_area and an investigation of parts removed from an actual machine, it was found that abnormal conditions of low speed rotating bearings can be detected by E_area.

(2) Trouble could be prevented in advance by periodically using a diagnostic instrument employing E_area.

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