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Fundamental study on early detection of seizure in journal bearing by using acoustic emission technique

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ABSTRACT

In monitoring and maintaining machineries, it is extremely important to identify and quantify friction and wear phenomena, for example the progression of wear and the state of friction between sliding surfaces. Because friction and wear processes involve deformation and fracture of materials, they generate elastic stress waves that can be detected and measured as acoustic emission (AE) signals. By measuring these AE signals, it is then possible to monitor tribological processes between sliding materials *in situ*. To establish parameters for condition-based maintenance based on AE technique, the relationship between changes in the wear state and changes in AE signals was investigated using a high-speed grease-lubricated slide bearing. Monitoring high-frequency AE signals of more than 1 MHz that originates from adhesion is an effective way to detect early seizure in machineries.

1. Introduction

Timely and appropriate maintenance based on tribology can improve the lifetime of machinery and can contribute significantly in promoting and developing "green tribology" [1]. In terms of maintenance, it is extremely important to be able to recognize the state of wear of a mechanical system and, in particular, to detect the onset of seizure at an early stage, as seizure can cause critical damage to machinery. In this respect, condition-based maintenance is preferable to time-based maintenance, because the time of onset of seizure cannot readily be predicted. In this communication, we use the term 'seizure' (defined as "the stopping of relative motion as the result of interfacial friction" [2]) to identify the state in which severe adhesion between surfaces in frictional contact occurs as a final outcome, although other similar terms have been used for this phenomenon, such as scuffing, scoring, or galling [3,4]. Tribological phenomena are usually characterized in terms of the coefficients of friction, specific wear rates, observations and analyses of worn surfaces, or analyses of lubricating oil. However, equipment must be stopped to permit amounts of wear to be measured and worn surfaces to be examined to assess their tribological state. Also, large amounts of time and labor are required to disassemble the machine, remove relevant parts, and check them. Furthermore, because worn surfaces are examined when the machine is not motion, it is difficult to deduce what is actually happening, which then makes the identification of tribological phenomena merely based on educated guesswork.

Acoustic emission (AE) technique is a nondestructive inspection technique that permits the evaluation of the states of materials by measuring elastic stress waves generated by deformation and fracture. AE technique has a higher sensitivity to deformation and fracture phenomena than other techniques, and permits the evaluation of the state of materials in real time. By measuring and analyzing AE signals produced by tribological processes, the state of sliding surfaces on a machine can be identified and evaluated *in situ*.

A great deal of effort has been made to establish relationships between AE signals and wear phenomena [5–8]. We have previously examined relationships between tribological phenomena and AE signals by applying various approaches [9–13]. A new approach using AE technique for bearing health monitoring and fault diagnosis has been reported recently [14,15]. However, studies on the frequency components of AE signals have generally been superficial. Micro-sliding friction experiments and *in situ* observation by scanning electron microscopy (SEM) have recently shown that features of the AE frequency spectrum are dependent on the mode of wear (adhesive wear, abrasive wear, etc.) [16,17]. These findings are particularly useful in the identification of the tribological states of slide bearings.

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In this study, we performed and examined friction and wear in a high-speed slide bearing by using an experimental setup that resembles a real machine; the experiment was designed to provide fundamental results to permit assessment of the lifetime of bearing until seizure. Changes in the amplitude [root-mean-square (RMS) value] and frequency components of AE signals detected during the rupture of the lubricating film, the progress of wear, and phenomena preceding seizure are described.

2. Materials and methods

2.1. Friction and wear experiments

We used a journal bearing-type friction-and-wear tester in this study. Fig. 1 shows an image of the actual setup for the experiment. Fig. 2 is a schematic showing the experimental setup and the AE measurement system. A normal load carrying a dead weight was applied to the side of the bush specimen, as shown in Figs. 1 and 2. A motor rotated the shaft specimen intermittently every two seconds. Friction and wear experiments were stopped by means of the electromagnetic clutch when the system was overloaded, which corresponds to seizure.

The shaft specimen consisted of carburized chromium molybdenum steel and the bush specimen consisted of phosphor bronze. The experiments were performed with a normal load W of 31.4 N and an intermittent rotational speed N of 1000–6000 rpm with intermittent rotation and grease lubrication. The clearance between the shaft and the bush specimen was 10.90–18.20 μm. Experiments were also performed with water lubrication and under unlubricated dry conditions to compare wear states under different conditions. Materials and sizes of the specimens and the properties of the grease used in this study are listed in Tables 1 and 2, respectively.

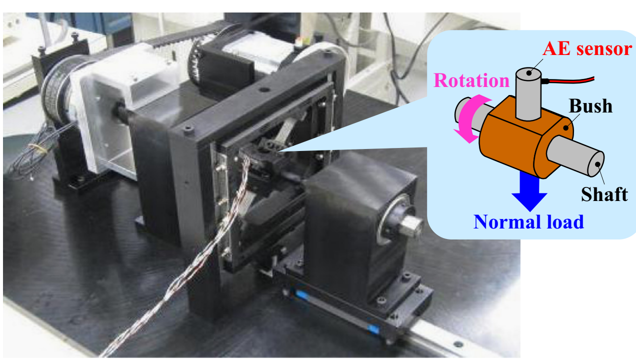

Fig. 1. Appearance of the experimental setup.

2.2. AE signal measurements

A wideband-type AE sensor (frequency band 0.3–2 MHz) was mounted on the bush specimen by a means of a jig, as shown in Fig. 1. The output signals from the AE sensor were amplified to 40 dB. The AE signals were then passed through a band-pass filter consisting of 0.2 MHz high-pass filter and 2 MHz low-pass filter to eliminate noise signals. The thresholds for detection of the AE signals varied from 45 dB (N=1000 rpm) to 50 dB (N=6000 rpm). The sampling rate for acquisition of AE signal waveforms was 5 MSPS. In this study, the AE RMS value and the AE signal waveforms were measured and evaluated. And, the AE signal waveforms were subjected to fast-Fourier-transform analysis after the experiments.

3. Results and discussion

3.1. Changes in the wear process and AE signals preceding seizure

Fig. 3 shows the changes in the AE signal (AE RMS value; graph) and micrographs of the worn surface of the shaft specimen (Fig. 3 (a)–(d)) in the interval up to and including seizure under grease-lubricated condition. Micrographs of the worn surface of the shaft

Table 1
Materials and sizes of specimens.

Bush material	C5191B-H (phosphor bronze)
Bush bore diameter	10 mm (0 to +100 μm)
Shaft material	SCM415 (carburized chromium molybdenum steel)
Shaft outside diameter	10 mm (−10 to 0 μm)
Contact length	20 mm
Surface roughness	R_{max}=4.7 μm
Clearance	~15 μm

Table 2
Properties of the grease.

NLGI consistency	No. 1
Mixed consistency (at 25 °C)	325
Density (at 20 °C)	0.84 g/cm^3
Operating temperature limit	−55 to +130 °C
Dropping point	205 °C
Corrosion test (24 h at 100 °C)	no corrosion
Evaporation (22 h at 99 °C)	0.1%
Oil separation (24 h at 100 °C)	3.5%

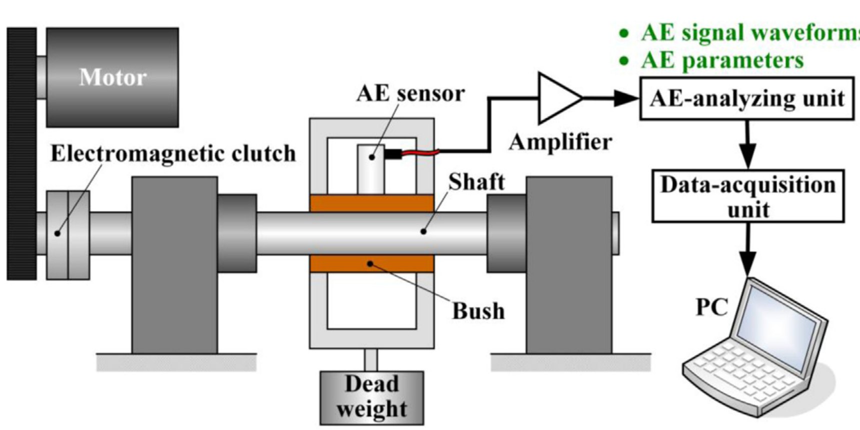

Fig. 2. Schematic representation of the experimental setup and the AE measuring system.