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Highly Sensitive Failure Detection of Mechanical Seals Using High-Frequency Acoustic Emission Waves over 1 MHz

1 MHz 以上の高周波 AE 波を用いたメカニカルシールの高感度故障検知

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1. Introduction

The main factor in failure of rotating equipment in power plants or chemical plants is degradation of the mechanical seal used for shaft sealing. To evaluate damage of sliding surface of the mechanical seal due to friction and wear, the possibility of failure diagnosis by monitoring acoustic emission (AE) signals has been reported [1]. It has also been reported that when a seal is damaged, the frequency range of AE signals is 0.1–0.7 MHz [2].

The purpose of this research is to investigate the frequency range of AE signals when mechanical seals are damaged. The change in the AE signal as particles intrude into the sliding portion of the mechanical seal, which is the main cause of seal breakage, was measured. As a result, the frequency range of the AE signal expanded to include a higher frequency over 1 MHz when an abnormality was caused by particle intrusion. The abnormality could be detected with high sensitivity before seal breakage by monitoring the high-frequency range of AE waves.

2. Experimental Methods

The experimental setup for sliding test of mechanical seal and AE measurement is shown schematically in **Fig. 1**. The test conditions and AE measurement conditions are listed in **Tables I and II**, respectively. The tank is filled with pure water, a silicon-carbide (SiC) rotating ring is driven by a motor, and a vertical load is applied from the fixed shaft of the testing machine through a carbon fixed ring. As listed in Table II, two types of AE sensors were used: two sensors with frequency range of 1 MHz (0.1–1.0 MHz) and one sensor with frequency range of 2 MHz (0.3–2.2 MHz) were used. To simulate particle intrusion into the sliding portion and breaking the mechanical seal, a suspension of iron-hydroxide and iron-oxide particles was put into the water. Change of the AE signal before and after the particle contamination was measured.

3. Results and Discussion

The spike waveform generated after contamination of particle suspensions is shown in **Fig. 2**. Comparing the spike rise times reveals that the spike wave of Ch. C is delayed by 70 μs from that of Ch. A. This time lag of the AE signal corresponds to the AE-signal propagation distance of 107 mm in water,

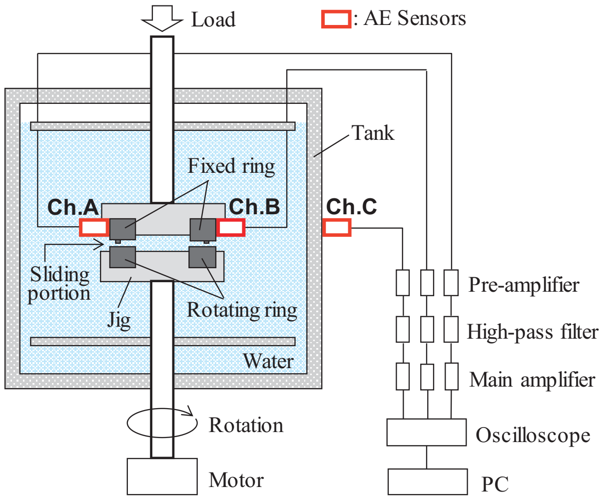

Fig. 1 Experimental setup for sliding test of mechanical seal and AE measurement.

Table I Test conditions.

Items		Conditions
Materials of mechanical seals	Fixed ring	Carbon
	Rotating ring	SiC
Sliding section of mechanical seals	Outer diameter	49 mm
	Inner diameter	45 mm
	Contact width	2 mm
Sliding conditions	Rotation speed	3,013 rpm
	Load	4,900 N
Particle-contamination conditions	Particle materials	Iron hydroxide and Iron oxide
	Particle size	~1 μm
	Concentration	500 ppm

Table II AE measurement conditions.

Items		Conditions		
		Ch. A	Ch. B	Ch. C
AE sensor	Type	Broad-band type		
	Frequency range	1 MHz (0.1-1.0 MHz)	2 MHz (0.3-2.2 MHz)	1 MHz (0.1-1.0 MHz)
	Location	Fixed ring	Fixed ring	Tank
Amplification factor		40 dB	40 dB	60 dB
High-pass filter		100 kHz		
Sampling rate		5.0 MS/s		

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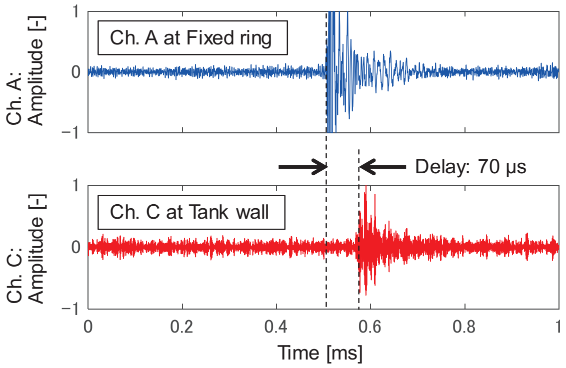
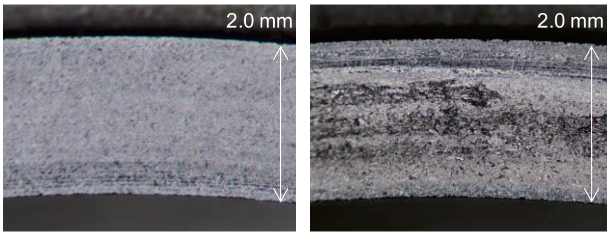


Fig. 2 Spike waveforms generated after injection of particle suspensions.



(a) Normal (b) Damaged

Fig. 3 Comparison of normal sliding surface and damaged sliding surface of the carbon fixed ring.

which is approximately equal to the shortest distance from the sliding surface to the tank wall (100 mm). This result therefore confirms that AE waves propagated from the sliding surface through the water were detected by the sensor on the tank outer wall.

It was observed that water leakage from the sliding portion increased 1.2 minutes after the particle contamination. This result means that the sealing performance had deteriorated. According to that result, the rotating device stopped abnormally 2.2 minutes after the particle contamination. As shown in **Fig. 3**, the damaged sliding surface of the carbon ring has deep scratches and streaks due to particle biting.

Time-series changes in the RMS and frequency domain of the AE signals measured with the 2-MHz sensor (Ch. B) before and after particle contamination are shown in **Fig. 4**. In Fig. 4(a), about one minute after particle contamination, the RMS amplitude of the AE signal increased, and the AE frequency range extended to higher frequency. In Fig. 4(b), the frequency components above 0.3 MHz increased significantly. The change in measured AE signal corresponds to the increase in leaked water caused by the intrusion of particles into the sliding portion.

Frequency spectra before particle contamination (t = 0.6 min) and after the damage occurred (t = 2.6 min) shown in Fig. 4(b) are replotted in **Fig. 5**. It is clear that the two AE signals are distributed over a wide frequency band of 0.1−2.5 MHz, which is a higher frequency range than previously reported [2]. AE signal intensity over the entire frequency range increased after the damage; however, the magnitude of the increase depends on the frequency range. That is, it was around 5 dB at 0.1−0.3 MHz, 10−15 dB at 0.3−1.0 MHz, and 15 dB at 1.0−2.5 MHz. This result suggests that the damage of the sliding surface could be detected with higher sensitivity by monitoring the AE signal increase in the higher frequency range, especially above 1 MHz.

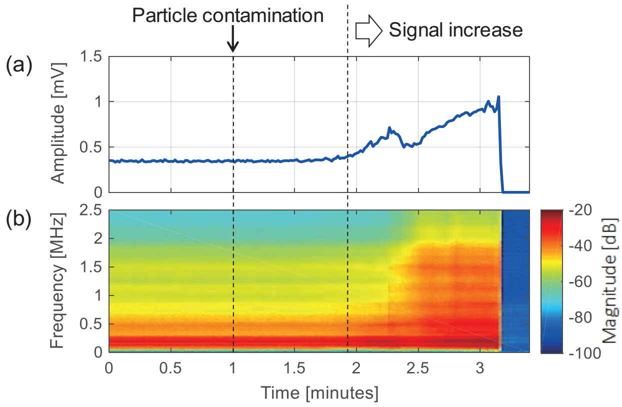


Fig. 4 AE-signal changes before and after particle contamination: (a)RMS and (b)spectrogram of 2-MHz sensor (Ch. B).

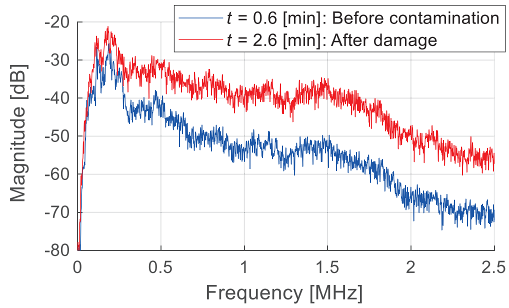


Fig. 5 FFT spectra of Ch. B before and after damage.

4. Summary

When the surface of a mechanical seal is damaged by particle intrusion into the sliding portion, the frequency range of the AE signal was expanded to higher frequency, and the frequency components in the range of 0.3−2.5 MHz increased remarkably. This result suggests that the abnormalities on the sliding surface could be detected with higher sensitivity by monitoring changes in the frequency range over 1 MHz, in which the AE signal increases significantly after damage.

References

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[2] S. Nishimoto and N. Shinke: Technical report of Nippon Physical Acoustics, Ltd.