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Fundamental Research on Dynamic Characteristics of Sliding Mechanical Seal during Axial Vibration

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Mechanical seals are attached to the rotor of high-speed, high-pressure turbomachinery to prevent fluid leakage. The mechanical seal will be exposed to axial vibration if the rotor has a mechanism that moves in the axial direction. In order to evaluate the stability of the entire rotor system, it is necessary to understand the dynamic characteristics of the mechanical seal. In this study, the axial dynamic characteristics of the mechanical seal were experimentally investigated by axial sweep excitation test. As a result, when the excitation frequency approaches the eigenvalue of the system, the stiffness and damping coefficients change negative, respectively.

Keywords: mechanical seal, axial vibration, dynamic characteristics, active magnetic bearing

1. Introduction

It is important to investigate the dynamic characteristics of the component parts in order to fully evaluate the stability of turbomachinery, but there have been few cases of investigating the dynamic characteristics of the mechanical seals. Recently, the author measured "rotordynamic" characteristics of mechanical seal, and it was revealed that the mechanical seal generates stabilizing force against rotor whirl [1]. In this study, the axial dynamic characteristics of the mechanical seal were experimentally investigated.

2. Experiment

Axial dynamic characteristics are calculated using the phase difference between excitation displacement and response force. Axial excitation displacement is given to the water lubricated mechanical seal via a rotor by a thrust active magnetic bearing. The response force is measured by using a 6-axis force torque sensor.

2.1. Test conditions
The test conditions are shown in Table 1.

Table 1: Test conditions

Rotational speed [rpm]	1,000
Axial excitation frequency [Hz]	5 to 60
Axial excitation amplitude [µm]	25
Shaft diameter [mm]	20

2.2. Axial dynamic characteristics
Stiffness coefficient K and damping coefficient C are calculated by the following Eq.(1)

$$K = -F_{ax} \cos\theta / X_{ax} + M\omega^2$$
$$C = -F_{ax} \sin\theta / (X_{ax}\omega) \quad (1)$$

where F_{ax} is the response force, X_{ax} is the excitation displacement given to the mechanical seal, θ is the phase difference. M is the mass of the mechanical seal, and ω is rotational speed.

3. Results and Discussion

Figure 1 shows that the mechanical seal is unstable above about 55 Hz, which is the eigenvalue of the rotor. As can be seen from Eq.(1), when θ is between $-\pi$ radians and -2π radians, C becomes negative. It is confirmed that the damping coefficient is negative above about 55 Hz as shown in Fig. 2. On the other hand, it was found that the stiffness coefficient gradually decreased from around 40 Hz, and reached the zero at about 50 Hz. This means that θ is equal to $-\pi/2$ radians. Despite such unstable situation, there was almost no change in average and fluctuation sliding torque, and no leakage from sliding surfaces was confirmed. One of the reasons for these phenomena is that these are related to the lubrication regime between the sealing surfaces of the mechanical seal. There is fluid film between the sliding surfaces in this experiment. It is considered that this fluid film has a function of absorbing the vibration that destabilizes the mechanical seal.

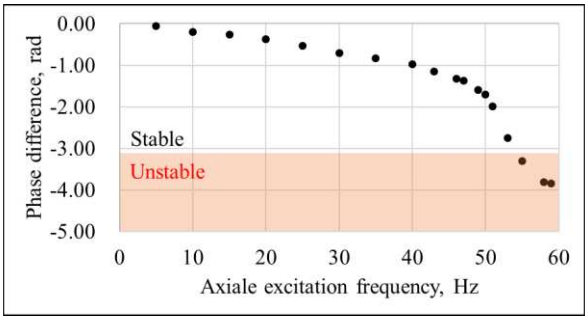

Figure 1: Relationship between phase difference and axial excitation frequency.

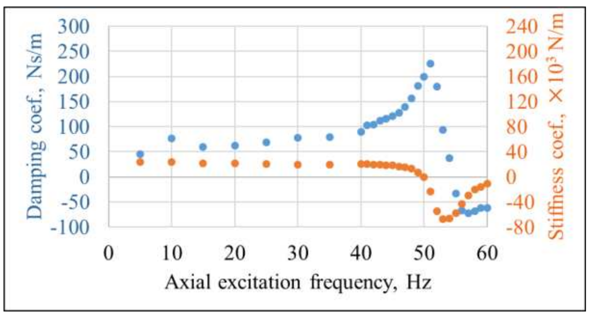

Figure 2: Relationship between damping/stiffness coefficient and axial excitation frequency.

4. References

[1] Inoue, H., et al., "The Characteristics of Rotordynamic Forces Generated by Mechanical Seals", J. Phys.: Conf. Ser., 1909, 012077, 2021.