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Elimination of Oil Whip Instability with Active Magnetic Bearing

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Introduction

Recently, energy demands have been glowing in many developing countries. In order to satisfy those demands, generators which generate electricity, pumps and compressors which are used for mining gas and oil have required higher rotational speed. Rotors of those rotational machineries are supported by oil film bearings owing to their high load capacity and large damping. However, at high rotational speed oil film bearings induce self-excitation such as oil whip. The self-excitation causes enormous rotor vibration and breaks rotor systems. Since the self-excitation limits the operational speed and condition, a method for eliminating the self-excitation is necessary. Although active magnetic bearings (AMBs) have small load capacity, their controllability is superior to that of oil film bearings. Thus, a rotor system supported by both oil film bearings and AMBs having large load capacity and high controllability has a potential to enhance the operational speed. There have been some previous researches on controlling the self-excitation by utilizing AMBs. However, most of them remain theoretical studies [1, 2] or experimental verification using basic control methods such as PD control [3]. The purpose of this study is to eliminate the self-excitation of the rotor-oil film bearing system by utilizing an AMB. Focusing on the cross-coupled stiffness of the oil film bearing indicated in the Bently/Muszynska model, a self-excitation suppression controller of the AMB is designed and implemented.

Test Rig

A rotor system supported by an oil film bearing and a ball bearing and controlled by a radial magnetic bearing is constructed. The configuration and dimensional specifications are shown in Fig. 1 and Table 1, respectively. The eddy current type displacement sensors (PU-05, Applied Electronics Corp.) were arranged just besides the radial magnetic bearing.

Fluid Force Model of Oil Film Bearing

According to the Bently/Muszynska model [4], lubricant oil is supposed to flow at the averaged angular velocity $\lambda\Omega$ as shown in Fig. 2. Note that λ and Ω are the fluid circumferential averaged velocity ratio and the rotational speed of the rotor, respectively. The bearing force Q_{brg} of the oil film bearing is expressed as Eq. (1).

$$Q_{brg} = -c_d(\dot{z}_b - j\lambda\Omega z_b) - k_d z_b \tag{1}$$

where $z_b = x_b + jy_b$ is the displacement of the rotor at the oil film bearing, and c_d and k_d are the damping and stiffness coefficients, respectively. The fluid force generated by the oil flow acts as an unstable force in the same direction as the whirling motion. If it exceeds the damping force, the self-excitation is induced.

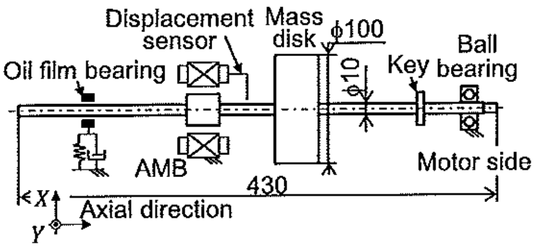

Fig. 1 Configuration of the test rig with AMB

Table 1 Dimensional specification of the test rig

Rotor	Shaft Total mass	L430 × ϕ10 [mm] 2.88 [kg]
Oil film bearing	Inner diameter Length Clearance	10 [mm] ϕ10 [mm] 50 [μm]
AMB	Type Inner diameter Length Clearance	Hetero, 8 poles ϕ29.5 [mm] 30 [mm] 500 [μm]

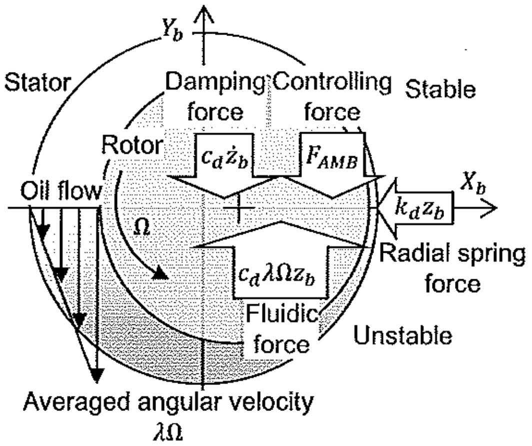

Fig. 2 Forces working of oil film bearing and AMB on the rotor

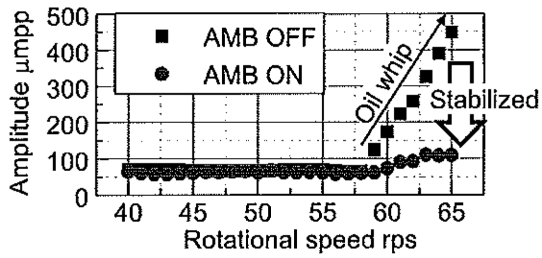

Fig. 3 Vibrational amplitude with/without AMB assist

Controller Design

In order to cancel the fluid force $jC_d\lambda\Omega z_b$ and stabilize the rotor system, AMB force in the same direction as the damping force is generated as shown in Fig. 2. By considering the Bently/Muszynska model, our method does not require any differential controller, which is sensitive to sensor noise. Without bias current, AMB force F_{AMB} is the nonlinear force as described in Eq. (2).

$$F_{AMB} = k_0 \frac{|i_z|^2}{g^2} \tag{2}$$

where k_0 is the coefficient of the current-displacement-force-relationship, i_z is the sum of the coil current $i_x + ji_y$ in X and Y direction, and g is the gap between the electromagnet and the rotor. In order to generate F_{AMB} in the same direction as the damping force, the coil current is controlled as Eq. (3) [5].

$$i_z = i_x + ji_y = k_p(y_s - jx_s) = -jk_p z_s \tag{3}$$

where k_p is the proportional gain, and $z_s = x_s + jy_s$ is the measured displacement. Therefore, by substituting Eq. (3) into Eq. (2), F_{AMB} can be expressed as follows;

$$F_{AMB} = k_0 \frac{k_p^2}{g^2} |z_s|^2 \approx k'|z_s|^2 \tag{4}$$

where k' is the constant coefficient when g is constant.

Experimental Results

The vibrational amplitudes of the rotor at rotational speeds from 40 to 65 rps are shown in Fig. 3. The square dots show the amplitude without the AMB assist. Oil whip occurred at 58 rps and the amplitudes significantly increased. On the other hand, the circle dots show those with the AMB assist. The vibrational amplitude at a higher rotational speed reduced.

Summary

In order to cancel the unstable fluid force, the controller of the AMB assist using the simple proportional feedback was designed and installed. The oil whip was effectively suppressed in the experimental test. Future work is to compare the effect of the proposed controlling method with that of the previous ones.

References

1. M. E. F. Kasarda, R. G. Kirk, H. Mendoza, *Proc. of the GT,* **4**, pp. 801-806, Nevada (2005)
2. A. El-Shafei, A. S. Dimitri, *J. Eng. Gas Turbines Power*, **132**, **1**, pp. 012502-1-9 (2010)
3. M. N. Sahinkaya, C. R. Burrows, *ASME J. Dyn. Syst., Meas., Control,* **107**, **2**, pp. 139-144 (1985)
4. A. Muszynska, *J. Sound Vibration*, **110**, pp. 443-462 (1986)
5. O. Matsushita, et al., *Proc. of the 3rd Intl. Conf. Eng. Aero-Hydroelasticity*, pp. 286-291, Prague (1999)