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Vibration Suppression of a Journal Bearing Using Temperature Control: A Preliminary Experiment

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Abstract

A prototype of a circular hydrodynamic journal bearing to control temperature distributions of the bearing bush and the oil film was manufactured, with a preliminary experiment subsequently conducted to evaluate the extent of vibration suppression within the bearing. The specifications of the bearing were as follows: a bearing diameter of 50 mm, a bearing length of 50 mm, and a radial clearance of 0.025 mm. The bearing bush was divided into six parts, and five Peltier devices were installed for cooling and heating each part. The parameters of the experiment were as follows: a load up to 100 N, a rotational speed up to 35 rps, and a lubricating oil of ISO VG22. When the lower half of the bearing bush was cooled and the upper half was heated, the vibration was suppressed under a specific operating condition.

Keywords: Tribology, Journal bearing, Self-excitation vibration, Temperature, Viscosity

1 INTRODUCTION

Hydrodynamic journal bearings[(1)] are widely used to support rotating shafts in various types of machinery. Under operating conditions of high load and low speed, eccentricity ratios increase and minimum clearances reach the roughness order, usually resulting in solid contact, wear, and seizure in the bearings. In addition, under operating conditions of high speed and low load, self-excited oscillations can occur that cause vibration, instability, and breakdown in the bearings.

The hydrodynamic pressures and load-carrying capacities depend on the contribution of the wedge effect and oil viscosity. If the lubricating film can be cooled and/or heated so as to increase and/or decrease the viscosity and fluid pressure, the pressure distribution can be modified and the vibration can be controlled.

Oil viscosity is a strong function of temperature, and a change in viscosity significantly influences bearing characteristics. Thus, the associated theoretical approach, primarily including the thermal effect, is established as the "thermohydrodynamic lubrication (THL) theory." On the basis of this theory, many results have been published in literatures[(2)].

Meanwhile, the viscosity of magnetorheological (MR) and electrorheological (ER) fluids can be changed by controlling magnetic and electric fields[(3)]. However, these liquids are unusual lubricants that possess unclarified characteristics and are expensive; in

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addition, the disposal of these liquids poses serious environmental risks.

We have thus proposed to use a thermoelectric module based on the Peltier effect, which refers to the presence of cooling or heating at an electrified junction of two different conductors, to control the temperature of the module's components. To improve the static tribological characteristics of journal bearings, the objective is to determine the optimum viscosity distribution through temperature control without the need for specially processing and texturing the sliding surfaces of the bearings.

To further enhance the dynamic characteristics of the existing journal bearings, a hydrodynamic journal bearing based on control of temperature distribution in an oil film was developed(4). In this experiment, a prototype of a journal bearing that can suppress vibration was manufactured, and a preliminary experimental trial was subsequently performed.

2 EXPERIMENT

2.1 Tester and methods

Figures 1 and 2 show the schematics of the plain circular hydrodynamic journal bearing tester. The specifications were as follows: a bearing diameter (D) of 50 mm, a bearing length (L) of 50 mm, and a radial clearance (C) of 0.025 mm.

The bearing bush was divided circumferentially into six blocks and assembled with them, in which thin polyoxymethylene plates were inserted in the mating faces of the blocks for heat insulation. The five air-cooling Peltier devices were installed on the blocks outside (except for the top block) for independently cooling and heating the bearing bush. The Peltier device mainly consisted of the Peltier module plate, the heat sink, and the DC electric motor fan. The module plate size was 20 mm × 250 mm, the maximum input voltage was 7 V, and the maximum endothermic energy was 10 W. The top left part was designated as T1, followed by T2, T3, T4, and T5 (counterclockwise), as shown in Fig. 2. The platinum resistance thermometers (PT100s) were also mounted on the plate of each Peltier device so that temperatures could be constantly monitored. Two non-contact type laser displacement sensors with a measurement distance of ±10 mm and a repeatability of 0.025 μm were set to measure the horizontal and vertical vibrations of the bearing.

The test oil was a naphthene-based crude oil (ISO VG22) whose temperature characteristics were a kinematic viscosity of 22.1 mm^2/s at 40 °C and 3.65 mm^2/s at 100 °C. The oil was supplied from a reservoir to the port on the top left portion of the bush.

The bearing load was acted upon by pulling the bearing bush by the screw of M20–P1.5 via the load-cell sensor with a rated capacity of 1 kN and a natural frequency of 1.75 kHz. The journal was supported with two rolling element bearings at both ends and was rotated by an electric servomotor with a rated output capacity of 400 W and a rated rotational speed of 50 s^{-1}.

Thus, the experimental trial was configured and implemented via the following procedure: setting the rotating speed (N) and load (W), then warming up the bearing to a stable oil temperature, and then finally starting the bearing vibration. Next, the Peltier devices were switched on to cool down and/or heat up the bearing bush and lubricating oil to generate the temperature distributions.

The test bearing was operated under the conditions of the load (W) up to 100 N and the rotational speed (N) from 21.7 to 35 s^{-1}. The bearing was vibrated under the limited conditions of lower load and higher speed. In this experiment, the conditions of the load W = 20 N, the speed N = 25 and 30 s^{-1}, and the oil temperature at about 45 °C, were representatively selected. At this stage, only one case of cooling with the T2, T3, and T4 devices, and heating with the T1 and T2 devices, under a maximum input voltage of 4 V was examined.

2.2 Results and discussion

Figures 3 and 4 show the temperature distributions and vibration waves before and after switching on the Peltier devices, respectively (The angle φ = 60° corresponded to the location of the device T1). The experimental conditions were specified as the load W = 20 N and the speed N = 30 s^{-1}. Before the switch-on of the Peltier devices, the temperature distribution was almost uniform (Fig. 3) and the amplitude of vibration was large (Fig. 4a).

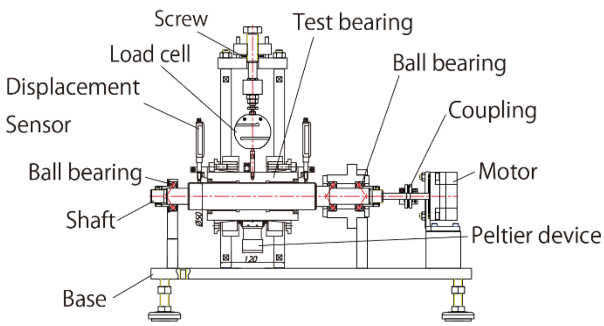


Fig. 1 Test rig of the hydrodynamic journal bearing

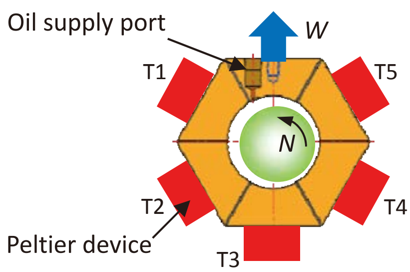


Fig. 2 Schematic of the bearing bush

After the switch-on, the temperature distribution varied as the temperature at the bearing bottom became low and temperature at the bearing top became high. Simultaneously, the amplitude became markedly small (Fig. 4b).

Figure 5 shows the Fourier spectrum of data based on Fig. 4. Before switch-on, the peak frequency of vibration was detected at 15 Hz, *i.e.*, 15 s^{-1} (Fig. 5a), which corresponded to the half rotational speed of the journal (N = 30 s^{-1}). After switch-on, subsequently, the peak virtually vanished (Fig. 5b). One can thus observe that the vibration was suppressed by temperature control.

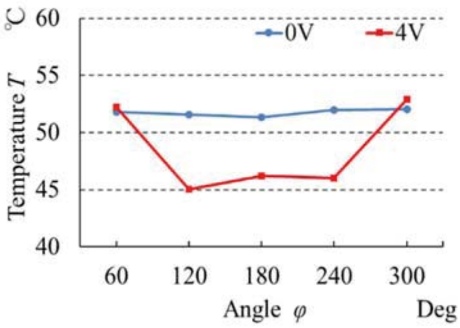
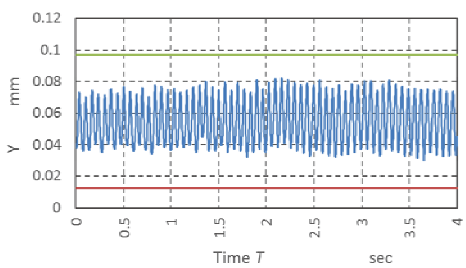
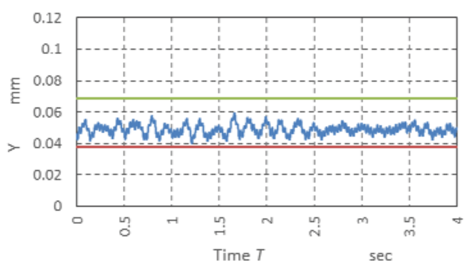


Fig. 3 Temperature distribution before and after temperature controlling (N = 30 s^{-1}; W = 20 N; Cooling of T2, T3, and T4; Heating of T1 and T5)



(a: before temperature controlling)



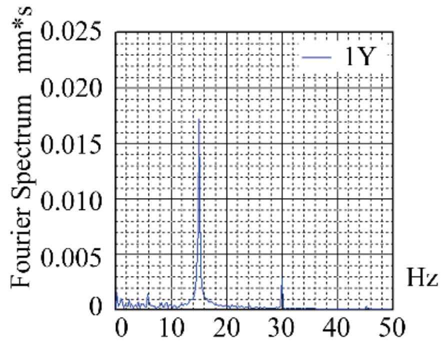
(b: after temperature controlling)

Fig. 4 Comparison of vibration waves (N = 30 s^{-1}; W = 20 N; Cooling of T2, T3, and T4; Heating of T1 and T5)

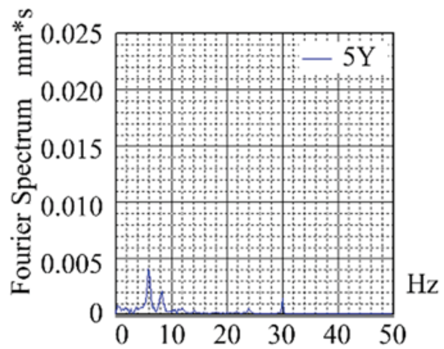
Figure 6 shows the vibration waves under the conditions of the load W = 20 N and the speed N = 25 s^{-1}; the speed was rather lower than that of Fig. 4. The vibration suppression (Fig.6 a → b) was similar to that as shown in Fig. 4 (a → b).

3 CONCLUSIONS

A tester for suppressing the vibration of a prototype journal bearing was developed. When the bearing bush was cooled and heated locally, the reduction of the vibration was verified experimentally. The condition was limited, and thus further verification experiments, including discussion of thermal and elastic deformation, will be conducted.

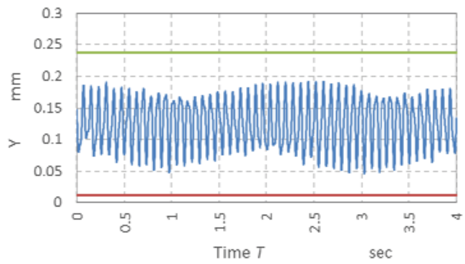


(a: before temperature controlling)

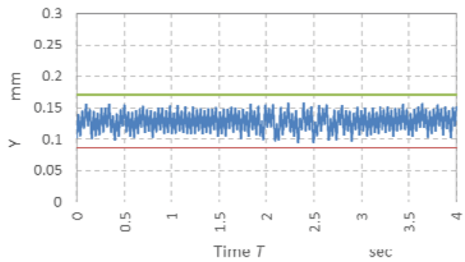


(b: after temperature controlling)

Fig. 5 FFT analysis of amplitude of test bearing (N = 30 s^{-1}, W = 20 N, Peltier device off (1Y) and on (5Y))



(a: before temperature controlling)



(b: after temperature controlling)

Fig. 6 Comparison of vibration waves (N = 25 s^{-1}; W = 20 N; Cooling of T2, T3, and T4; Heating of T1 and T5)

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APPENDIX

Nomenclature

N	: rotational speed
t	: temperature
W	: bearing load

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