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Experimental Study of Cage Imbalance and Wear in Deep Groove Ball Bearing Under Cryogenic Environments

TRACK OR CATEGORY

Rolling Element Bearings II (Session 6C): Rolling Element Bearing Dynamics

AUTHORS AND INSTITUTIONS

Yongbok Lee [a*], Bokseong Choe [a], Jaeseung Byun [a], Jeonkook Lee [b]

[a]Center for Urban Energy Research, [b]Center for Opto-Electronic Materials and Devices, Korea Institute of Science and Technology,

[*]Corresponding author. Tel.: +82 2 958 5663, Fax: +82 2 958 5659
E-mail address: lyb@kist.re.kr

INTRODUCTION

In cryogenic environments, Polytetrafluoroethylene (PTFE) is universally used in the ball bearing cages, since PTFE has a small coefficient of friction. Thus, PTFE cage is important to enhance stability of ball bearing functioned as solid lubricant. However, the PTFE cage is easy to appear the imbalance mass by friction and wear loss, since it has a large wear coefficient. In addition, accelerated wear loss generated by imbalance force can lead to damage of the cage. Gupta [1-2] presented a model of cage motion based on the software ADORE and studied the effect of cage design on cage stability. The analysis was performed by varying the cage guidance and ball-pocket clearances. In addition, cage wear was simulated while taking into account the mass imbalance of the cage. Boesiger et al. [3] evaluated the effects of cage instability using PADRE while taking into account the cage design as well as the operating conditions (rotating speed, lubrication conditions, lubricant used, external force, preload, and radial force). In this case too, the analysis data were confirmed experimentally. In addition, the study investigated the effects of cage stability based on the cage-ball friction and lubrication conditions. This study measured to evaluate the characteristics of cage dynamic as well as the bearing torque, cage whirling amplitude, probability density function of cage whirling frequency, and wear loss as functions of the inner race speed and cage imbalance mass under cryogenic conditions. The effects of the imbalance mass and rotating speed on cage dynamics and performance are discussed using the obtained results.

TEST RIG AND DESIGN PARAMETERS OF TEST BALL BEARING

The test rig could be driven at up to 11,000 rpm using a DC motor and provided a load of up to 20 kN using a pneumatic cylinder. The test rig was divided into three main parts along the axial direction. The first part was a 50 kW (driven at 11,000 rpm) DC motor capable of rotating at up to 11,000 rpm; water was used for cooling the motor. The second part was a middle chamber, which included a main shaft supported by ball bearings at both ends. The last part was the cryogenic chamber containing the test ball bearing. All the shafts of this part were connected through a flexible coupling to minimize misalignment. A staggered labyrinth and a lip-type seal were mounted between the oil lubrication chamber and the cryogenic chamber to minimize fluid mixing. Eddy current displacement sensors were fixed on the middle part in the oil lubrication chamber at intervals of 90° to measure the vibration of the main shaft. LN2 was supplied into the test chamber at a constant pressure through a pressure regulator from an outer LN2 tank (max. 170 l). A Coriolis-type mass flow meter was installed in the inlet pipe to measure the mass flow rate of the supplied LN2. All the LN2 supplied was made to pass through only the cage guidance land. The temperature and pressure of the LN2 were measured in order to determine the phase of the LN2 flow at the inlet and outlet. Axial and radial forces were applied by a pneumatic cylinder placed on the test bearing housing using loading arms.

Table 1 presents the design parameters of the ball bearing case as well as the boundary conditions used. Liquid nitrogen (LN2) was supplied to the test chamber for approximately 5 min to create a cryogenic environment before the speed-up test. The rotation test was started only when the temperature within the chamber had stabilized. Before the start of the test, the remaining oil was removed using a suction pump to prevent the oil from freezing in the support part. The oil was supplied to the support ball bearing when its rotational velocity was at least 2000 rpm. In addition, the time for which the operating speeds were maintained was restricted to approximately 60 s, owing to the capacity limitations of the LN2 tank (max. 170 l).

Table. 1. Design parameters of test ball bearing (geometry and materials)

Bearing geometry	
Inner race bore diameter, D_i	70 mm
Materials	
Cage	PTFE (with cylindrical pocket)
Boundary conditions	
Rotating speed of inner race	0-11,000 rpm
Axial/ radial load	3 kN/ 3kN
Cage imbalance weight	0.49-23.18 g·cm(correction mass R=49.25mm)

TEST RESULTS

1) Cage orbit and bearing torque

Figure 1 shows the cage whirling amplitude for different cage imbalance mass. The dotted lines indicate the maximum possible range of the cage motion at room temperature. The red lines represent the cage whirling amplitude for 1 s as measured after every 30 s during the operating period (60 s). Thus, the number of lines are proportional to the frequency of cage rotation for the corresponding speed. The cage whirling amplitude increased with an increase in the speed of rotation up to 5,000 rpm. Unstable whirling was observed for speeds higher than 8,000 rpm. For a cage imbalance mass of 0.493 g·cm, the cage whirling amplitude was larger than the cage imbalance mass of 23.178 g·cm. But, fluctuation of the cage whirling amplitude was the smallest. In addition, the degree of abnormal whirling fluctuation increased with an increase in cage imbalance mass. On the other hand, for cage imbalance mass of 0.493 g·cm, the whirling motion remained relatively stable with an increase in the rotating speed.

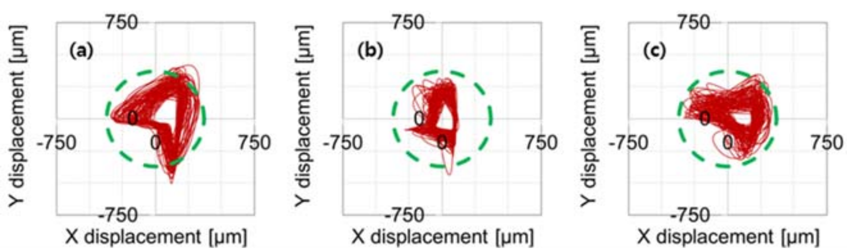

Figure 1. Measurement results of cage orbit for different cage imbalance mass (a) 0.493 g·cm, (b) 11.576 g·cm, (c) 23.178 g·cm (rotating speed of inner race: 11,000 rpm)

2) Cage wear loss

Figure 2 show the measured wear loss of each bearing element at the end of the tests for different cage imbalance mass. The wear loss of the cage was relatively larger than that of the metal elements, because the cage was made of PTFE. Thus, the wear losses of the cage for the different cage imbalance mass could be compared relatively easily. In practice, the PTFE particles generated by the physical abrasion of the cage reduced the frictional force on the ball bearing elements owing to the transfer of PTFE onto the ball track. However, abnormal wear caused damage to the cage by reducing its structural stability. Further, it can be seen from Figure 2 that the wear loss of the cage was the highest for a cage imbalance mass of 17.358 and 23.178 g·cm, owing to the large imbalance forces. When the cage imbalance mass is large, the wear loss of the cage bottom was larger than that of the cage top, owing to the force acting on the bottom surface of the cage bottom because of the instability motions of cage.

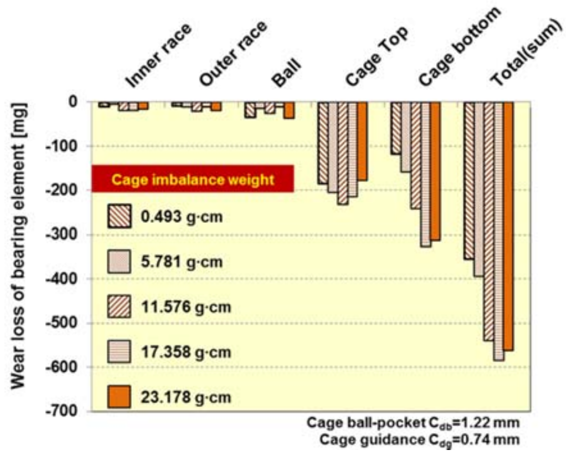

Figure 2. Wear losses of bearing elements at end of tests for different cage imbalance mass(0.493-23.178 g·cm)

CONCLUSIONS

The cage whirling amplitude increased with an increase in the rotation speed up to 5,000 rpm for which the amplitude decreased with the increase in the speed up to 11,000 rpm. In addition, the amplitude of abnormal whirling increased with the increase in the rotating speed. The effects of the imbalance mass of cage were more pronounced at 11,000 rpm, in contrast to the case for the lower speed range. The wear loss of the cage bottom was larger than that of the cage top, because of the force acting on the bottom surface of the cage bottom owing to the instable motions of cage. Further, the wear loss of the cage was relatively larger than that of the metal elements, because the cage was made of PTFE. In addition, the total wear loss of the cage was the highest for a cage imbalance mass of 17.358 and 23.178 g·cm, owing to the increased number of intermittent collisions.

The obtained experimental results highlighted the effects of the cage imbalance mass on the cage whirling motion and cage wear loss. In addition, the test results demonstrated that, for overly large cage imbalance mass, the cage instability decreased with an increase in the rotating speed of the inner race.

ACKNOWLEDGMENTS

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KEYWORDS

Cryogenic ball bearing, Cage whirling amplitude, Cage instability, Bearing torque, Cage imbalance