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Traction behavior for rolling bearing based solid lubrication under the cryogenic environment

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ABSTRACT – Cryogenic applications use in the harsh conditions such as the heavily load, high speed and low temperature. This research has constructed a tribo-test bench, it can operate under cryogenic environment. Through this experiment performed friction test with the cryogenic fluid, it came out the relationship the traction behavior with interacting in coated bearing components. Solid lubricants (silver, polytetrafluoroethylene) were shown the reasonable traction behavior under the cryogenic environment (low traction coefficient, rarely wear phenomenon). In addition, this work can discussion the overall trends of the solid films because it has a wide slip speed range (0.2 – 3.0 m/s).

1. INTRODUCTION

The rolling bearings in the space rocket engine operate under the extreme environment. For successful operation of the rocket engine, durability of rolling bearings is one of the important technologies. However, the conventional bearings have failure in the cryogenic environment (below about -180 ℃) because the materials and lubrication have influenced at the low temperature. To solve this problem, solid lubrication is used it has low friction and high wear resistance.

Good experience was investigated in the ball bearing test rig for the Liquid hydrogen rocket engine system [1], this research was considered through the result the dynamics of ball bearing under the low temperature. However, the study had limitation to consider the tribology behavior the solid lubrication in the rolling bearings. Therefore, many researchers had investigated the friction and wear test of solid lubricants useful under the cryogenic environment. It is well known that the solid lubricant of PTFE (polytetrafluoroethylene) and it based composites are strongly temperature-dependent [2-3]. A consequence of this is the change in wear mechanism of the polymers at low temperatures. While at ambient temperature adhesive wear dominates, abrasive wear is observed at low temperatures [3, 4]. This paper describes experimental apparatus and the results carried out the traction behavior of solid lubricant under the cryogenic environment. This study would be adapted for a simulation of the rolling bearing operated in the cryogenic applications.

2. BALL-ON-DISK UNDER THE CRYOGENIC ENVIRONMENT

This experiment was carried out with a ball-on-disk configuration in the cryogenic chamber described in Figure 1. This apparatus is cooled by a coolant directly connected liquid nitrogen (LN_2, T=77 K /-196 ℃) tank.

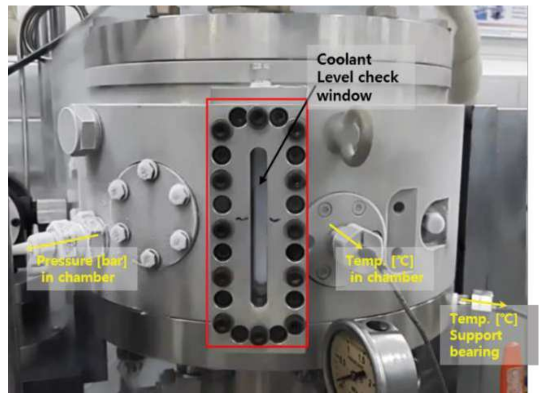

Figure 1 A photograph of test-rig during experiment with cryogenic fluid.

This experiment referred from ASTM G99-95 [5]. It recommend test procedures and materials to wear test with a type of pin-on-disk apparatus. We constructed a test rig like the type of pin-on-disk. In addition, It can change pin part (this test rig can be assembled a real bearing ball or pin) and experiment in the room temperature and the cryogenic temperature. The operating speed has the wide range to acquire the traction behaviors on the various slip velocities.

3. TEST APPARATUS

Whole system is constructed a driving part, an experimental part and the part of installed sensors for the data acquisition. In order to apply a static load on the test specimens, a pneumatic cylinder connect the rod arm. It is for acquisition the traction force between the ball and disk, and put pre-load on the ball. The temperature and pressure of liquid nitrogen is measured to check the phase of fluid. The chamber has the window which can be noticed the level of the coolant during the experiment. While experiment, the test specimens are merged in cryogenic fluids.

Figure 2 shows a crossed schematic view inside the experimental part. To measure the temperature inside the chamber, the T-type thermocouple is assembled.

4. EXPERIMENT PROCEDURES AND MATERIALS

Table 1 and Figure 3 show the main design parameters of the test specimens, ball and disk. The fixed ball is assembled the end side of load arm and the disk can rotating with assembled on the top of the rotor system. As mentioned, it has a changeable system about the real bearing ball or pin. The substrate material is used SUS440C. Because this austenitic stainless steel is not embrittlement in the cryogenic environment, therefore, it can adaptable as the test substrate.

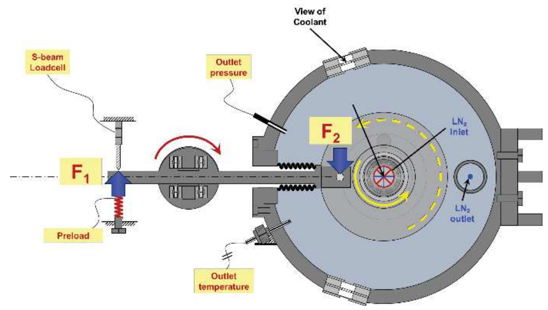

Figure 2 Crossed schematic view of test rig.

Table 1 Design Parameters of ball-on-disk specimens.

Test specimens	
Disk diameter, D_d [mm]	138
Ball diameter, D_p [mm]	5
Wear Track diameter, D_t [mm]	66.3
Disk width, Wd [mm]	5
Materials	
Disk and ball	SUS440C
Solid lubricants (coated on disk)	Ag / PTFE
Operating conditions	
Slip velocity [m/s]	0.2 – 3.0
Contact stress [GPa]	1.114
Coolant type	Liquid nitrogen(LN_2)

The experiment was performed in difference configurations. The three type test were investigated. First, the experiment was constructed by the steel ball on the steel disk. Secondly configuration was the steel ball on the silver (Ag) 7 um coated disk. The other one was the steel ball on the PTFE 7 um coated disk. These design and configurations were decided to can simulate the effect of solid lubrication in the rolling bearing.

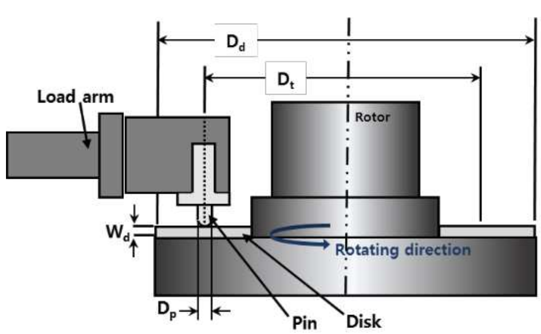

Figure 3 Schematic view of test specimens combined ball on disk.

The operating speed is considered at the contact point to drag the friction coefficient against slip velocity.

Finally, by using this test rig, it can observe the tribology behavior of the solid lubricant, commonly using on the rolling bearings operated under the cryogenic environment.

5. RESULTS AND DISCUSSION

The device for traction behavior were operated successfully under the cryogenic environment and acquired the data as well to investigate the tribology behavior. Each point (Figure 4) of the slip velocities was acquired the traction coefficient against the operating time. And then, selected the state-steady range, it calculated the average value of real-time data.

After experiment, all traction coefficients show below 0.5 under the cryogenic environments. Especially, in case of the steel ball on the PTFE coated disk shows the low coefficient and has remained the lowest quantity debris by wear. Through the results, this study can investigate the traction behavior of each interactions of the rolling bearing like cage-races, cage-balls and races-balls under the cryogenic environment.

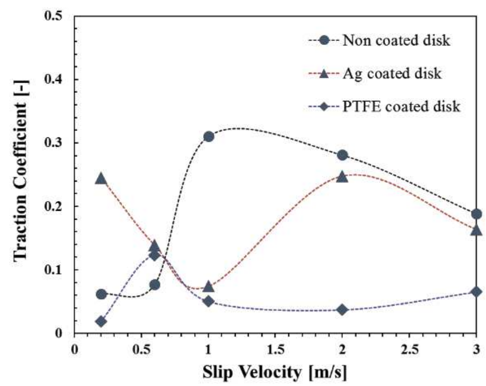

Figure 4 Traction behaviors in the tribo-test (traction-slip curve), the point results are calculated using average method.

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