SM/SEED SPACE EXPOSURE EXPERIMENT OF BALL BEARING LUBRICATED BY TRIBO-COATING

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Degradation of friction properties of three types of ball bearings (conventional vacuum ball bearing and two types of ball bearings lubricated by tribo-coating of indium) exposed to real space environment was investigated on SM/SEED experiment. Well-friction properties of ball bearings lubricated by tribo-coating of indium were maintained for one year exposure to real space field. Even after degradation of ball bearing due to exposure to the real space environment, friction properties could be restored by in-situ tribo-coating.

Keywords: Tribo-coating, SM/SEED, In-situ and On-demand Restoration, Tribology

1. Introduction

Lubrication is one of the most important key technologies for the reliability and long life of space systems.

In the present space systems, solid lubricants such as lead, indium, silver, gold and molybdenum disulfide are pre-coated with certain thickness before assembling. The life of present space systems is, therefore, determined by the wear life of the coating of lubricant.

If solid lubricants could be restored in-situ and on-demand during operation even under exposure to real space environment, the life of the space systems could be extended. It is believed that “a self-restoring lubrication system with in-situ and on-demand controllable lubrication method” is needed for the future space systems to improve reliability and overcome unexpected tribological troubles in space.

To reply to the requirements, a new solid lubrication method called "Tribo-coating" has been proposed [1-3]. And it has been clarified that this method gives the unique advantage of excellent tribological performance such as low friction and semi-permanent lifetime by in-situ and on-demand forming of an optimum tribo-coating film [1-3].

The purposes of this paper are to clarify the effect of the real space environment such as radiation and atomic oxygen etc. on friction properties of ball bearings lubricated by the tribo-coating of indium on SM/SEED space exposure experiment and to show possibility of restoration of lubricant which might be damaged by exposure to the real space environment.

2. Experimental apparatus and specimens

Fig. 1 shows the schematic illustration of friction apparatus with in-situ tribo-coating system, where solid lubricant (indium) is evaporated from the Al_2O_3 crucible by heating of the Mo heater in vacuum of 10^{-6} Pa during sliding. Two types of ball bearings coated by the tribo-coating of indium and conventional vacuum ball bearing coated by sputtered MoS_2 with special retainer of PTFE as shown in Table 1 were used as one set of specimens. Three sets were placed on a panel of SM/SEED (Service Module/Space Environment Exposure Device) [4], and it was attached on the outside of Russian Service Module in the International Space Station (Fig. 2). Individual set was exposed to the real space environment for about one year (10 months), two years (28 months) and three years (46 months). After experiment, each set was returned to earth to evaluate friction properties by using friction apparatus as shown in Fig. 1.

On the other hand, ground environment exposure test (Atomic Oxygen, Ultra Violet, EB (Electron Beam) bombardment) were conducted for each set to compare the friction properties against on orbit exposure effect.

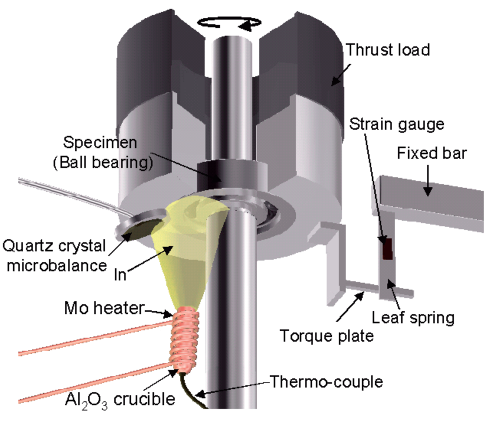
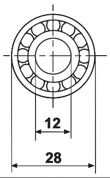
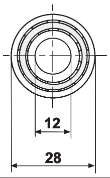
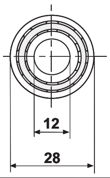


Fig. 1 Schematic illustration of friction apparatus for ball bearings with tribo-coating system

Table 1 Specification of three types of ball bearings used in the test

ID	BR1	BR2	BR3
Size (t=8 mm)			
Inner & Outer race	SUS440C		
Ball	Si_3N_4		SUS440C (MoS_2)
Retainer	———	SUS440C	Fluorine resin
Lubricant	Tribo-coated In		MoS_2 Fluorine resin
Weight	17.32 g	18.21 g	18.00 g

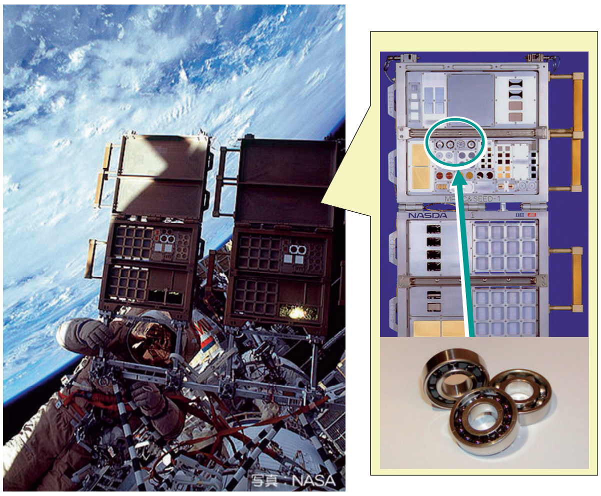


Fig. 2 Installation of a SM/SEED unit

3. Experimental results

3.1 Friction properties of ball bearings before exposure

Figure 3 shows a representative friction curves of ball bearings lubricated by tribo-coating of indium (BR1) and conventional vacuum ball bearing (BR3). Friction coefficient of ball bearing lubricated by tribo-coating (BR1) increases and decreases after evaporation of indium at the initial running-in stage, and it reaches a low value. Although some variation of friction are observed, Tribo-coating of indium gives sufficient low value of friction coefficient (=0.005) which is similar as that of conventional vacuum ball bearing (BR3).

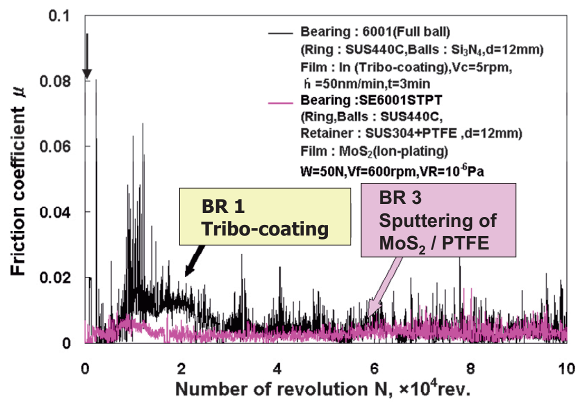


Fig. 3 Representative friction curves of ball bearings of BR1 and BR3

3.2 Effect of exposure in space environment on friction properties of the ball bearings

Friction curves of ball bearings of BR1 and BR3 before and after exposure in space environment for one year are shown in Figs. 4 and 5, respectively. It is clearly seen that friction coefficients of both bearings after one year exposure are kept similar values as those of before exposure. It is, therefore, considered that tribo-coating of indium is useful lubricant for space systems, which works for short time less than one year.

Figures 6 and 7 show effect of exposure period on friction properties of two types of ball bearings (BR1 and BR3), respectively. Although friction coefficients are kept low values after one year exposure as mentioned before, those values increase by exposure for more than two years. It is sure that life time of both bearings under exposure condition in space is less than two years. Indeed, friction property of conventional vacuum ball bearing (BR3) after two years exposure shows quite unstable with high variation of friction coefficient.

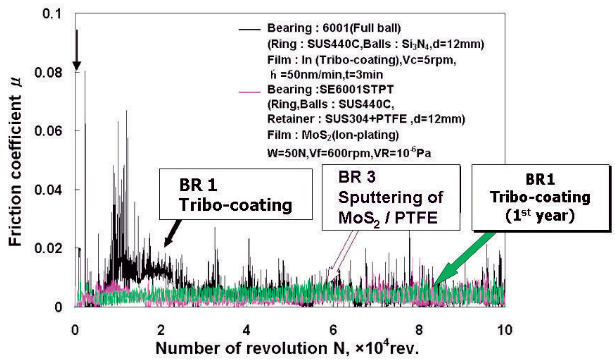


Fig. 4 Friction curves of ball bearings of BR1 before and after exposure in the space environment for one year

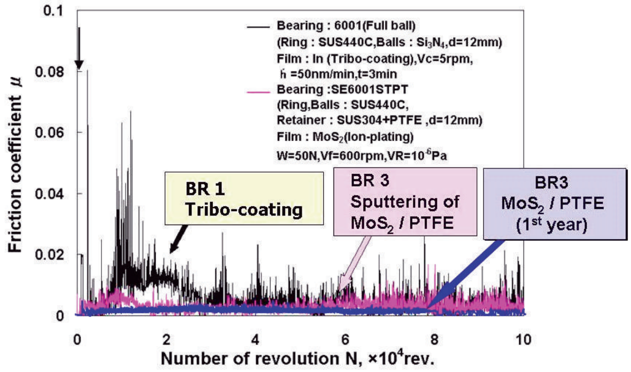


Fig. 5 Friction curves of ball bearings of BR3 before and after exposure in the space environment for one year

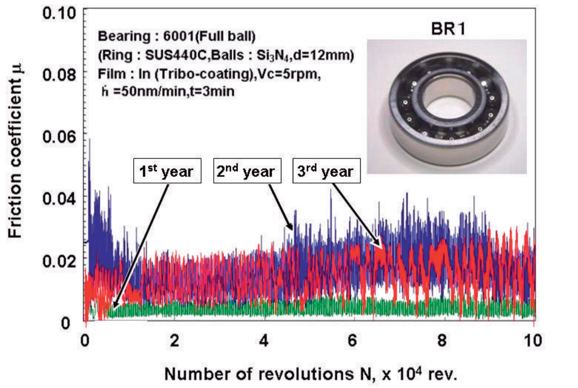


Fig. 6 Friction curves of ball bearings lubricated by tribo-coating (BR1) after exposure in the space environment for one, two and three years

However, friction curves of ball bearing lubricated by tribo-coating (BR1) after two years exposure shows relatively low and stable, in addition its value is almost no change even after three years exposure. These stable friction phenomena against long exposure period in space are considered as the reason of high seizure resistance of silicon nitride ball. It should be necessary for in-situ and on-demand restored system for future.

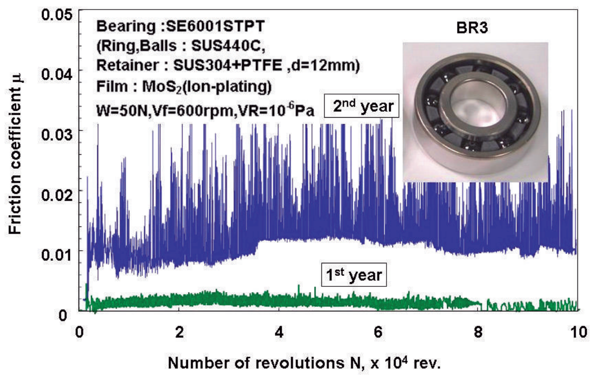


Fig. 7 Friction curves of conventional vacuum ball bearings (BR3) after exposure in the space environment for one and two years

4. Discussion

4.1 Degradation of ball bearing performance by exposure in space environment

Figure 8 shows friction curves of ball bearing lubricated by tribo-coating of indium (BR1) after bombardment of affective two elements such as atomic oxygen and electron beam. Atomic oxygen is the most affective bombardment element on degradation of bearing performance comparison with those of ultra violet and electron beam. With increasing of amount of atomic oxygen bombardment (from 1.32×10^{25} to 4.08×10^{25} atoms/m^2), its friction coefficient increases clearly as shown in Fig. 9. Atomic oxygen is believed to be a key element to control friction of ball bearing lubricated by tribo-coated In and sputtered MoS_2.

Figure 10 shows atomic oxygen effect on friction properties of two types of ball bearings (BR1 and BR3). In case of conventional ball bearing (BR3), the value of friction coefficient drastically increases and becomes unstable by bombardment of atomic oxygen (4.08×10^{25} atoms/m^2). On the other hand, ball bearing lubricated by tribo-coating of In (BR1) shows 0.01 of friction coefficient even after bombardment of atomic oxygen. It is suggested from Figs. 6, 7 and 10 that degradation of ball bearing performance by exposure in space environment is mainly caused by atomic oxygen.

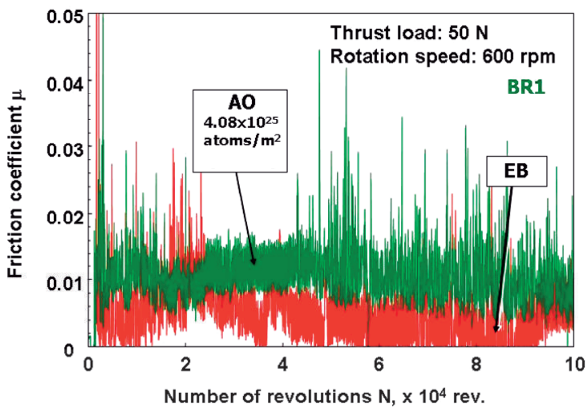


Fig. 8 Friction curves of ball bearing lubricated by tribo-coating (BR1) after bombardment of affective two elements of AO and EB

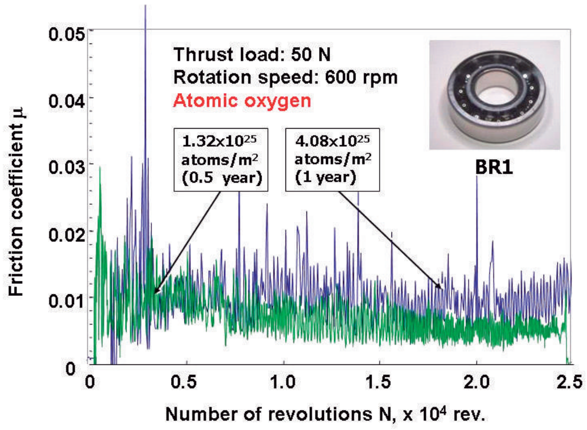


Fig. 9 Friction curves of ball bearing lubricated by tribo-coating (BR1) under different amount of atomic oxygen bombardment

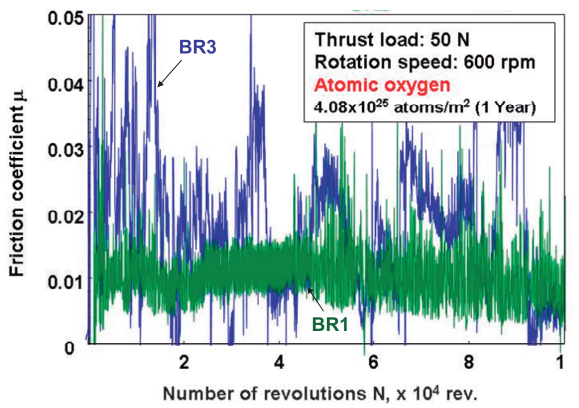


Fig. 10 Effect of atomic oxygen bombardment on friction properties of both ball bearing lubricated by tribo-coating (BR1) and conventional ball bearing (BR3)

4.2 Possibility of in-situ and on-demand restoration of vacuum ball bearing

In Fig. 11, indium was evaporated when friction coefficient of ball bearing lubricated by tribo-coating (BR2) starts to increase due to its lifetime after exposure for one year. The friction coefficient is kept low value by re-tribo-coating (In-situ tribo-coating). This shows the possibility of in-situ and on-demand restoration of solid lubricant in lubrication system with tribo-coating for mechanical system in real space environment.

It is unique advantage of tribo-coating as in-situ and on-demand restoration of lubricant for space mechanisms, which might be damaged by exposure to the real space environment.

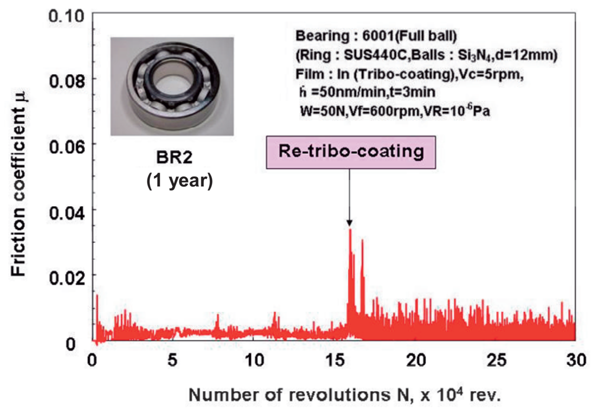


Fig. 11 Possibility in-situ restoration of lubricant for ball bearing after exposure to real space environment

5. Conclusions

1) Well-friction properties of ball bearing lubricated by tribo-coating of indium were maintained for one year exposure to real space field.
2) Friction coefficient of conventional ball bearing after two years exposure to space showed much higher and unstable than those of ball bearing lubricated by tribo-coating of indium.
3) By tribo-coating of indium, possibility of in-situ restoration of friction property of ball bearing damaged by exposure to the real space environment was clearly shown.

Acknowledgements

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