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Vacuum 77 (2005) 187–193
VACUUM
SURFACE ENGINEERING, SURFACE INSTRUMENTATION & VACUUM TECHNOLOGY
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Investigation of failure mechanism and modification for film-lubricated precise angular-contact ball bearing

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Received 16 July 2004; received in revised form 31 August 2004; accepted 13 September 2004

Abstract

This paper describes an experimental investigation into the performance and lubrication failure mechanism of precise angular-contact ball bearings treated with MoS_2-sputtered film, etc. As an important executive component of various spacecrafts, there are some strict requirements on the lubrication performance of angular-contact ball bearing, but the related experimental data are rare to see in literatures. In this experiment, the lubrication performances of MoS_2-sputtered ball bearing pairs were evaluated by using lifetime test as a main method, and the topographies and compositions of working surfaces were investigated through SEM, AES and EDS. The systematical experiment results reveal that the degradation and failure process of solid lubrication for such ball bearing is divided into three stages with different characters. A supposed failure mechanism has been proposed. An improved lubrication treatment based on above mechanism was conducted for the precise ball bearings, and a later test showed that long endurance life with more than 10^8 revolutions has been reached.

Keywords: Angular-contact ball bearing; MoS_2-sputtered film; Lubrication failure process and mechanism

1. Introduction

As a common kind of an executive component, precise angular-contact ball bearing can be used to play many important roles in spacecraft, e.g., orientation, motion control and instrument operation. However, without a reliable lubrication, the ball bearing is almost impossible to have a favorable space usage due to early wear failure, cold welding, etc, [1,2]. Since motion reliability of such ball bearing largely depends on its lubrication condition, the studies of applicable lubrication method, lubrication mechanism and modification have attracted considerable interest under condition that the space program brought requirements to tribological systems, e.g., requiring precise ball

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doi:10.1016/j.vacuum.2004.09.004

bearing with trobological characters of low friction, long and steady lifetime [2–4].

This research is mainly involved with improving the lifetime of space ball bearing through applicable solid lubrication technique. Such research is challenging for us: not only the solid films with high-quality characters of low fiction and long-time stability need to be selected and prepared, but also the optimal combination matching and films setting need to be followed. The lubrication failure process and mechanisms of complex component are not easy to see in literatures till now, especially rare in the systematic experimental data: (1) wear dynamics and tribological behavior of various typical tribological systems; (2) failure diagnosis methods for working surfaces of various actual friction pairs; (3) effect of operating modes and working parameters on tribological performances of actual friction pair. These problems have hindered the progress of lubrication application [5–6].

Prior to aerospace application, each synthesized friction pair must pass the test examination in that a small fallibility may affect the tribological behavior of whole system [7]. In this study, a vacuum life test is used for evaluating the ball bearing performance. Using the life test result not only can measure whether the synthesized ball bearings meet the space application requirement, but also can provide some valuable data for predicting its actual orbital property.

After conducting the lifetime tests, the systematic experimental analyses were carried out by scanning electron microscopy (SEM), energy dispersive spectrometer (EDS) and Auger electron spectrometer (AES). In the early experiment, the lifetime test revealed that the ball bearing had more than 1×10^6 revolutions with steady and low friction torque. Based on the experimental data, the lubrication failure process and mechanism of pairs of precise ball bearings has been illuminated in this paper. After investigating the lubrication degradation and failure history for the pair of ball bearings, a modified lubricated precision ball bearing, jointly using co-sputtered MoS_2-based composite film and ion-plated TiN-based composite film, is also evaluated.

2. Experimental details

In this experiment, angular-contact ball bearing to be tested, type C6205 ($\phi 25 \times \phi 52 \times 15$ mm), was assembled with inner and outer rings, balls and a retainer. Schematic diagram of configuration and early treatment of ball bearing is shown in Fig. 1.The comparison of early and later treatments on different parts of angular-contact ball bearing is shown in Table 1 to reveal the difference between early and later treatments.

The test parameters of vacuum lifetime test for the ball bearings were as follows: vacuum degree adjusted from 10 to 0.1 Pa; rotating speed of 100 r/min; loading an axial pre-tight force of 49.0 N, where outer rings were fixed and inner rings fastened with axis were rotated. During the test, a pair of two ball bearings was employed for measuring average friction torque $\overline{M}$. Meanwhile, temperature (T_r) at outer rings and temperature (T_c) in vacuum chamber were continuously detected, and the difference between T_r and T_c was in a range of $\pm 0.3\,^{\circ}C$ during normal condition. Schematic diagram of vacuum lifetime test equipment is shown in Fig. 2. During lifetime test, the failure of ball bearing was determined like this: a noise of vibration and friction can be detected, accompanied by an obvious increase of detected friction torque.

After conducting the vacuum lifetime test, each part of tested ball bearing was immersed in a acetone bath for an ultrasonic cleaning; the wear debris were filtered and collected for EDS analysis, and the working surfaces of ball bearings were

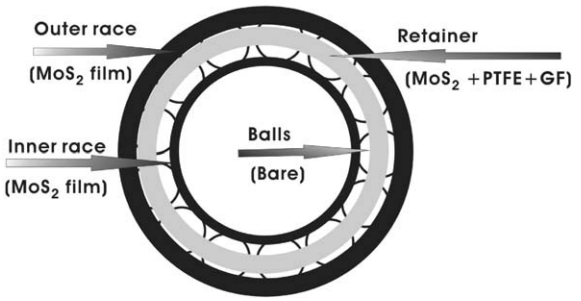

Fig. 1. Schematic diagram of configuration and treatments of angular-contact ball bearing to be tested.