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Case Study

Ferrographic analysis of pivot jewel bearing in oil-bath lubrication

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ABSTRACT

The wear mechanism and life of the pivot jewel bearing in oil bath lubrication needs to be well understood. Forty five spinning wear test sets were built to reveal the wear behavior and wear life to achieve proper design of pivot bearing for high speed application such as in flywheels for energy storage, small centrifuges and fabric spindles. The ferrographic analysis of the used oil in wear test showed that the wear debris particles had the length of 0.5–30 of micrometers, had glossy surface and distributed on the ferrogram in strings. Some special wear particles such as ball, curling chip, and sliver were also found on the ferrogram. Four main kinds of substances in the wear particles were iron, iron oxides, non-ferrous metal and friction polymer. Image segmentation by recognition of background color presented the covered area of the wear particles on the freogram, and the volume of the wear particles was calculated according to the characteristics of the particles. The wear particle quantity analysis showed that the jewel-pivot bearing in oil lubrication could be used for long time duration in the vertical support system of small, high speed rotating machinery.

1. Introduction

Jewel bearings had applications in watches and sensitive measuring instruments such as galvanometers, compasses, gyroscopes, gimbals, and turbine flow meters. In the traditional application, the load of the jewel bearing was lower than 10N without lubricant. A pivot jewel bearing consists of a ball or a shaft tip that spins on an axis perpendicular to the contact area and a support element which is usually a concave or plate surface of hard anti-wear material such as ruby or steel. For small high speed flywheels and centrifuges in vertical installation, pivot jewel bearings with lubrication are usually combined with permanent magnetic bearings, and thus only 5–10 percent of the rotor's weight is borne on the jewel bearing. The lubrication oil resists wear and extracts the friction heat of the bearing.

In the hybrid magnetic bearing for a flywheel energy storage system, a synthetic ruby or sapphire ball on the flywheel and a stationary, flat sapphire plate were used as the axial support [1]. The test rig with the jewel bearing as the axial support arrived at the speed of 5500 rpm in the experimental study of the permanent magnetic bearings for spacecraft applications [2]. Sankar and Tzenov presented a mechanical model for the jewel bearings to predict the errors and friction loss [3]. They also presented and modeled a jewel bearing with a free ball between the cup surface fixed to the rotor and the stationary cup to solve the concentrated wear due to the circular contact band of the spherical end of the rotor [4].

As manifested in the above published papers, pivot jewel bearings were used as thrust bearings with dry friction [1–4]. The wear was very light for the case of watches or instruments jewel bearing because of low load and low speed. However, in the high speed application, the wear behavior became an important factor for its operational life span.

For the jewel bearings in oil-bath lubrication, the experimental study on the pivot jewel bearing in boundary lubrication revealed that the friction coefficients of the pivot jewel varied from 0.05 to 0.10 [5], abrasive wear, fatigue wear and adhesive wear occurred in a sequence [6]. However, the quantity analysis of pivot bearing wear was not published before. In this paper, we did the ferrography analysis of the used lubricant of the pivot jewel bearing in wear tests in order to get some quantity data about wear for the first time. The wear debris was observed and its volume was evaluated.

Ferrography is a powerful tool used for oil analysis in tribology [7,8]. It involves separating solid particles from a lubricant and examining them under a microscope checking characteristics like particle size, concentration, composition, morphology and surface condition of the ferrous and non-ferrous wear particles. The qualitative ferrography analysis on lubricant has matured and been used widely in the industry machinery monitoring [9]. The key step in ferrographic analysis is the image identification and processing to get the particle morphology and classification to

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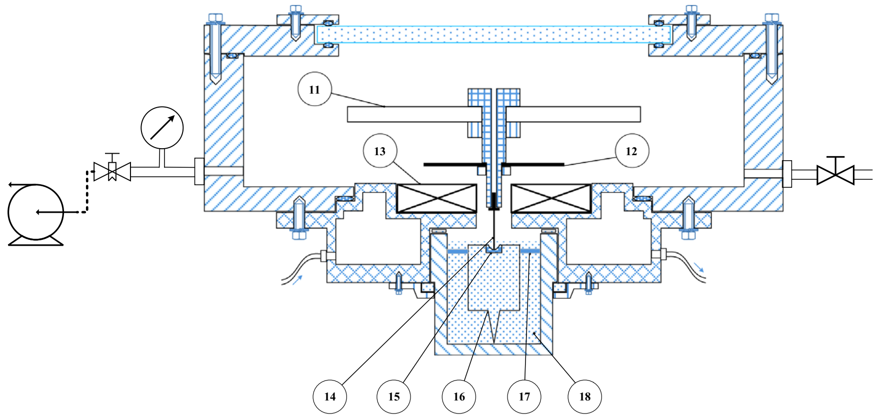
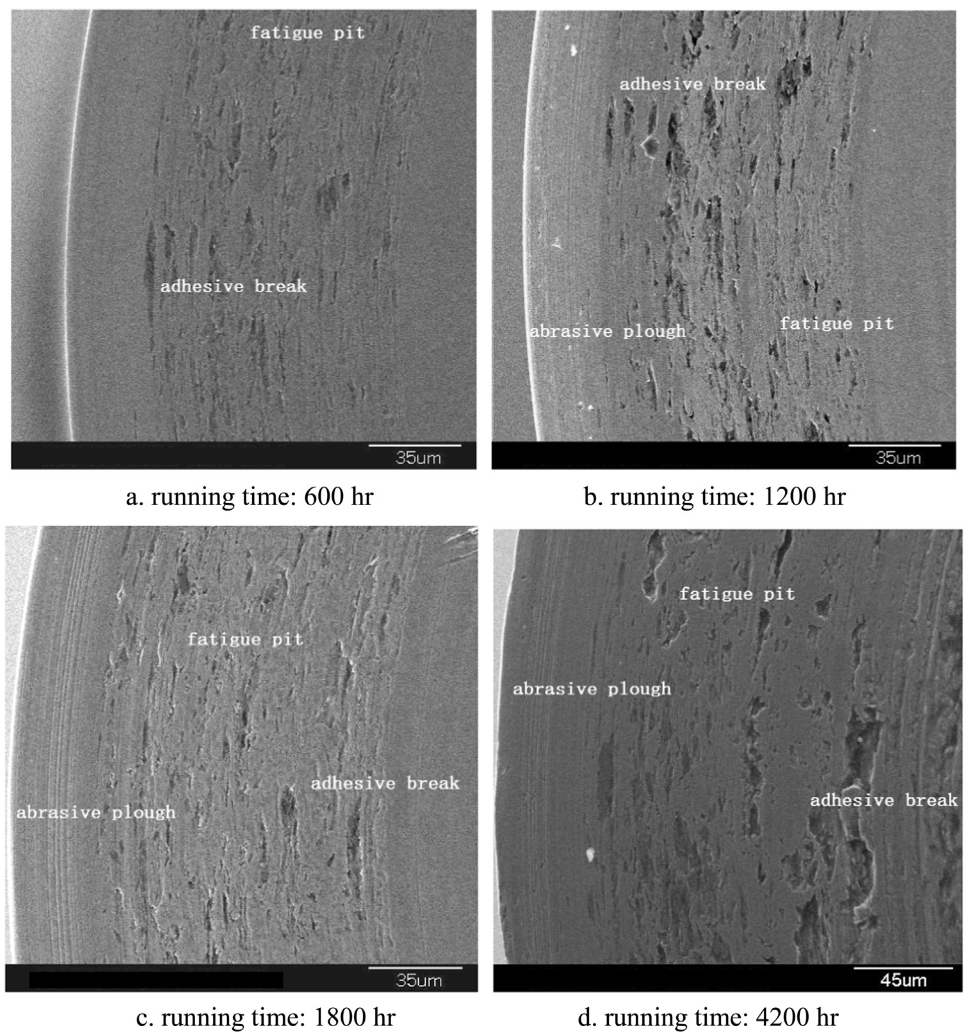


Fig. 1. Spin wear test rig for jewel bearing. 11: flywheel for load; 12: motor rotor; 13: motor stator; 14: pivot tip; 15: jewel cup; 16: damper; 17: elastic element for centering; 18: lubricant.



a. running time: 600 hr
b. running time: 1200 hr
c. running time: 1800 hr
d. running time: 4200 hr

Fig. 2. Wear surface of the pivot shaft.

evaluate the wear state, rate and mechanism [7]. New research in recent years was focused on the efficiency and accuracy of the particle recognition. An improved multi-scale corrosion-expansion method for watershed-based morphological separation was proposed for on-line ferrographic analysis [10]. The wear particles were segmented by an algorithm combining watershed and an improved ant colony clustering [11]. An integrated approach using both gray-and boundary-based method for wear debris particle chain segmentation was proposed in ferrogram image processing [12]. These new methods seemed complex and time consuming. A simple ferrogram image segmentation method was used in this paper.

In this study, the original qualitative and quantitative ferrographic analysis results on the wear particles in lubricant for pivot jewel bearing were presented. Forty five spinning wear test rigs were built to do wear test of the forty five jewel bearings divided