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Study of solid contamination in ball bearings through vibration and wear analyses

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Abstract

In rolling bearings, contamination of lubricant oil by solid particles is one of the main reasons for early bearing failure. In order to deal with this problem, it is fundamental not only the use of reliable techniques concerning detection of solid contamination but also the investigation of the effects of certain contaminant characteristics on bearing performance. Nowadays, non-invasive techniques, such as vibration measurements, are being increasingly used for on-time monitoring of machinery performance. In this context, the present work investigates the effect of lubricant contamination by solid particles on the dynamical behavior of rolling bearings, in order to determine the trends in the amounts of vibration affected by contamination in the oil and by the bearing wear itself. Experimental tests were performed with radial ball bearings lubricated by oil bath. Quartz powder in three concentration levels and different particle sizes was used to contaminate the oil. Vibration signals were analyzed in terms of the root mean square (rms) values. The results show that changes in the rms values of vibration in the high-frequency band, from 600 to 10,000 Hz, were associated to the changes in oil lubrication in the bearing contacts, caused by oil contamination and wear damage on the bearing surfaces.

Keywords: Contamination concentration; Particle size; Vibration; Ball bearing; Wear; Denting

1. Introduction

In the elastohydrodynamic lubrication regime occurring in rolling bearings, very high contact pressures elastically deform the surfaces, giving origin to small elliptical contact areas. The repetitive formation of the elastically deformed contacts eventually leads to surface fatigue [1]. Spalling is known as the typical failure mechanism happening in rolling bearings lubricated by oil bath [2]. The development of sites of elastic deformation is susceptible to the existence of material defects near the subsurface region, as well as to the presence of hard particles in the contact interface, among other factors. However, since improvements in cleanliness of bearing materials have led to the reduction of material defect initiated damage, surface initiated damage due to oil contamination has become one of the main causes of bearing failure [3,4].

Contaminants in oil-lubricated parts may be either solids or liquids. Hard contaminants can have origin in several sources, such as the environment and handling or else as a consequence of wear itself. They can produce direct effect on lubrication; for instance, in plain bearings, an increase in contaminant concentration can make the oil film thickness to decrease [5].

Concerning wear mechanisms in rolling contacts, when hard particles go into the interface, surface damage by mechanisms such as denting is inevitable. Dents essentially represent stress concentration sites, which increases the possibilities for the occurrence of spalling, accelerating the failure process [2,4]. In terms of contaminant particle sizes, some authors [1] state that the critical size is of the order of oil the film thickness, whereas others [6] report that, when particles of sizes larger than the oil film thickness pass through the contact, localized pressure peaks have greater chance of occurring in the contact area. This fact could indicate that larger particles have a greater tendency to

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cause early fatigue spalling in the contact zone. Besides spalling, contaminant particles can lead to other damage mechanisms, such as scuffing, originated from oil starvation in the inlet of the contact zone [7], and melting, which is due to heating produced by friction among particles and bearing elements [8]. Scuffing is related to larger particle sizes (100 μm) while smaller particles (5–20 μm) can pass through the contact, giving origin to denting [8]. It is evident that the findings in the literature on wear mechanisms caused by solid particles point to several possible mechanisms.

A way of monitoring machinery performance during operation is through mechanical vibration measurement. In rolling bearings, a sudden increase in vibration can be indicative of failure occurrence. According to Serridge [9], other techniques such as oil analyses and temperature monitoring can also provide advance warning of faults; however, vibration monitoring is more versatile since it can reveal a wider range of faults. Defects in bearings can excite vibration frequencies in both low- and high-frequency bands. Several works on ranges of vibration frequencies affected by rubbing phenomena occurring in lubricated contacts can be found in the literature. One of these works suggests [6] that phenomena at the contact interface are related to dynamic excitations in the acoustic emission range, higher than 50 kHz. Another work [10] describes the detection of wear in the contacting elements by vibration spectrum analysis in the low-frequency range, up to 0.3 kHz. Alternatively, in tests with plain bearings under boundary lubrication, it was observed that shifts in the vibration frequencies in the range from 0.2 to 10 kHz were related to the evolution of surface topography caused by running-in [11]. In what specifically concerns the contamination effect on vibration of lubricated systems, one finding is that contaminants in the oil can disturb smooth operation of bearings [17]; in this case, according to bearing manufacturers, no typical frequency pattern is generated although an audible and disturbing noise may be created [18].

Extensive research [12–16 among others] is found in the literature concerning the influence of contaminant particles on the wear of metallic bodies in lubricated contacts. On the other hand, investigations on the effect of solid contamination on both wear and vibration are more occasional.

From the literature overview on vibration, oil contaminant and wear, it can be concluded that:

(1) it is not clear which spectral band is affected due to hard contaminant;
(2) it is not clear which spectral band is affected due to wear;
(3) it is not clear how both oil contaminant and wear simultaneously affect vibration.

On the other hand, in a previous work [19], the authors found out that vibration analysis through the root mean square (rms) value was able to show that particle size and the concentration affect the dynamical response of the bearing in the 600–10,000 Hz frequency range, in distinct trends:

- the vibration increases with concentration; and
- the vibration first increases and after decreases with particle size.

In these tests, surface damage was noticed in the bearings after they had been run in contaminated oil.

By means of the same basic procedures previously adopted for vibration analysis, the present study investigates both the dependence of the dynamical response of ball bearings on oil contamination characteristics (contaminant concentration and particle size) and its correlation to wear. Wear was characterized through surface roughness measurements and oil analyses. This study aimed at:

- detailing the wear mechanism;
- quantifying the wear damage;
- determining the vibration amount specifically related to worn bearings;
- determine the vibration specifically related to the presence of solid particles in the interface;
- finding out to what extent the vibration due to the presence of contaminant was correlated to the vibration of the worn bearing;
- finding out to what extent the vibration of worn bearings can be correlated to wear damage.

2. Experimental method

Vibration signals were acquired from ball bearings, oil bath lubricated, assembled in an experimental rig. Fig. 1 schematically shows a testing ball bearing in the rig. The applied load was radial, set through a load cell. An accelerometer placed on the bearing housing measured radial vibration. During tests, a mixing system was used to disperse the contaminant particles in the oil bath. A detailed description of the electronic instrumentation can be seen elsewhere [19]. The ball bearing geometry is shown in Fig. 2, while Fig. 3 presents pictures of the microscopic

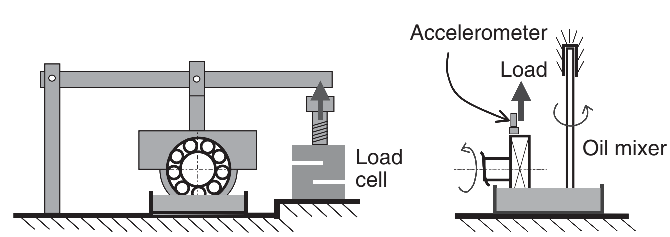

Fig. 1. Experimental rig used in the ball bearing tests.