ABSTRACT

This paper has examined the influence of bearing design and operation in controlling lubricant supply to the contact zone. Grease lubricated contacts are liable to starvation and as a result the film thickness is reduced, this can result in surface damage or premature bearing failure. It is of obvious importance to know when starvation occurs and the effect of grease type, bearing design and operation on lubrication replenishment. The aim therefore is to develop a starvation parameter capable of predicting the operating limits for a particular bearing/grease system.

A number of bearing design parameters are examined in the paper, these include cage design, ball spin and bearing size. Ball spin and cage effects can be efficient mechanisms for maintaining the lubricant supply to the track. Increased bearing size, line contact geometries and high load result in reduced lubricant replenishment of the contact. Using this analysis it will be possible to establish operating limits for families of bearings.

INTRODUCTION

The operation and life of rolling element bearings is highly dependent on the lubricant performance. Both friction and surface damage will be influenced by the properties and thickness of the lubricant layer. The critical contacts in such bearings operate under Elastohydrodynamic lubrication (EHL) conditions. In this case film thickness is determined by lubricant properties, bearing geometry and operating conditions and can be predicted assuming fully flooded conditions [1]. However the actual film thickness can be much less than predicted due to reduced availability of lubricant, this is the starved regime and is often encountered with grease lubrication [2]. In contrast to the established film thickness rules applying to the fully flooded condition, the starved regime dependence is less well understood. It is of obvious importance to know under what conditions the transition from the fully flooded regime to the starved regime occurs for a particular lubricant and application. A typical film thickness/speed starvation curve is shown in Figure 1. The speed at which this transition occurs is identified as the starvation speed and this depends on the lubricant properties, operating conditions and lubricant layer thickness in the inlet [3]. The most important factor determining lubrication level in bearings is the lubricant supply to the contact zone. The traditional view has been that oil bleeds from the grease reservoir to replenish the rolling track. However this is too simplistic and ignores the role of lubrication mechanisms specific to the bearing.

Examination of used bearings has provided useful insights into lubrication mechanisms. In these tests [4] the bearings were dismantled and the lubricant distribution and chemical composition assessed. Most of the grease was present on the seals with a small amount in the cage pockets and a thin lubricant layer on the raceways. This implied that a limited amount of lubricant was available to the contact and that efficient replenishment mechanisms are required to maintain an adequate film thickness level.
NOMENCLATURE

$\eta_0$ viscosity, $u$ entrainment speed, $a$ contact width, $h_{oil}$ oil layer height, $\sigma_s$ surface tension.

DEVELOPMENT OF LUBRICATION MODEL

In an earlier paper [3] a dimensionless parameter (SD) was developed to define the fully flooded/starved transition. The relationship between film thickness and oil properties was studied in an optical EHL device. Four parameters were varied: oil volume, speed, contact dimensions (load) and viscosity, all of which influence starvation speed and maximum film thickness but in a different fashion. These results were replotted (Figure 2) as a relative film thickness (starved/fully flooded) against a dimensionless starvation parameter (SD). The SD parameter study was limited to a simple test device and base oil. The challenge is now to extend the analysis to include both bearing and grease parameters.

Figure 2 Relative film thickness (starved/fully flooded) as a function of the SD parameter

The bearing parameters considered in this analysis include size, type, clearance and cage design. The operating parameters are speed, load, and temperature. Bearing dimension affects lubrication level as it determines the distance from lubricant reservoir at edge of track to the contact centre. As such it influences the replenishment of the rolling track, thus the maximum allowable speed is reduced for larger bearings.

Bearing type is determined by the rolling element geometry such as rollers, needles, tapered and spherical that will all give elongated contacts. Such geometries do not facilitate replenishment because of the distance required. Spherical rolling elements on the other hand have slightly elongated or even circular contacts, which favour contact replenishment. Furthermore such spherical bodies can spin, causing a minor displacement of the rolling track; this movement provides a substantial lubricant supply to the contact. Tests with a model-bearing device have shown that there is a significant increase in film thickness when spin is imposed on the rolling element.

Cage design will also influence lubricant redistribution within a bearing; this can be both beneficial and detrimental. In the worst case the cage acts as a scraper removing lubricant from the already depleted track. In best case the cage redistributes the lubricant supplying the track from the reservoir at the sides. The gap between the rolling element and the cage also provides a site for shearing the grease and a reservoir of lubricant for replenishment. The design of the cage will obviously have strong influence on both of these roles. Experimental measurements of film thickness in a model-bearing device have shown that the closely conforming cages provide the most efficient relubrication. An example is shown in Figure 3, which compares film thickness/speed behaviour with and without a cage present.

Figure 3 Effect of a cage on starvation speed with grease

CONCLUSIONS

This paper has examined the influence of bearing design and operation in controlling lubricant supply to the contact zone. The conclusions are as follows:

1. Efficient relubrication is the key to higher speed operation and extended bearing life.
2. The design of the bearing plays a critical role in determining operating limits of lubricating grease.
   - Ball spin and cage effects can be efficient mechanisms for maintaining the lubricant supply to the track.
   - Increased bearing size, line contact geometries and high load result in reduced lubricant replenishment of the contact.
3. Using this analysis it will be possible to establish operating limits for families of bearings.

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