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CONTACT FATIGUE IN ROLLING-ELEMENT BEARINGS

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1. INTRODUCTION

In the paper entitled "Surface contact fatigue failures in gears", Fernandes and McDuling [1] discuss the mechanism of contact fatigue damage frequently encountered on the active flanks of gear teeth. This mode of failure operates not only on counterformal surfaces in contact, as in matching gear teeth, but also on conformal surfaces (Fig. 1). The latter are found in ball bearings in contact with the inner and outer raceways, in roller or needle bearings in contact with the outer raceway, and in shafts in contact with sliding bearings [2]. In the case of gears, three types of contact fatigue damage were identified, depending on the relative movement of the contacting bodies, and the resulting stress distribution in the surface and near-surface material [1]. The characteristics of each type of failure were discussed in detail in [1].

Rolling-element bearings consist of balls or rollers positioned between raceways which conform to the shape of the rolling element. Depending on the bearing design, the loads acting on the bearing may be radial, angular or axial [3]. These loads lead to elastic deformation at the points of contact between the rolling elements and the raceways. The stress distribution in the surface and near-surface material under these conditions depends on the loads and the curvature and relative movement between the contacting bodies.

2. ROLLING AND ROLLING–SLIDING CONTACT FATIGUE

When bearing operation leads to pure rolling contact between the rolling elements and the raceway, the maximum shear stress occurs at some distance below the surface. This situation is similar to that encountered along the pitch-line of gear teeth [1]. In the early stages of damage, pure rolling forms a highly polished surface, as shown in the case of a bearing cup from a large thrust

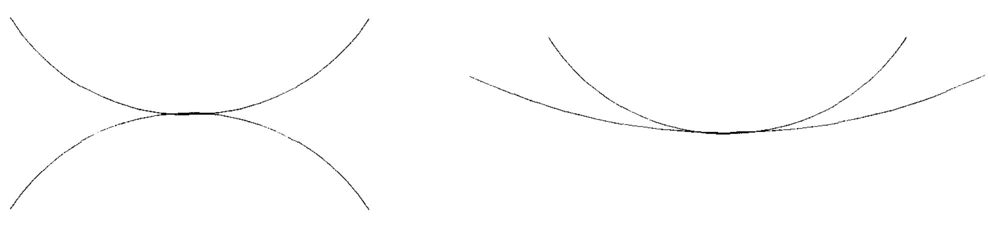

Fig. 1. Schematic illustration of counterformal (a) and conformal (b) surfaces in contact.

bearing (Fig. 2) [4] Under repeated loading, cracks ultimately initiate at the point of maximum stress, and propagate parallel to the surface. At some stage, these cracks deviate and grow towards the contact surface, resulting in the formation of steep-sided pits. These pits are usually microscopic, but may, with continued bearing operation, act as stress concentration sites for further damage.

Under normal bearing operation, it is more common that contact between the rolling elements and the raceway includes both rolling and sliding. The resulting stress distribution in the near-surface material under these conditions changes, and the maximum stress point moves closer to the surface. Again, this situation is similar to that encountered in the addenda and dedenda of gear teeth [1]. Cracks initiate at the contact surface, and propagate to form small, irregular-shaped pits. In some cases, the pits may form in the shape of an arrow-head pointing in the direction of load approach [3]. This is similar to the "cyclone pitting effect" also observed in gear teeth [1].

The initiation of surface cracks under rolling–sliding contact can be significantly accelerated by the presence of stress concentration sites on the contact surfaces [3]. These include corrosion pits, handling damage, surface inclusions, and dents formed by solid particles entrapped in the lubrication fluid. These geometric inhomogeneities lead to high localized stresses, rapid crack initiation, and the formation of contact fatigue pits. In some cases, the cracks initiated in this way may propagate through the bearing rings to cause complete fracture. An example of this is given in Fig. 3, which shows the inner ring of a thrust bearing [5]. Extensive surface damage, probably resulting from the action of solid particles entrapped in the lubricating fluid, is clearly noticeable, as is the through-crack emanating from this damage. Figure 4 shows the crack face in the vicinity of the region marked with an arrow in Fig. 3, and clearly indicates that crack growth was by fatigue.

3. FLAKING AND SPALLING

Under continued operation, the pits formed by rolling and rolling–sliding contact fatigue may progress to form a more severe form of damage known as flaking [3]. This results in the formation of large, irregular pits which cause rapid deterioration and failure of the bearings. Flaking is usually first observed on the stationary ring of a bearing, since the surface of this ring is subjected to the maximum stress every time a rolling element passes over it. In the case of the rotating ring, the

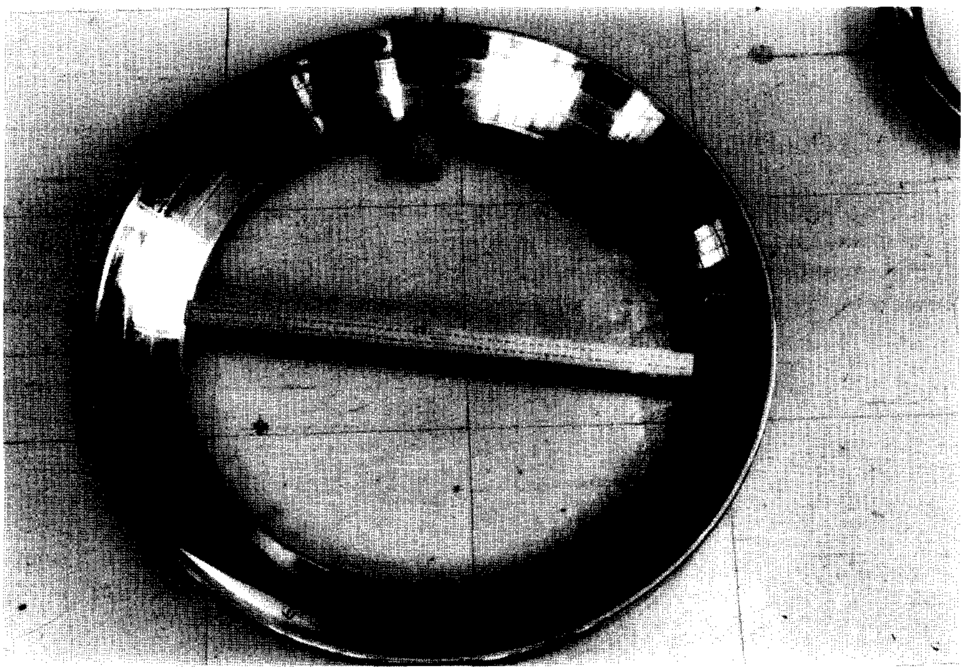

Fig. 2. Thrust bearing cup showing highly polished surfaces typical of the initial stages of rolling contact fatigue.

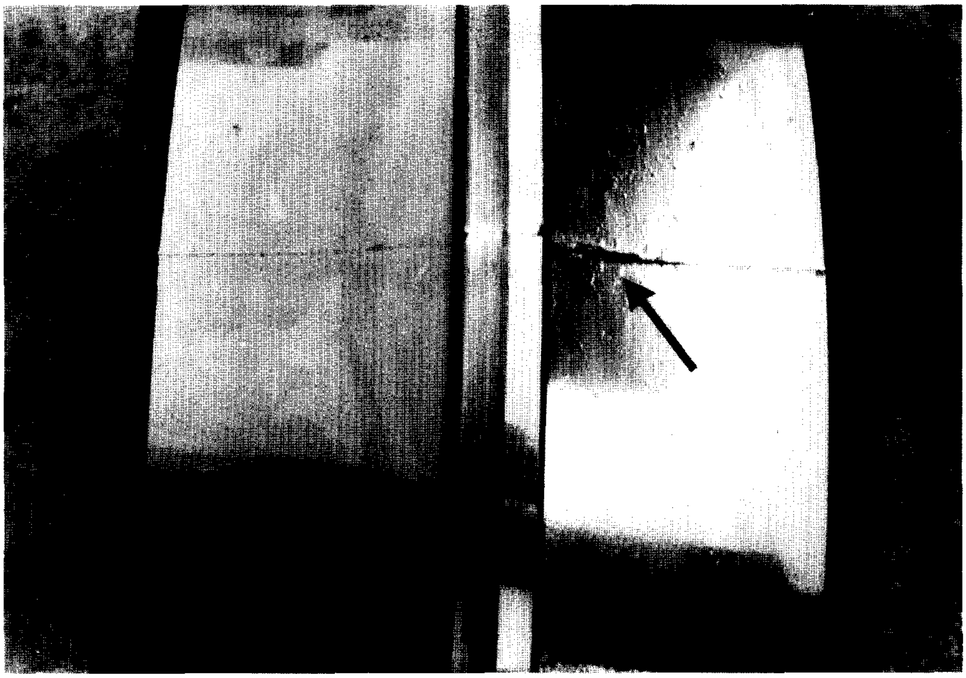

Fig. 3. Inner ring of a thrust bearing showing extensive surface damage on one raceway, and through-cracking of the bearing ring.

Fig. 4. Crack face in the vicinity of the region marked with an arrow in Fig. 3.

position of maximum stress changes continuously, so that any one point on the surface effectively undergoes fewer load cycles. Figure 5 shows an example of extensive flaking damage on the outer raceway of a roller bearing [6].

The location and distribution of flaking damage provides an indication of the cause of failure. Under marginal lubrication conditions, flaking is widespread and distributed over the entire raceway. If the damage is localized, as is the case on the inner ring of a thrust bearing in Fig. 6 [5], flaking is

Fig. 5. Flaking damage on the outer raceway of a roller bearing.

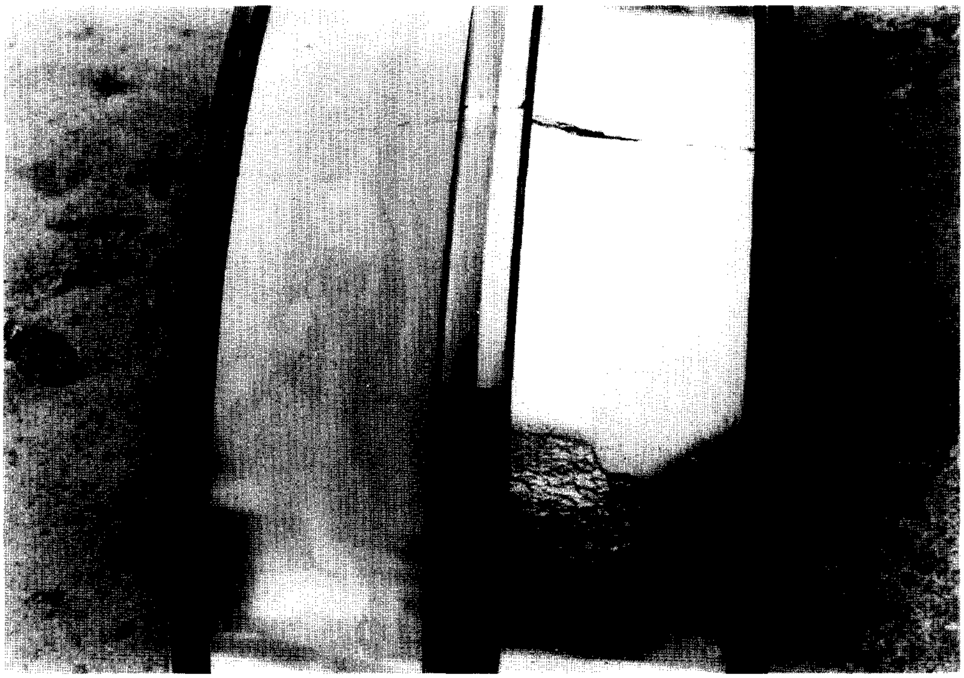

Fig. 6. Localized flaking damage on the inner ring of a thrust bearing.

generally found to be associated with pitting originating from surface stress concentration sites. In roller bearings, flaking sometimes occurs along a ring on a plane corresponding to the end of the rollers. This indicates that the bearing is misaligned, and the loads unevenly distributed. Finally, flaking damage is occasionally found at regular intervals corresponding to the rolling element spacing. In these cases, damage is associated with indentations produced when the stationary bearing is loaded, these indentations being referred to as *true brinnelling*.

Another form of severe contact fatigue damage is known as *spalling*. As in the case of gear teeth [1], spalling occurs as a progression of the pits formed by rolling and rolling–sliding contact fatigue,

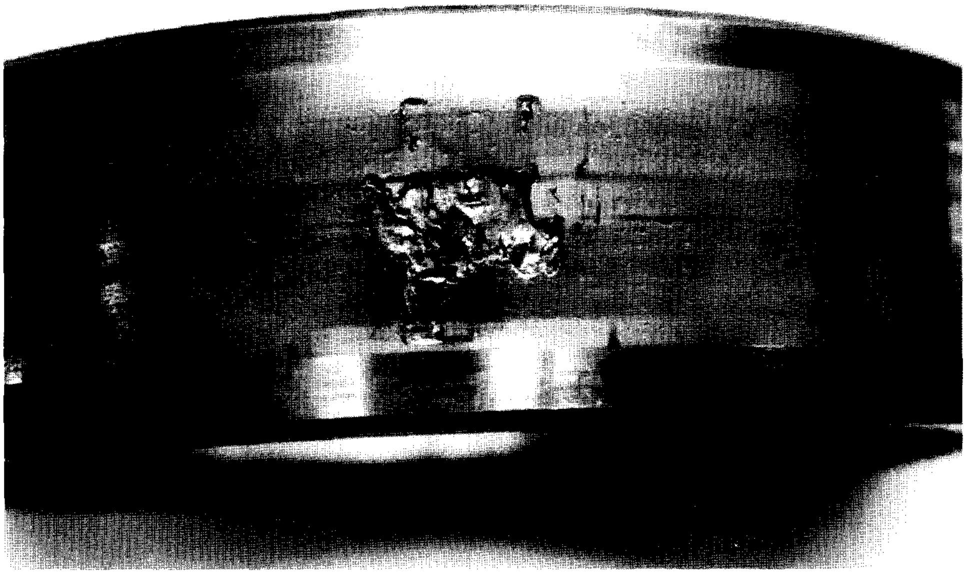

Fig. 7. Severe spalling on the inner ring of a thrust bearing.

or as a result of cracking at the case–core interface in case-hardened components. The damage in this case results in the formation of large, deep pits with sharp edges, steep sides, and flat bases. A good example of this is given in Fig. 7, which shows the inner raceway of the failed thrust bearing [6].

4. SUMMARY

Surface contact fatigue is a common cause of failure in rolling-element bearings. The extent of damage observed depends on the contact loads, the curvature of the rolling elements, and the relative motion between the contacting surfaces. The characteristics of the various types of contact fatigue are as follows:

(a) Microscopic pits form under pure rolling contact. These may act as stress concentration sites for further damage.
(b) Under rolling–sliding contact, irregular-shaped pits are formed. This type of damage is accelerated by the presence of geometric inhomogeneities such as corrosion pits, handling damage, and dents.
(c) Flaking occurs as a progression of the pits formed under rolling and rolling–sliding contact fatigue, and leads to the formation of large, irregular-shaped pits.
(d) Spalling refers to the formation of large, deep pits with sharp edges, steep sides, and flat bases, or to cracking at the case–core interface in case-hardened surfaces.

A number of practical examples of bearing failure have been used to illustrate the various types of contact fatigue damage.

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