Fatigue Life Performance Comparisons of Tapered Roller Bearings with Debris-Damaged Raceways®

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Debris-contaminated lubrication environment is inherent in many equipment applications and requires mechanical components that, as much as possible, are resistant to the potential detrimental effects of debris particles. Housing fatigue life performance comparisons were made for various bearing materials and manufacturer origin, in order to assess the suitability in performance of debris-damaged raceways. The evaluation was conducted using a repetitive debris-damaging process prior to fatigue testing of each group of bearings. The performance results reveal wide variations in the impact that debris damage can have on various bearing products and materials.

KEY WORDS
Contaminants, Wear and Failure, Fatigue, Lubricant Contamination, Particulates

INTRODUCTION
In 1963, Littmann and Moyser (1) described the five modes of competitive fatigue damage occurring in tapered rolling bearings. The two predominant modes in those years were the inclusion origin and the geometric stress concentration (GSC) modes. Since that time, however, the improvements in the cleanliness of bearing steels and the improvements in bearing design and manufacturing have minimized these two modes of fatigue damage. The point source origin (PSO) has emerged as the primary mode of fatigue damage, especially in those applications involving debris-contaminated lubricants.

Investigators over the years have focused on the debris damage in bearings and its effect on fatigue life (2)–(6). More recently, investigators have found that by developing new steel specifications and/or new heat treatments, bearings could be developed that would attain a higher level of fatigue life in debris-contaminated lubricants than could be reached with their standard materials and heat treatments. (7)–(9).

Due to the increasing interest in this area and the need to evaluate the effects of various steels and heat treatments on bearing life on a common basis, a standardized test was proposed by Nixon et al. (10). In this approach the bearings are first pretested in a special rig using an SAE 5 oil containing SIC particles. The bearings are then cleaned and fatigue tests run in a standard life test housing in an SAE 5 oil without SIC particles. The details of these procedures are outlined later in the paper. Using this method, two separate tests were run to evaluate the effect of debris defects on bearing life. One test compared the fatigue life results of bearings made by three different manufacturers. The other test compared the fatigue life results of bearings in which all components were made from case carburized steel, bearings in which all components were made of through hardened steel and bearings in which the races were made of case-carburized steel and the rollers through hardened steel. In this second test, all bearings were from one manufacturer.

PREDEMENTING OF BEARINGS
The first step was to individually predent the bearings using the special equipment shown in Fig. 1. The cup is pressed into an adapter and placed in the test housing. The cone assembly is pressed onto an adapter and attached to the spindle extending from the pillow block. The contaminated lubricant is then poured into the cup cavity and the test housing moved upward by the load cylinder until the bearing is seated. The load is applied through the load cylinder while the motor rotates the bearing for 2,000 revolutions. After each bearing is premented, it is cleaned and prepared for the fatigue life test. The conditions used in this procedure are listed in Table 1. A typical comparison of the surfaces before and after denting is presented in Fig. 2.

Table: Conditions for Predenting Procedure

<table>
<thead>
<tr>
<th>Condition</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Axial Load</td>
<td>4,000 N</td>
</tr>
<tr>
<td>Speed</td>
<td>800 rpm</td>
</tr>
<tr>
<td>Lubricant</td>
<td>SAE 5 Oil Bath</td>
</tr>
<tr>
<td>System</td>
<td>55 ml</td>
</tr>
<tr>
<td>Amount</td>
<td>SIC</td>
</tr>
<tr>
<td>Particles</td>
<td>10.5 mg</td>
</tr>
<tr>
<td>Concentration</td>
<td>96-125 microns</td>
</tr>
<tr>
<td>Number of Resolutions</td>
<td>2,000</td>
</tr>
</tbody>
</table>

Fig. 2—Comparison of SEM micrographs of a bearing surface before and after denting.

TAINED FROM DIFFERENT MANUFACTURERS. THESE GROUPS ARE Labeled A, B, AND C FOR COMPARISON PURPOSES AND ARE ALL OF THE SAME PART NUMBER.

All bearings were subject to the same predenting procedure. A portion of each group of bearings without predenting was also fatigue life tested under the same operating conditions in order to evaluate the performance without any prior surface damage. Each group of bearings was tested in a standard 127 mm life testing housing as shown in Fig. 3. The test conditions are summarized in Table 2.

As can be seen in Table 2, the test method is the least-of-four, also called first-in four or sudden death. This technique was developed by Johnson (11) and is used extensively in life testing of bearings. Referring to Fig. 5, it can be seen that four bearings are being tested at one time. When one bearing fails, all four of the bearings are replaced. Each bearing life thus obtained is an estimate of the L10h life, i.e., the minimum life in a group of four. For the first test, there are six least-of-four estimates for each test group for both the premented and not premented (undamaged) bearings. In the second test, the same part number was used as in the first test but the bearings are not from any of the populations used in the first test. There are six least-of-four estimates for each of the undamaged bearing groups but only three estimates for the premented groups. The life test conditions are the same as for the first test.

In summary, the predenting process is a simple, but effective means of establishing the inherent fatigue life of bearings in debris-contaminated environments. The results of this study indicate that the use of debris-contaminated lubricants can significantly reduce the fatigue life of bearings, and that the use of debris-free lubricants can significantly increase the fatigue life of bearings. The results also indicate that the use of debris-contaminated lubricants can significantly reduce the fatigue life of bearings, and that the use of debris-free lubricants can significantly increase the fatigue life of bearings.
Under the test load of 22,600 N, the maximum compressive stress on the most heavily loaded roller is 2515 MPa (356 ksi) with a half-width of contact of 0.138 mm. The test conditions gave a lambda (A) ratio of 0.08. As a result, the predominant mode of fatigue was of the POF variety initiated at a dent. A typical example of the mode of fatigue for all groups is shown in Fig. 4.

**TEST RESULTS AND DISCUSSION**

The test results for both the predented and not dented (undamaged) bearings for all groups are given in Table 3. The lives for Groups A, B, and C are relative to Group A, undamaged while the lives for Groups D, E, and F are relative to Group D, undamaged. The severity of the test method can be seen as all groups have large reductions in fatigue life when the bearings are predented.

To establish that one group is significantly better than another group with a 90 percent confidence level requires the use of 60 percent confidence bands according to Johnson (11). For example, if the lower confidence band of the group with the higher $L_{100h}$ life coincides with the upper confidence band of the group with the lower $L_{100h}$ life, then the group with the higher life is better than the group with the lower 90 percent confidence. If the bands overlap, the confidence is less than 90 percent. If the bands are disjoint, then the confidence is greater than 90 percent. Thus, the use of the 60 percent confidence bands gives a quick determination of the significance of the comparisons. The exact confidence level can also be determined as well as how much better one group is than another group at the 90 percent level. This has been done in Tables 4 and 5.

From Table 4 it can be seen that Manufacturers A and B are comparable in performance under the same test conditions with the bearing undamaged. Performance by Manufacturer C with undamaged bearings is much less than the other two. The comparison of fatigue life with predented racers under identical test conditions reveals that Manufacturer B has demonstrated a life performance of more than two times that of Manufacturer C and 9 percent better than that of Manufacturer A with 90 percent confidence.

It was shown in Ref. (10) that there were no apparent or statistical differences in the surface characteristics of the predented groups A, B, and C. This indicates that the denting procedure was uniform and that the response of each of the manufacturers' bearings, in terms of topographical modifications, was essentially identical. This infers that the differences observed in the fatigue lives appear to be a function of the material and manufacturing process used by each manufacturer. This is in agreement with previous work (7)-(9).

From Fig. 5 it can be seen that there is no significant difference at the 90 percent confidence level between Groups D and E, both of which have case-carburized races, for either the predented or undamaged groups. However, both Groups D and E are significantly better in performance than Group F that has through hardened rollers and races. This is true for both the predented and undamaged groups. Thus, it would appear that the use of case-carburized races is benevolent to bearing fatigue life. This could be the result of the residual compressive stresses developed in the carburized races resisting the propagation of the fatigue cracks.

**CONCLUSIONS**

1. Even though there is no significant difference in the fatigue lives of the undamaged bearings between Manufacturers A and B, there is a significant difference for the predented bearings. Since it was shown in Ref. (10) that the dents in Groups A, B, and C were geometrically “identical,” the material and/or manufacturing process used by Manufacturer B seems to be beneficial to the bearing fatigue life in a debris-contaminated lubricant environment.

2. Comparing the case-carburized steel with the through hardened steel, both groups with the case-carburized races gave better life performance than the group with the through hardened races, indicating that the use of the case-carburized steel minimizes the detrimental effect of the debris. This could be a result of the resistance to fatigue crack propagation caused by the residual compressive stresses developed in the carburized races.

3. The increased lives observed in both of these tests appear to be a function of two effects: First, the resistance to debris denting and/or the initiation of cracks in the material, and second, the resistance to crack propagation once the crack has been initiated. Additional work...
is in progress to substantiate these effects and determine which material properties contribute to the increased lives of the bearings.

4. The use of silicon carbide debris particles in denting the bearing races gives consistent results, in a relatively short time, in ranking materials as to their effectiveness in maximizing fatigue lives of bearings in debris-contaminated lubricant environments.

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REFERENCES


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