Studies in plain bearing failures

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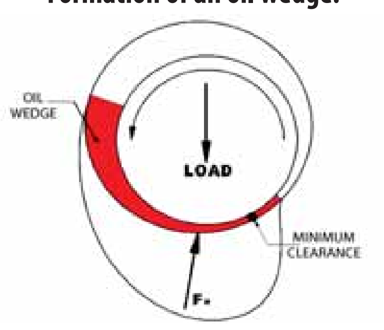
Editor's note: *The examples shown in this article were all identified by the author from first principles when investigating actual equipment failures and are not shown in the reference material typically available.*

Introduction

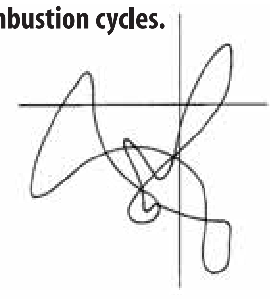
Plain or sliding bearings are lubricated by the formation of a hydrodynamic film of lubricant, where the wedge formed lifts the shaft or journal off the bearing. The formation of an oil wedge and pressure in the wedge is depicted in Figure 1. For clarity the bearing clearance is greatly exaggerated. Since pressure in the wedge increases to a maximum near the point of minimum oil film thickness, and then completely disappears as the bearing clearance increases, the resultant force, F_R, both lifts the journal and displaces it slightly away from the wedge.

Figure 1. Formation of an oil wedge.



Slight changes in load, lubricant flow to the bearing or temperature will alter the oil film thickness, the most common of these being load changes due to some vibration or harmonic in the system. A vibrating load alternately will decrease the film thickness and increase the bearing offset; thus the journal center will follow an elliptical path within the bearing if the vibration is a constant or may follow a complex path, as in the case of an engine main bearing. An example of a V engine main bearing during only two combustion cycles is shown in Figure 2.

Figure 2. Example of a V engine main bearing during only two combustion cycles.



(Source: Neale, M.J., *The Tribology Handbook*)

To prevent contact between a journal and its bearing, the minimum oil film thickness must at all times be greater than the combined mean surface roughness of the journal and bearing. This film thickness depends on the following four factors:

1. The lubricant viscosity.
2. Speed of journal rotation.
3. Load on the journal.
4. Operating temperature.

Abnormal wear and failures occur as the oil film thickness decreases to less than the combined mean surface roughness. This may occur due to a lack of lubricant, an abnormal load, excessive temperature or a combination of any of these factors.

Lack of lubricant

An unfortunately common cause of engine failure occurs as an engine runs dry of oil, resulting in a diminished flow of lubricant to the bearings. Because the big end bearings rotate about the main bearings and are lubricated via the main bearings, the crankshaft becomes a centrifugal pump, and the available lubricant supply preferentially feeds the big end bearings. A typical example is shown in Figure 3. Note how the main bearings are more severely damaged than the big end bearings.

Abnormal load

Bearing wear due to a vibrating load is shown in Figure 4. Note the undulating wear pattern formed on the surface of the unloaded bearing half. The loaded half of this bearing was excessively worn.

Figure 3.

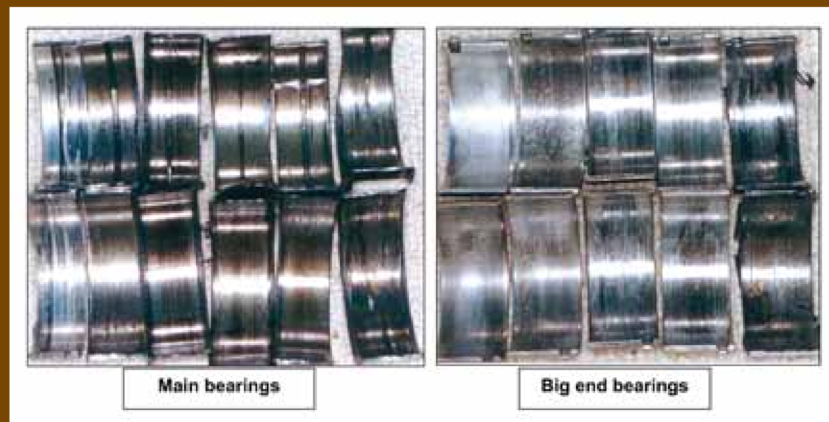


Figure 4. Bearing wear due to a vibrating load.

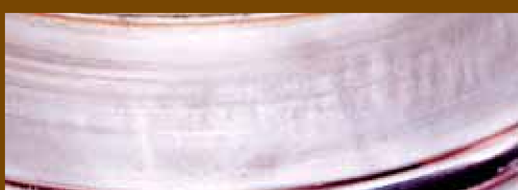


Figure 5. Evidence of bearing material fatigue.

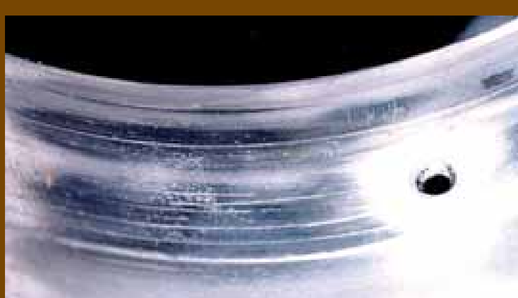
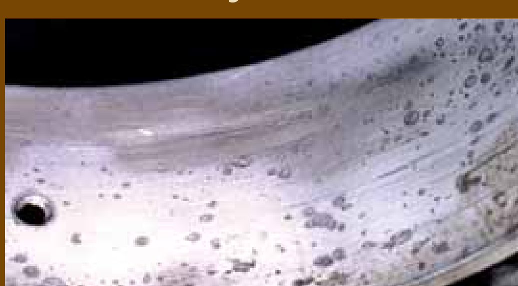


Figure 6. Haloes from embedded material taken from a bearing.



Material failures

Under a continuous normal operation, a bearing should have infinite life because it is protected by the oil wedge, and no metal-to-metal contact occurs. Bearing life then is only limited by the fatigue life of the bearing material. Early evidence of bearing material fatigue is visible in Figure 5. This is fatigue only of the bearing overlay material and does not impair bearing life.

In reality, bearings must stop and restart at regular intervals. An oil wedge can only be formed in a rotating bearing; hence, it is when a bearing stops and restarts that wear occurs.

Bearings also must absorb particles in the lubricant that otherwise would lead to abnormal wear and failure. This property is called embedability. Typical haloes from embedded material are seen in Figure 6. Although the bearing surface is marked, this is not a failure, and the bearing could have been expected to continue in service for a normal life.

Bearing erosion may occur from either cavitation or corrosion.

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Cavitation

Changes in the pressure wedge from grooves cut across the bearing caused

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entrained air to be released at a microlevel, causing the cavitation seen in Figure 7. Cavitation initially erodes the bearing overlay material but over a period of time will progress into the bearing material, causing eventual failure if the bearing material has a poor resistance to fatigue.

Figure 7.

Corrosion

Oxidation occurs during the service life of a lubricant, which produces acids. In engines strong acids are produced from combustion. Acids attack the intergranular matrix, as seen in Figure 8. In addition, further corrosion will break out larger grains of material resulting in bearing failure.

Figure 8. Acids attacking the intergranular matrix.

Figure 9. A bearing which shows the operating temperature above the overlay material melting point.

Bearing melting

Heat is generated in bearings by friction in the lubricant as it forms an oil wedge. By definition viscosity is the lubricant's resistance to shear; thus, higher viscosity lubricants and bearings operating under higher loads stabilize at higher operating temperatures. The bearing material chosen for any operation must have a melting point higher than the operating temperature. Figure 9 shows a bearing where the operating temperature was above the overlay material melting point.

The extra friction in a section of the load zone from a high spot in the bearing will cause a localized failure. Since bearings are generally precision components, high spots are caused by a solid object lodged behind the bearing shell. An example of this is shown in Figure 10.

Final failure

Ultimately bearings fail because the bond between the steel back and the bearing material breaks down, and the bearing material delaminates from the steel back. Failure of this bond is caused by abnormally high temperatures generated in the load zone by the real cause of the failure. Figure 11 shows the bearing delaminating from the steel back of a bearing.

After the bearing material has been lost from a bearing, the resultant excessive clearance between the steel back and journal in a reciprocating application, such as an engine, allows the extra momentum to pound and flatten the steel back. Consequently, after a typical failure all that is left is the deformed pieces of steel bearing backing that can be seen in Figure 12, which don't tell what caused the failure in the first place.

Conclusion

When considering any excessive bearing wear or failure, look at as many bearings and as much of the system as possible and consider the overall dynamics of the system. The real cause of failure is usually lost in the failed bearing but normally will still be present on other bearings in the system. Remember that all the bearings normally see the same operating conditions, but that one bearing has to fail first. **<<**

For further reading:

Neale, M.J. (1995), *Component Failures Maintenance and Repair: A Tribology Handbook*, Butterworth-Heinemann.

Oil and Your Engine, Caterpillar publication, (SEBD0640-020).

Bearing Damage, Glacier Metal Co. publication, (ILM0003).

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Figure 10.

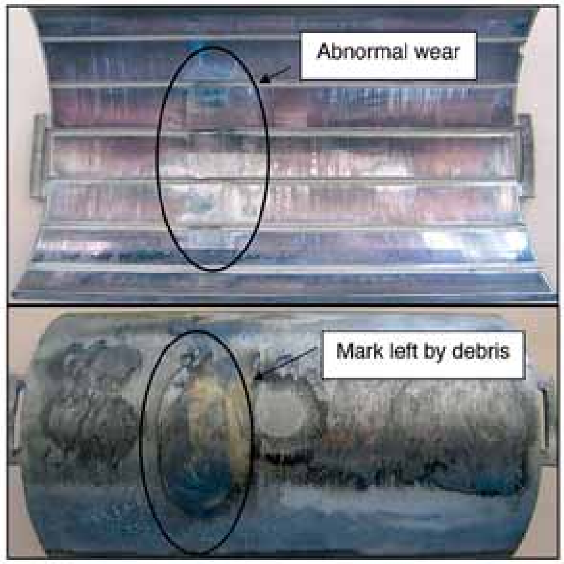

Figure 11. A bearing delaminating from the steel back of a bearing.

Figure 12. Deformed pieces of steel bearing backing.