Mike Johnson / Contributing Editor

Selecting the correct lubrica

Lubricant selection for plain bearing applications requires consideration of many inter-related machine conditions.

KEY CONCEPTS:

- Reducing lubricant selection for a plain bearing down to practical guidance is difficult. Plain bearing design includes 20-plus variables, including aspects of build design and materials and lubricant considerations.
- Plain bearings can be used in a variety of applications; however, there is no single set of criteria that can be used. Selection depends on the equipment design and operating conditions.
- Grease selection begins with consideration of the oil. Heavy oils are used to formulate greases used for manual lubrication of plain bearings in high-duty service.

In the August TLT we discussed element bearings in the first of two articles addressing lubricant selection. This month we'll provide guidelines that can be followed to select lubricants with the correct chemical and viscometric qualities necessary for long-term, reliable operation of plain bearings.

Reducing lubricant selection for a plain bearing down to a few pages of practical guidance is difficult. Plain bearing design includes 20-plus variables, including aspects of the build design and materials (bearing size, shaft radius, clearance, frictional force, friction coefficient, shaft speed, eccentricity, etc.) and the lubricant considerations (viscosity, viscosity index, pressure viscosity index, lubricant-specific heat, temperature, supply rate, egress rate, recirculation flow rate, etc.).

This article provides a simplistic overview of the broad aspects of lubricant selection. For those with an appetite for details, I recommend Dr. Michael Khonsari's *The Tribology Data Handbook*.[1] A less detailed review is provided effectively by Michael J. Neale in *The Tribology Handbook, 2nd Edition*.[2]

PLAIN BEARINGS

Plain bearings and bushings come in a wide variety of shapes, sizes, types of surface contact modes, material compositions and operating profiles, including:

- Single-sided
- Double-sided
- Vertical shaft
- Horizontal shaft
- Solid housing
- Split housing
- Clinched housing
- Thin wall
- Thick wall

nt for plain bearings

- Vertically loaded
- Horizontally loaded
- Thrust bearings
- Segmented thrust bearings
- Spherical bearings and bushings
- Oscillatory bearings
- Linear bearings
- Ball joints and more.

Machine design textbooks, including the texts noted above, dedicate significant space to the illustration of the differences between the design, installation and application of these varied types of components. Lubricant type and grade are two of the many criteria that represent variables that must be solved in order to arrive at a reliable and useful design.

Plain or journal bearings are used for high radial loads (perpendicular to the axis of the shaft) and low- to high-speeds. Typical applications include turbines, large milling systems, engine cranks, compressors, gearboxes, shaft bearing supports, etc. Every journal bearing has some common design characteristics, as shown in Figure 1.

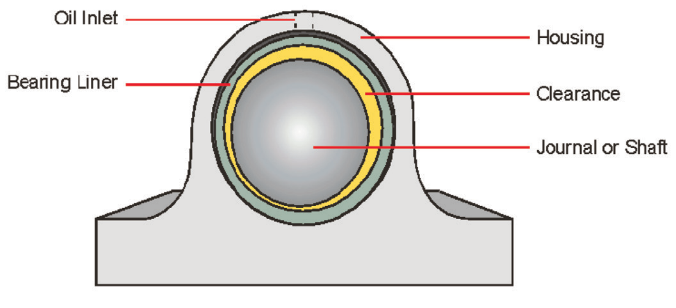

Figure 1 | **Pillow-block style journal bearing** *(Courtesy of Trico Corp.)*

The components that are separated by the oil film in a plain bearing are the bearing liner and the shaft. The shaft is composed of high-quality, wear-resistant, structurally strong steel. The bearing liner may be made of a single layer or multiple layers, depending on the design features of the equipment (*see Figure* 2).

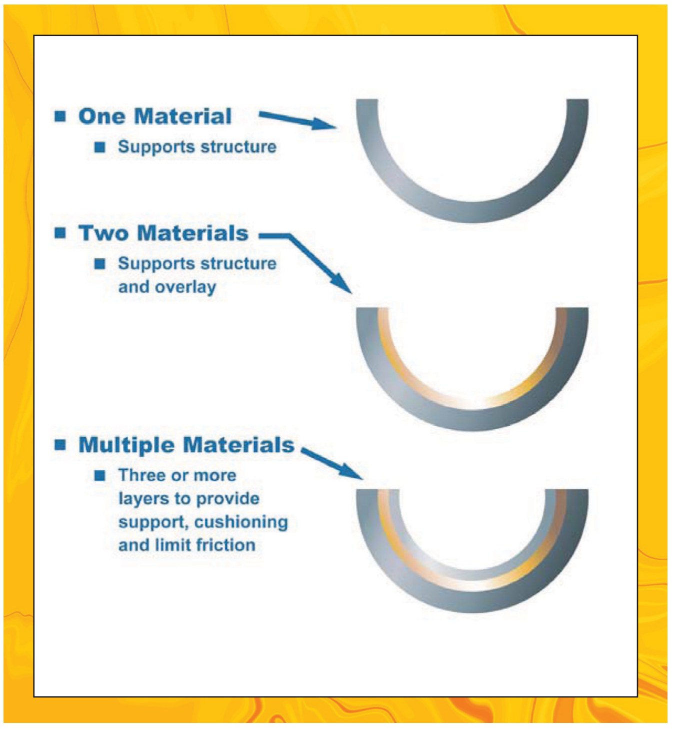

Figure 2 | **Journal bearing construction** *(Courtesy of Trico Corp.)*

LUBRICATION REGIME

If the journal bearing is assumed to be steadily loaded, and flow is laminar (non-turbulent) and the fluid is incompressible and linearly viscous (Newtonian) and there are no transient effects, then the dimensionless Reynolds equation is used to calculate the design requirements.[3]

Under normal operating conditions, the lubrication regime is a hydrodynamic full-fluid film. A hydrodynamic film occurs when there is sufficient lubricant between the lubricated surfaces at the point of loading to form a fluid wedge that separates the sliding surfaces. In this state, the lubricated components do not touch each another, reducing friction and wear.

In the March TLT we explained this idea and characterized this in the form of the Stribeck Curve. This condition is represented by the equation Z*N/P, where Z = viscosity, N = speed (rpm) and P = load. Figure 4 is a representation of the conditions that occur when plain surfaces accelerate

Operating under proper speed, surface area, viscosity and oil volume, a plain bearing can support very heavy loads.

to normal speeds. The box at the top left of Figure 3 reflects a state called Boundary Film condition.

The box on the lower right side of Figure 3 represents a state of complete surface separation that occurs once the machine has reached its normal operating speed and load, and the viscosity selected for the machine is appropriate for those conditions.

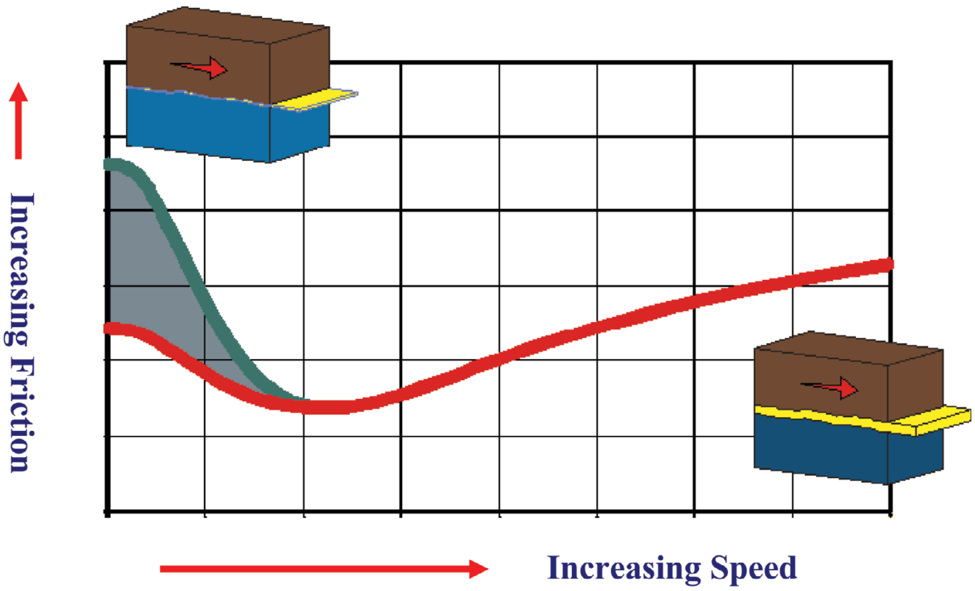

Figure 3 | **The Stribeck Curve** *(Courtesy of Lubcon Consult GMBH)*

A state that lies between full (boundary) contact and full (hydrodynamic) fluid separation can occur within many machine types, particularly slowly moving, heavily loaded plain bearings. This is referred to as Mixed Film condition. This condition may occur in response to changes in surface area, machine running speed, sump operating temperature or in response to variations in loading (AKA shock-loading) that can collapse the film, resulting in physical contact of machine surfaces. Figure 4 depicts the changes in relative position of two interacting surfaces, as the machine moves from a dead stop to its full operating speed. Values r represents average surface roughness, and h represents film thickness.

VISCOSITY REQUIREMENTS

Operating under proper speed, surface area, viscosity and oil volume, a plain bearing can support very heavy loads. The balance between these conditions is important. If the load or the speed changes, the lubricant viscosity must be adjusted to compensate for the change. While there is no simple, single equation that can be used to estimate the ideal lubricant viscosity for a state of operating conditions, the following approximation gives an estimate of what the final outcome should be.

The first step is to estimate the machine's surface speed, u. That estimate is done as follows:

$$\mathbf{u = \pi * d * n}$$

Where **u** = surface speed
d = bore diameter, meters
n = shaft speed, revolutions per second
π = 3.1415

The next step is to estimate the machine's unit surface pressure, based on machine total load in kilonewtons per square meter of surface area.

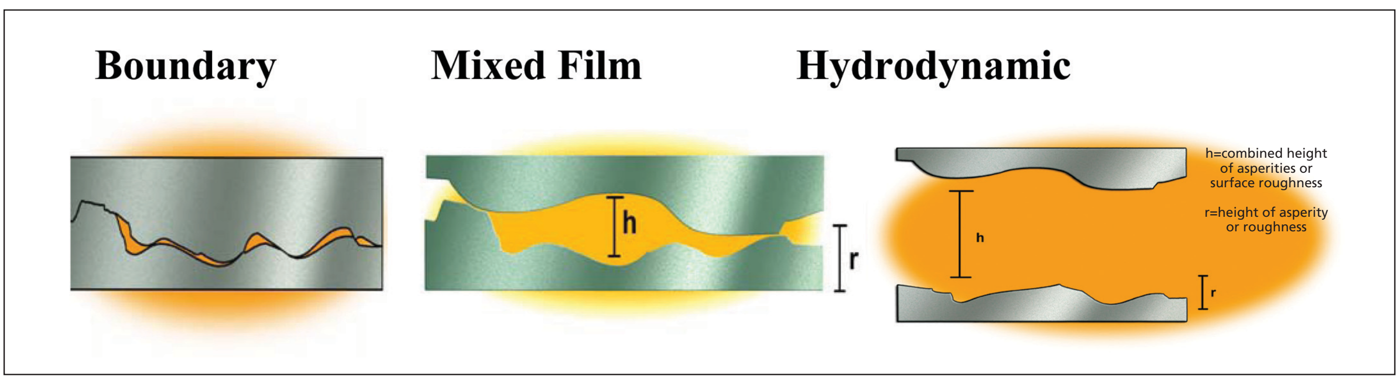

Figure 4 | **States of machine surface separation based on change in film thickness**

$$\rho = \frac{\mathbf{W}}{\mathbf{l} * \mathbf{d}}$$

Where ρ = pressure, kN/m2
l = bearing width
d = shaft diameter
W = load, kN (Kilonewtons)

Once known these values can be plotted on a table for a rough estimate of minimum allowable viscosity, as shown by the red and blue lines on Figure 5.[4] The target viscosity is noted on the Y axis, shown as 30 cPs (centipoise) at the machine average operating temperature. The reliability engineer still needs to evaluate available lubricants to assure that the selected target, in fact, will provide at least 30 cPs at operating temperature.

***Note**: This is intended only to be a rough approximation for the sake of illustrating the principles behind lubricant selection. Please consult with a lubrication engineering professional prior to attempting to make any change in the lubricant selection for any actual operating machines.*

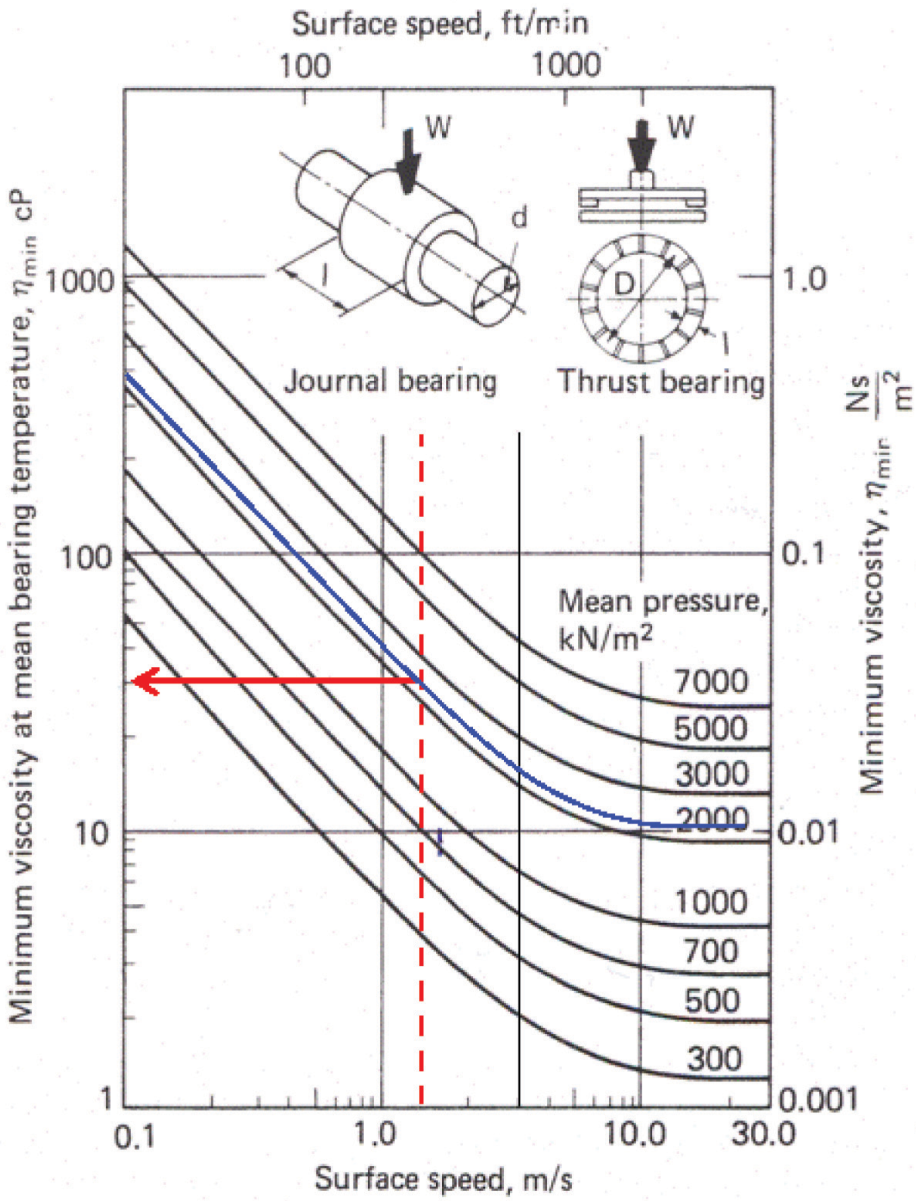

Figure 5 | **Viscosity estimation chart based on actual speed and unit loads** *(Courtesy of The Tribology Handbook, Second Edition, Michael J. Neale)*

OTHER CONSIDERATIONS

The final lubricant type decision should include considerations for oxidation stability, corrosion protection, wear protection, water and air-separation properties, etc. Because plain bearings can be used in a variety of applications, there is no single set of criteria that can be used. Selection depends on the equipment design and operating conditions.

Plain bearings are normally oil-lubricated but may be lubricated with grease for slow-speed equipment, particularly if they are subject to frequent starts and stops or the bearings are physically difficult to reach.

The type and amount of grease depends on the replenishment rate of the body of grease that is held within the dynamic clearances. Equipment with poor sealing characteristics may require a heavier body of lubricant and more frequent replenishment cycles. Under manual (intermittent) relubrication, the volume and the frequency are influenced by operating conditions, grease quality and available time for the task.

Grease selection begins with consideration of the oil. Heavy oils are used to formulate greases used for manual lubrication of plain bearings in high-duty service. After the target viscosity has been established, the soap thickener, oxidation and rust characteristics, worked consistency properties, pumpability (for automatic systems) and load-bearing (AW) properties are considered. For long resupply intervals and obvious intermittent loading, solid-film agents such as molybdenum disulfide or graphite may be incorporated. The solid additives serve to mechanically prevent metal contact in mixed film and boundary lubrication conditions.

Lubricants should be applied to the bearing in front of the load zone and at the location of the grease grooves used for lubricant distribution.

CONCLUSION

Lubricant selection, particularly viscosity selection, for journal bearings and other sliding surfaces is not a simple task. The correct viscosity selection is integral to a variety of other design objectives and is established through careful iterative calculations. The principle for journal bearings is simple: As machine speed increases, the lubricated surfaces feed lubricant into the load zone at a rate high enough to cause the lubricant to pile up and create a pressure wedge.

Once the pressure is high enough, it lifts and separates the machine surfaces. Boundary, mixed film and hydrodynamic films are created during routine operation of sliding bearings. The lubricant film can be calculated based on the Reynolds equation once all the factors are known. After selecting the optimum viscosity, considerations are made for shock-loading, corrosion protection, air- and water-separation characteristics and application method. Grease grade, flow properties and thickener type finally come into consideration.

Lubricant selection for plain and journal bearing applications should only be done in concert with the assistance of a recognized lubrication engineering specialist. TLT

Mike Johnson, CLS, CMRP, MLT, is the principal consultant for Advanced Machine Reliability Resources, in Franklin, Tenn. You can reach him at ***mike.johnson@precisionlubrication.com****.*

1.*The Tribology Data Handbook, Ch. 61: Journal Bearing Design and Analysis, CRC Press-STLE.*

2. *The Tribology Handbook, Section C7: Plain Bearing Lubrication, Butterworth Heinemann Publishers.*

3. *Ibid i., p. 670.*

4. *Ibid ii, p. C7.2*

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