

Journal Bearings and Their Lubrication

Robert Scott, Noria Corporation

Journal or plain bearings consist of a shaft or journal which rotates freely in a supporting metal sleeve or shell. There are no rolling elements in these bearings. Their design and construction may be relatively simple, but the theory and operation of these bearings can be complex. This article concentrates on oil- and grease-lubricated full fluid film journal bearings; but first a brief discussion of pins and bushings, dry and semi-lubricated journal bearings, and tilting-pad bearings.

Low-speed pins and bushings are a form of journal bearing in which the shaft or shell generally does not make a full rotation. The partial rotation at low speed, before typically reversing direction, does not allow for the formation of a full fluid film and thus metal-to-metal contact does occur within the bearing. Pins and bushings continually operate in the boundary lubrication regime. These types of bearings are typically lubricated with an extreme pressure (EP) grease to aid in supporting the load. Solid molybdenum disulfide (moly) is included in the grease to enhance the load-carrying capability of the lubricant. Many outdoor construction and mining equipment applications incorporate pins and bushings. Consequently, shock loading and water and dirt contamination are often major factors in their lubrication.

Dry journal bearings consist of a shaft rotating in a dry sleeve, usually a polymer, which may be blended with solids such as molybdenum, graphite, PTFE or nylon. These bearings are limited to low-load and low-surface speed applications. Semi-lubricated journal bearings consist of a shaft rotating in a porous metal sleeve of sintered bronze or aluminum in which lubricating oil is contained within the pores of the porous metal. These bearings are restricted to low loads, low-to-medium velocity and temperatures up to 100°C (210°F).

Tilting-pad or pivoting-shoe bearings consist of a shaft rotating within a shell made up of curved pads. Each pad is able to pivot independently and align with the curvature of the shaft. A diagram of a tilt-pad bearing is presented in Figure 1. The advantage of this design is the more accurate alignment of the supporting shell to the rotating shaft and the increase in shaft stability which is obtained.¹ An article on tilting-pad bearings appeared in the March–April 2004 issue of *Machinery Lubrication* magazine.



Figure 1. Kingsbury Radial and Thrust Pad Bearing

Journal bearings are meant to include sleeve, plain, shell and babbitt bearings. The term babbitt actually refers to the layers of softer metals (lead, tin and copper) which form the metal contact surface of the bearing shell. These softer metals overlay a stronger steel support shell and are needed to cushion the shell from the harder rotating shaft.

Simple shell-type journal bearings accept only radial loading, perpendicular to the shaft, generally due to the downward weight or load of the shaft. Thrust or axial loads, along the axis of the shaft, can also be accommodated by journal bearings designed for this purpose. Figure 1 shows a tilt-pad bearing capable of accepting both radial and thrust loads.

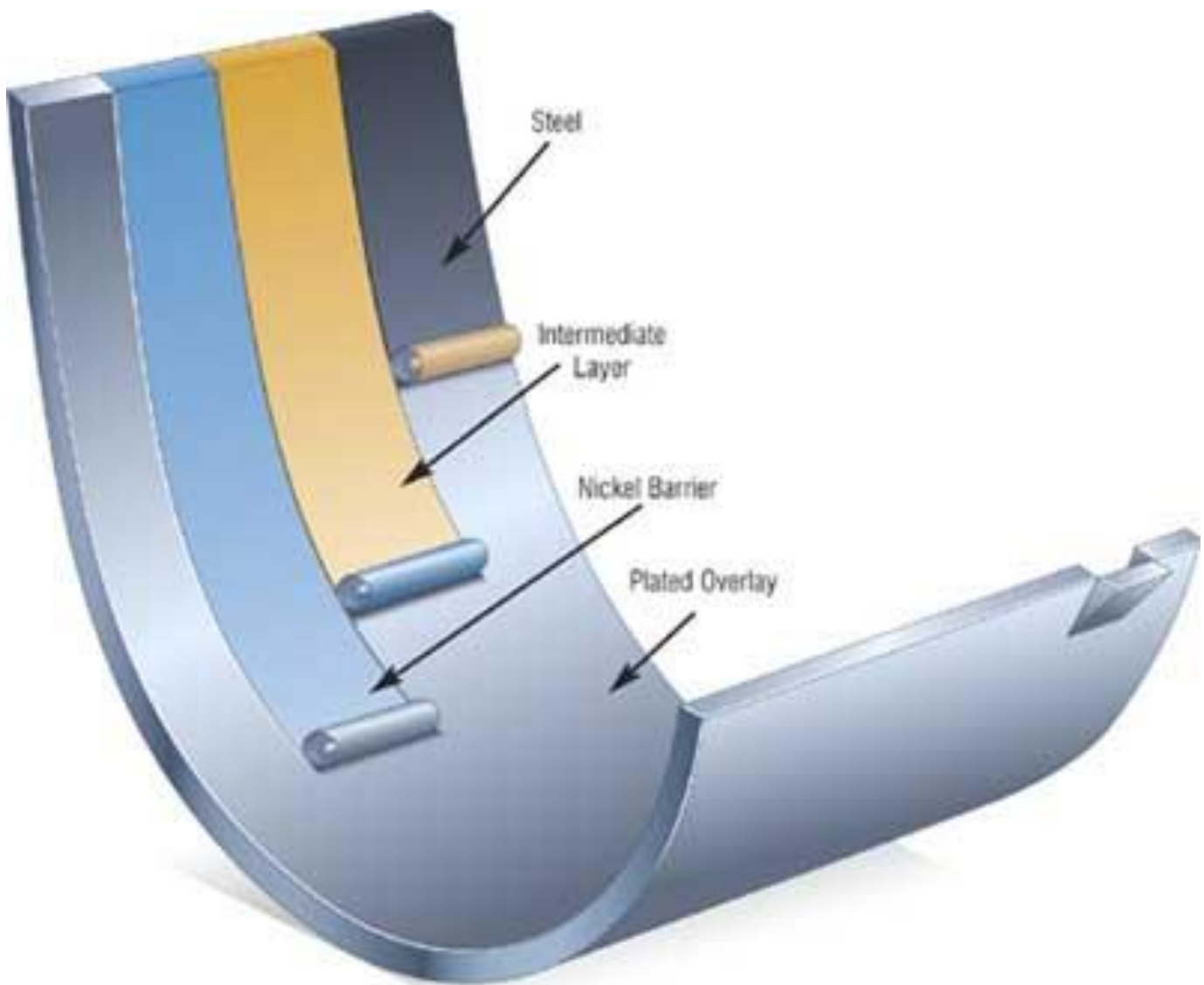


Figure 2. Layers of Journal Bearing Structure

Journal bearings operate in the boundary regime (metal-to-metal contact) only during the startup and shutdown of the equipment when the rotational speed of the shaft (journal) is insufficient to create an oil film. It is during startup and shutdown when almost all of the damage to the bearing occurs.² Information on plain bearing failures was discussed in an article in the July - August 2004 issue of *ML* magazine. Hydrostatic lift, created by an external pressurized oil feed, may be employed to float large, heavy journals prior to startup (shaft rotation) to prevent this type of damage. During normal operation, the shaft rotates at sufficient speed to force oil between the conforming curved surfaces of the shaft and shell, thus creating an oil wedge and a hydrodynamic oil film. This full hydrodynamic fluid film allows these bearings to support extremely heavy loads and operate at high rotational speeds. Surface speeds of 175 to 250 meters/second (30,000 to 50,000 feet/minute) are common. Temperatures are often limited by the lubricant used, as the lead and tin babbitt is capable of temperatures reaching 150°C (300°F).

It is important to understand that the rotating shaft is not centered in the bearing shell during normal operation. This offset distance is referred to as the eccentricity of the bearing and creates a unique location for the minimum oil film thickness, as illustrated in Figure 3.



Figure 3. Shaft Motion During Startup

Normally, the minimum oil film thickness is also the dynamic operating clearance of the bearing. Knowledge of the oil film thickness or dynamic clearances is also useful in determining filtration and metal surface finish requirements. Typically, minimum oil film thicknesses in the load zone during operation ranges from 1.0 to 300 microns, but values of 5 to 75 microns are more common in midsized industrial equipment. The film thickness will be greater in equipment which has a larger diameter shaft. Persons requiring a more exact value should seek information on the Sommerfeld Number and the Reynolds Number. Discussion of these calculations in greater detail is beyond the scope of this article. Note that these values are significantly larger than the one-micron values encountered in rolling element bearings.

The pressures encountered in the contact area of journal bearings are significantly less than those generated in rolling bearings. This is due to the larger contact area created by the conforming (similar curvature) surfaces of the journal and the shell. The mean pressure in the load zone of a journal bearing is determined by the force per unit area or in this case, the weight or load supported by the bearing divided by the approximate load area of the bearing (the bearing diameter times the length of the bearing). In most industrial applications, these values range from 690 to 2,070 kPa (100 to 300 psi). At these low pressures, there is virtually no increase in the oil viscosity in the bearing contact area due to pressure. Automotive reciprocating engine bearings and some severely loaded industrial applications may have mean pressures of 20.7 to 35 MPa (3,000 to 5,000 psi). At these pressure levels, the viscosity may slightly increase. The maximum pressure encountered by the bearing is typically about twice the mean value, to a maximum of about 70 MPa (10,000 psi).

Oil whirl is a phenomenon that can occur in high-speed journal bearings when the shaft position within the shell becomes unstable and the shaft continues to change its position during normal operation, due to the fluid forces created within the bearing. Oil whirl may be reduced by increasing the load or changing the viscosity, temperature or oil pressure in the bearing. A permanent solution may involve a new bearing with different clearances or design. Oil whip occurs when the oil whirl frequency coincides with the system natural frequency. The result can be a catastrophic failure.³

Oil Lubrication

Oils are used in journal bearings when cooling is required or contaminants or debris need to be flushed away from the bearing. High-speed journal bearings are always lubricated with oil rather than a grease. Oil is supplied to the bearing by either a pressurized oil pump system, an oil ring or collar or a wick. Grooves in the bearing shell are used to distribute the oil throughout the bearings' surfaces.

The viscosity grade required is dependent upon bearing RPM, oil temperature and load. The bearing speed is often measured strictly by the revolutions per minute of the shaft, with no consideration of the surface speed of the shaft, as per the “ndm” values calculated for rolling bearings. Table 1 provides a general guideline to selecting the correct ISO viscosity grade.

The ISO grade number indicated is the preferred grade for speed and temperature range. ISO 68- and 100-grade oils are commonly used in indoor, heated applications, with 32-grade oils being used for high-speed (10,000 RPM) units and some outdoor low-temperature applications. Note in the table that the higher the bearing speed, the lower the oil viscosity required; and that the higher the operating temperature of the unit, the higher the oil viscosity that is required. If vibration or minor shock loading is possible, a higher grade of oil than the one indicated in Table 1 should be considered.

Bearing Speed (rpm)	Bearing / Oil Temperature (°C)			
	0 to 50	60	75	90
300 to 1,500	-	68	100 to 150	-
~1,800	32	32 to 46	68 to 100	100
~3,600	32	32	46 to 68	68 to 100
~10,000	32	32	32	32 to 46

Table 1. Journal Bearing ISO Viscosity Grade Selection

Another method of determining the proper viscosity grade is by applying minimum and optimum viscosity criteria to a viscosity-temperature plot. A generally accepted minimum viscosity of the oil at the operating temperature for journal bearings is 13 cSt, although some designs allow for an oil as thin as 7 or 8 cSt at the operating temperature. The optimum viscosity at operating temperature is 22 to 35 cSt, for moderate-speed bearings if no shock loading occurs. The optimum viscosity may be as high as 95 cSt for low-speed, heavily loaded or shock-loaded journal bearings.

Using this method requires some knowledge of the oil temperature within the bearing under operating conditions, which can be difficult to determine. Fortunately, an accurate oil temperature is not needed for most viscosity determinations. It is common to determine the temperature of the outer surface of the pipes carrying oil to and away from the bearing. The temperature of the oil inside of the pipes will generally be higher (5 to 10 度, 10 to 18 度) than the outer metal surface of the pipe. The oil temperature within the bearing can be taken as the average of the oil entering versus the temperature exiting the bearing.⁴

A third and more complex method is to calculate the oil viscosity needed to obtain a satisfactory oil film thickness. Persons wishing to learn more about this method should seek information regarding the Sommerfeld equation and either eccentricity ratios or Reynolds Numbers.⁴

If the oil selected is too low in viscosity, heat will generate due to an insufficient film thickness and some metal-to-metal contact will occur. If the oil is too high in viscosity, heat will again be generated, but due to the internal fluid friction created within the oil. Selecting an oil which is too high in viscosity can also increase the likelihood of cavitation. The high- and low-pressure zones, which are created within the oil on each side of the area of minimum film thickness, can cause oil cavitation in these bearings. Cavitation is a result of expansion of dissolved air or a vapor (water or fuel) in the low-pressure zone of the bearing. The resulting bubble implodes, causing damage, as it passes through the high-pressure portion of the bearing. If the implosion or collapse of the vapor bubble occurs next to the metal surface, this can cause cavitation pitting damage to the metal. If the implosion of the bubble occurs within the oil, a micro hot spot or micro-dieseling can occur, which may lead to varnishing within the system.

Typically, a rust and oxidation (R&O) inhibited additive system is used in the oils employed in these applications. Antifoam and pour point depressant additives may also be present. Antiwear (AW) hydraulic oils may also be used as long as the high-temperature limit of the zinc AW component is not exceeded and excessive water is not present. R&O oils tend to have better water separation characteristics, which is beneficial, and the AW properties of a hydraulic oil would be beneficial only during startup and shutdown, assuming a properly operating bearing.

Grease Lubrication

Grease is used to lubricate journal bearings when cooling of the bearing is not a factor, typically if the bearing operates at relatively low speeds. Grease is also beneficial if shock loading occurs or if the bearing frequently starts and stops or reverses direction. Grease is almost always used to lubricate pins and bushings because it provides a thicker lubricant than oil to support static loads and to protect against vibration and shock-loading that are common in many of these applications.

Lithium soap or lithium complex thickeners are the most common thickeners used in greases and are excellent for most journal bearing applications. The grade of grease used is typically an NLGI grade #2 with a base oil viscosity of approximately 150 to 220 cSt at 40°C. Greases for low-speed, high-load, high temperatures and for pins and

TECHNICAL INFORMATION

bushings may use a higher viscosity base oil and be formulated with EP and solid additives. Greases for improved water resistance may be formulated with heavier base oils, different thickeners and special additive formulations. Greases for better low-temperature dispensing may incorporate a lower viscosity base oil manufactured to an NLGI #1 specification. Bearings lubricated by a centralized grease dispensing systems typically use a #1, 0 or 00 grade of grease.

The apparent viscosity of grease changes with shear (pressure, load and speed) that is, greases are non-Newtonian or thixotropic. Within a rotating journal bearing, as the bearing rotates faster (shear rate increases), the apparent viscosity of the grease decreases and approaches the viscosity of the base oil used in grease. At both ends of the bearing shell, the pressure is lower and therefore the apparent viscosity remains higher. The resulting thicker grease at the bearing ends acts as a built-in seal to reduce the ingress of contaminants.

Greasing Procedures

The greasing procedures for journal bearings and pins and bushings are not as well-defined or as critical as for rolling bearings because the grease is not subjected to the churning action created by the rolling elements. The volume of grease to inject and the frequency of application are dictated more by trial and error. Generally, most journal bearings cannot be overgreased. Caution must be taken when pumping grease into a bearing that is fitted with seals, so they are not damaged or displaced by the force and volume of the incoming grease. The harshness of the environment, shock loading and especially the operating temperature will be major factors in determining the frequency of relubrication.

Journal bearings are generally a simpler design and not as difficult to lubricate as rolling element bearings. The proper viscosity matched to the operating conditions and a clean and dry lubricant will usually suffice to form a full fluid lubricating film and provide excellent bearing life.

References

1. Strecker, William. "Troubleshooting Tilting Pad Thrust Bearings." *Machinery Lubrication* magazine, March-April 2004.
2. Strecker, William. "Failure Analysis for Plain Bearings." *Machinery Lubrication* magazine, July-August 2004.
3. Berry, James. "Oil Whirl and Whip Instabilities within Journal Bearings." *Machinery Lubrication* magazine, May-June 2005.
4. *Tribology Data Handbook*. Chapter 61, Journal Bearing Design and Analysis. Khonsari, M. CRC Press, 1997.

Editor's Note:

All articles from past issues of *Machinery Lubrication* magazine can be read online at www.machinerylubrication.com. Portions of this article have been previously published in the Society of Tribologists and Lubrication Engineers (STLE) Alberta Section, *Basic Handbook of Lubrication*, Second Edition, 2003.

Please reference this article as:

Robert Scott, Noria Corporation, "Journal Bearings and Their Lubrication". *Machinery Lubrication* Magazine. July 2005

Issue Number: 200507
Machinery Lubrication
Lubricant Application