Bearing Solutions for High-Speed Gearbox Applications

Lufkin-RMT has developed a tilting pad bearing that’s able to withstand high gear loads and ultra-high surface velocities.

By John C. Nicholas, Ph.D.
Another motivation to operate at higher surface speeds has been driven partly by the stringent American Petroleum Institute (API) rotordynamics specifications that gearbox manufacturers must adhere to in order to sell their equipment. Large journal diameters produce stiffer shaft ends, and thus less severe critical speeds at higher frequencies. This allows higher speed operation while still meeting the API rotordynamics specification for separation margin. Also, large pinion journal diameters are often required to transmit the higher torque ratings. However, larger diameter journals result in high surface velocities, often exceeding 90 m/s.

The journal surface velocity (Us) limit often quoted by bearing designers is 300 ft/sec, 90 m/s. Operation above this speed limit on conventional tilting pad bearings with Babbitted steel pads often results in excessive operating temperatures.

The tilting pad journal bearing unit load, Lu, is defined as the journal resultant load (gravity plus gear) divided by the product of the bearing diameter times the pad axial length. API specifies a bearing unit load limit of 500 psi, 3.45 MPa.

One problem associated with conventional tilting pad bearings is that the inlet oil is preheated prior to entering the pad’s leading edge. Another problem with conventional tilting pad bearings is that a substantial portion of the oil that exits the pad’s trailing edge stays on the shaft and transported into the leading edge of the downstream pad. This is called hot oil carryover. The generally accepted value for the amount of hot oil carryover is 60 percent. Thus, only 40 percent of the inlet oil enters the pad leading edge but only after it is preheated from mixing. Clearly, in order to operate at higher surface velocities, newer and more-innovative tilting pad bearing designs must utilize the cool inlet oil more effectively.

To address bearing operation in excess of 90 m/s, Lufkin-RMT developed the tilting pad Ultra Bearing (figs. 1, 2). This bearing features four chrome copper tilting pads...
with heavy pad pivot offset. The pad locations are oriented such that the resultant load (gear plus gravity) is directed between pivots. The bearing housing is generally evacuated and without end seals, but flooded housings may also be utilized in some applications where the oil flow rate is a concern. Other special features include Spray-Bar Blockers and Behind-The-Pad By-Pass Cooling.

The Spray-Bar Blocker was developed by Lufkin-RMT to handle increasingly severe applications where the efficient use of the cool inlet oil is necessary. The Spray-Bar Blocker sits directly in front of each loaded pad and effectively blocks much of the pad-to-pad hot oil carryover, directing that hot oil through wide-open end plates and directly into the drain. It also sprays cool inlet oil directly into the leading edge of the downstream pad. Besides allowing the cool inlet oil to directly enter the pad’s leading edge, the design prevents the trailing
edge hot oil and the cool inlet oil from mixing. A Spray-Bar-Blocker is shown between all four pads in fig. 1, and in the center of fig. 2.

Behind-The-Pad By-Pass Cooling is a cooling scheme developed by Lufkin-RMT that utilizes cool inlet oil to transfer heat away from the pad’s Babbitt surface. With Babbitted chrome copper pads and circumferential heat transfer chambers (left side of fig. 2), cool inlet oil is directed onto the back of the pad and into the heat transfer grooves. Spray-Bar Blockers direct the By-Pass Cooling oil directly into the housing drain. The By-Pass Cooling oil does not participate in lubricating the bearing, but serves only to transfer heat. This design takes advantage of the high thermal conductivity of chrome copper which is a factor of six above steel and bronze.

Lufkin-RMT’s tilting pad bearing severe application experience plot is shown in fig. 3, with journal surface velocity plotted on the horizontal axis and bearing unit load plotted on the vertical axis. All applications shown on the plot are for geared systems, mostly Lufkin gearboxes. As previously noted, the API specified bearing unit load limit is 3.45 MPa, 500 psi. Applications shown above this limit are non-API gearboxes used in test stand applications. The red dots represent Ultra Bearings with the features discussed previously, while the blue dots represent steel pad bearings that retain some of the Ultra Bearings features also discussed.

Note that there are many API Lufkin gearbox applications shown on the plot that are above 90 m/s, 300 f/s. Many of these would not be possible with a conventional steel pad bearing. The Ultra Bearing has allowed Lufkin to design API gearboxes whose bearings operate at a surface velocity all the way up to 120 m/s, 395 f/s. Additionally, the Ultra Bearing has allowed Lufkin to design non-API test stand gearboxes with bearing surface velocities approaching 140 m/s, 460 f/s.

Figure 4 is a plot comparing a steel pad bearing to the Ultra Bearing. Inlet oil temperature is plotted on the horizontal axis with the bearing’s maximum operating temperature, Tmax, plotted on the vertical axis. Tmax is the embedded temperature sensor reading. Only one sensor was available for the steel pad bearing while the Ultra Bearing had four embedded sensors in the loaded pads.

The test data from fig. 4 was taken at a constant speed of 10,580 rpm. With a journal diameter of 200mm, 7.87", this results in a surface velocity of 112 m/s, 368
f/s, well above the conventional bearing limit of 90 m/s. The bearing unit load was held constant at 2.1 MPa, 305 psi.

Clearly, fig. 4 shows an almost constant temperature drop of 15 °C for the Ultra Bearing over the entire inlet temperature range. For example, at Tin = 55 °C, 131 °F, the steel pad bearing’s sensor reading is 108 °C, 226 °F, while the average Ultra Bearing sensor reading is 93 °C, 199 °F.

Additional test data for a 127mm, 5.0” Ultra Bearing is illustrated in figs. 5 and 6. Figure 5 is a plot of Tmax data vs. journal surface velocity at a constant bearing unit load of 3.45 MPa, 500 psi. Readings from two loaded pad embedded temperature sensors are potted on the vertical axis.

At Us = 120 m/s, 395 f/s the sensor readings are 91 °C, 196 °F, and 100 °C, 212 °F.

Also plotted in fig. 5 is the analytically predicted Tmax value calculated from the Lufkin-RMT tilting pad computer code, XLTitpad. Note that XLTitpad predicts conservatively below 85 m/s, 280 f/s. Above 85 m/s, XLTitpad predicts Tmax values that are right between the two sensor readings.

Figure 6 is a plot of Tmax data vs bearing unit load at a constant surface velocity of 106 m/s. Readings from two loaded pad embedded temperature sensors are potted on the vertical axis. At Lu = 5.9 MPa, 855 psi, 71 percent above the API load limit, the sensor readings are 99 °C and 103 °C.

In summary, from the test data and extensive experience history, the Ultra Bearing is an extremely efficient tilting pad bearing that is able to withstand both high gear loads and ultra high surface velocities that range up to 140 m/s, 460 f/s. The Ultra Bearing’s performance under severe applications has provided Lufkin gearbox designers with the flexibility of operating at higher pinion speeds without compromising the integrity of the bearing.

REFERENCE:
Nicholas, J.C., "Tilting Pad Journal Bearings with Spray-Bar Blockers and By-Pass Cooling for High Speed, High Load Applications," Proceedings of the Thirty-Second Turbomachinery Symposium, Texas A&M University, College Station, TX, September 2003.

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