



Tilt-Pad Bearing Preload

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Fluid-film journal bearings provide the primary support for horizontal turbomachinery rotors. These bearings come in many configurations from simple fixed geometry to complex tilt-pad units such as the bottom-half bearing assembly (Fig. 1). Bearing design is dependent upon criteria such as load, speed, stability, rotor dynamics, lubricants, and cost. Within the array of design parameters, preload* is significant in controlling bearing performance, which ultimately impacts maintenance and operating costs.

* Preload is a dimensionless number describing the relationship between shaft and bearing-pad curvature, which combine to form the bearing oil wedge.

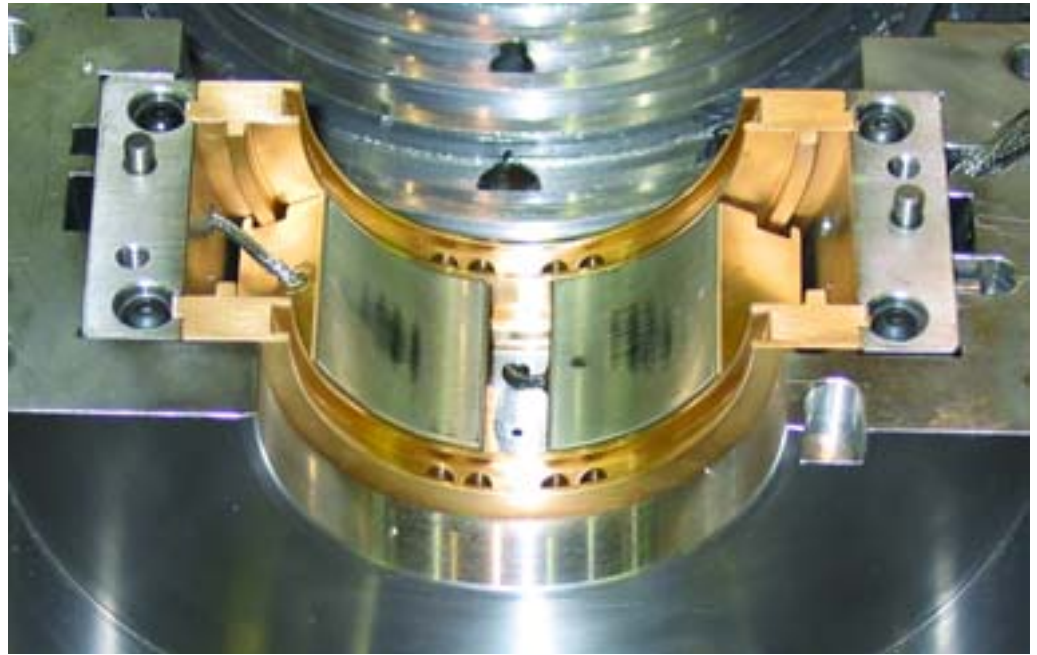
► Tilting pad bearings generally contain three to six pads. Orientation of the pads is defined as either load on pivot (LOP) or load between pivots (LBP). If a horizontal rotor has a single pad centered at the bottom of the bearing, an LOP condition exists. If two pads straddle the bottom centerline, then the bearing is referred to as an LBP. The pad rotation of an LBP bearing results in a drop of the shaft centerline below the LOP bearing (Fig.2). The amount of shaft drop is dependent on the bearing geometry. The diametrical clearance is related to a lift check performed with a dial indicator mounted next to the bearing, using the following factors:

	LOP	LBP
3 pads	$0.667 \times \text{lift}$	$0.667 \times \text{lift}$
4 pads	lift	$0.707 \times \text{lift}$
5 pads	$0.894 \times \text{lift}$	$0.894 \times \text{lift}$
6 pads	lift	$0.866 \times \text{lift}$

Multiplication of the lift by the appropriate factor provides a good approximation of the bearing diametrical, or, assembly clearance (C_{brg}). It is equal to the assembly bore diameter minus the journal diameter. It is also equal to the diameter of the largest mandrel that can be inserted into the bearing minus the journal diameter. For example, consider a four-pad LBP bearing with a measured lift of 0.216 mm (0.0085 inches). From the table, the correction factor is 0.707, and the clearance is easy to compute:

$$\begin{aligned}
 C_{brg} &= 0.707 \times \text{lift} \\
 &= 0.707 \times 0.216 \text{ mm (0.0085 inches)} \\
 &= 0.153 \text{ mm (0.006 inches)}
 \end{aligned}$$

The curvature of the tilt-pad shoes exceeds the shaft curvature (Fig.2). This characteristic provides a converging gap that forms the minimum oil film between bearing and shaft. The pad curvature is established prior to initial



1 Bottom half of tilt-pad bearing assembly.

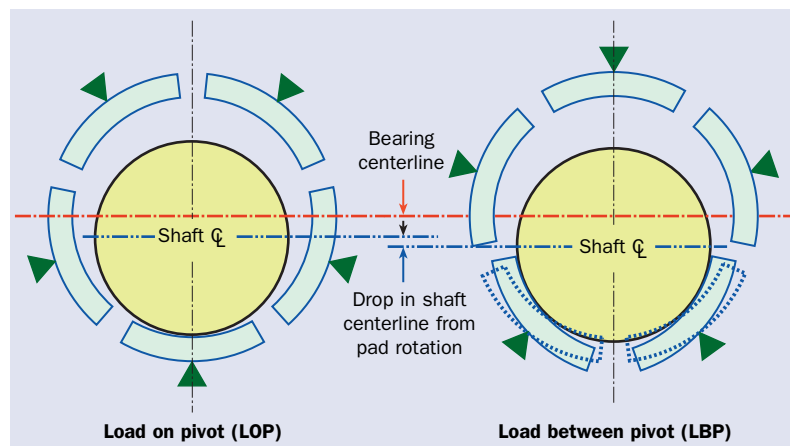
machining, and the diametrical pad clearance (C_{pad}) is equal to the machined pad bore diameter minus the journal diameter.

Bearing Preload

As the oil wedge clearance changes, bearing stiffness and damping are influenced. In order to provide a common method of describing these variations, the concept of preload is applied. Preload is often used to adjust bear-

ing coefficients in order to obtain specific rotor response characteristics. Since the translational first-critical and the pivotal second-critical speeds depend on bearing stiffness, proper selection of preload may be necessary to keep the rotor critical speeds out of the operating speed range. Bearing preload is defined as follows:

$$\text{Preload} = 1 - \frac{C_{brg}}{C_{pad}}$$



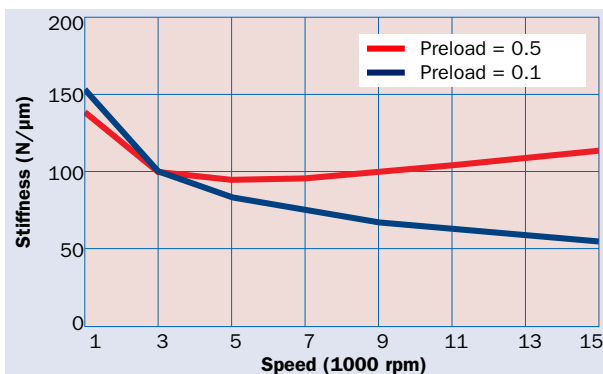
2 Pad deflection in a five-pad bearing. Pad rotation is evident in the LBP assembly.

The clearance values must be consistent—either radial or diametrical. For example, consider a 101.6 mm (4.000 inch) diameter shaft with a tilt-pad bearing that has a diametrical assembly clearance of 0.153 mm (0.006 inches). If this bearing has a machined pad bore diametrical clearance of 0.254 mm (0.010 inches), the preload is:

$$\begin{aligned}\text{Preload} &= 1 - \frac{C_{\text{brg}}}{C_{\text{pad}}} \\ &= 1 - \frac{0.153 \text{ mm (0.006 inches)}}{0.254 \text{ mm (0.010 inches)}} \\ &= 1 - 0.6 \\ &= 0.4\end{aligned}$$

Industrial machines usually have preloads between 0.1 and 0.5; this value may be changed by adjusting the bearing assembly clearance C_{brg} . For instance, ball-and-socket pad supports may be adjusted with flat shims located behind the ball seats. Decreasing the assembly clearance will increase preload; conversely, increasing the assembly clearance will decrease preload. Smaller clearances will reduce shaft vibration amplitudes at the expense of increased bearing temperatures. Conversely, increasing clearances will allow the bearing to run at a cooler temperature, but the shaft vibration will increase due to the lower oil film stiffness.

3 Stiffness vs. speed for two preload conditions.



Changes to the pad curvature and associated pad clearance generally require a new set of pads that are machined to the correct diameter. Occasionally, the pad radius may be slightly increased by manually grinding the pads on fine emery cloth wrapped around a properly dimensioned mandrel. Although this is a long and arduous process, production demands sometimes make it necessary to perform these types of field modifications.

Stiffness Calculations

The influence of preload may be demonstrated by computing coefficients with different preloads. For instance, consider the previous four-pad LBP bearing with an assembly clearance of 0.153 mm (0.006 inches) on a 101.6 mm (4.000 inch) diameter shaft, a bearing length of 76.2 mm (3.000 inches), a center pivot on each pad, and a load of 272 kg (600 pounds). For preload values of 0.1 and 0.5, the stiffness varies at speeds between 1000 and 15000 rpm (Fig. 3). Clearly the 0.5 preload provides significantly more stiffness than the 0.1 preload at all speeds above 3000 rpm.

Design Considerations

Since stiffness and damping change with preload, and since preload is dependant upon bearing clearances, it is important to compute the parameter changes between minimum and maximum clearances. These parameters are then used to examine the rotor response characteristics across the entire speed range and verify that the vibratory behavior is acceptable across the full clearance (and preload) range of the bearings. At Sulzer Hickham, it is mandatory to

fully examine the influence of these variables upon the rotor behavior for all designs.

Field Considerations

Preload is not only an important design tool, it is also useful in machinery troubleshooting. Clearance changes or variations in pad curvature due to attrition or physical damage will alter the preload. This may manifest as changes in machine vibration, ability to safely pass through critical speeds, full-speed synchronous response, and ability to tolerate external excitations. In essence, proper preload and associated bearing clearances may directly lower maintenance and operating costs for turbomachinery operation. ◀

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