INDUSTRIAL BEARING JOURNAL

Gear loads in horizontal gearboxes

At Miba, we routinely repair and manufacture sleeve and tilting pad journal bearings for gearboxes. Typically, these gearboxes are single or double helix parallel shaft design and are used as single stage speed increasers or reducers in critical service in a refinery or chemical plant. The two questions often asked are; "What is the load on these journal bearings?" and "Where should temperature sensors be located in these bearings?"

The load on the journal bearings in a gearbox is a function of the weight of the shafting, the gear pitch diameters, and the transmitted torque. For the purposes of this discussion we will ignore the axial forces generated (due to the helix angle) since they are accommodated by the thrust bearings and, quite often, the gears we work with have double helixes (sometimes called herringbone) where the axial forces cancel to zero.

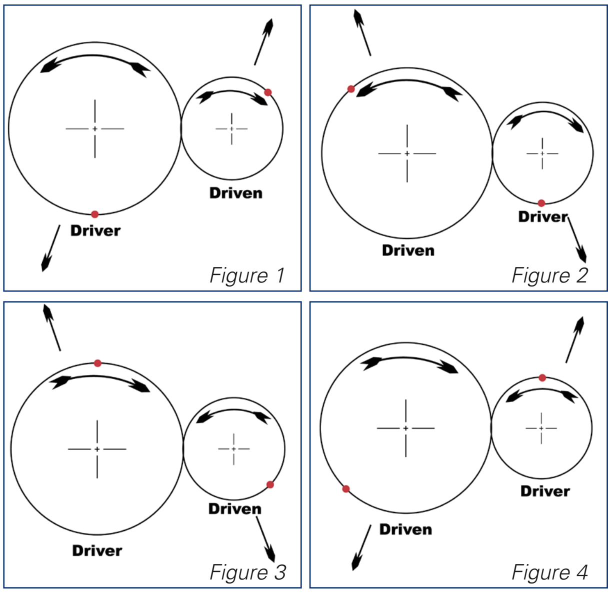

Figure 1 Figure 2 Figure 3 Figure 4

CALCULATING THE LOAD

Recall that the formula for torque is:

$$T = 63025 \times \frac{HP}{N}$$

Where T is the torque in inch-pounds, HP is the power transmitted by the gearbox in horsepower, and N is the speed of the shafting under consideration in rpm. The high-speed shaft is the pinion and the low speed shaft is the gear (or bull gear).

When torque is transmitted through a gear mesh there is a resulting tangential force and a radial (or separating) force transmitted to the journal bearings. The vectorial sum of these forces and the shaft weight determines the load and load direction on the bearings.

The tangential force is simply the torque transmitted divided by the pitch radius of the pinion or gear. Or:

$$WT = \frac{T}{\left(\frac{pd}{2}\right)}$$

Where Wt is the tangential force in pounds, pd is the pinion or gear pitch diameter in inches, and T is the torque transmitted for the appropriate shaft (in-lb).

Gear teeth are generated with a normal pressure angle (θ_n) and due to the helix angle (ψ), there is a corresponding transverse pressure angle (θ_t) for the tooth. This transverse pressure angle determines the angle of the load on the bearings because it determines the amount of radial force.

$$\tan\theta_t = \frac{\tan\theta_n}{\cos\psi}$$

A typical normal pressure angle is 20 degrees, and typical helix angles may be between 20 to 30 degrees.

The radial load (Wr) is calculated as follows:

$$Wr = Wt \times \tan\theta_t$$

Note: If the helix angle is unknown it can be assumed to be zero, this will have a minimal impact on the final analysis.

The bearing load, Wb, is calculated by dividing the total load equally between the two bearings (usually a good assumption) or:

$$Wb = \tfrac{1}{2} \times \sqrt{(Wt + Wrtr)^2 + Wr^2}$$

where Wrtr is the total shaft weight for the shaft under consideration. For this formula it is necessary to use a negative shaft weight if the shaft being considered is uploaded. If the shaft weights are not known, or cannot be estimated, they can usually be ignored since their contribution to the bearing loading is usually rather small.

THE LOAD ANGLE

The load angle can then be calculated using standard trigonometric relations. Note: For the gears discussed here the load angle is measured from the vertical centerline.

As discussed above the bearing loads are a vectorial sum of the tangential and radial gear loads and the rotor weight. If the rotor weight is ignored, then the load angle will be the transverse pressure angle. If the rotor weight is used, then the formula for the load angle is:

$$\text{angle} = \tan^{-1}\left(\frac{Wr}{Wt + Wrtr}\right)$$

Again, use a negative value for the rotor weight if the gear is uploaded.

LOAD DIRECTION AND TEMPERATURE SENSOR PLACEMENT

Figures 1 through 4 on page 1 generally illustrate the load direction for the four possible combinations of gearbox configurations being discussed. Note that the red circles denote the approximate location to place temperature instrumentation to accurately measure the hot spot in the bearings. API 613 (Special Purpose Gear Units for Petroleum, Chemical, and Gas Industry Services) refers to API 670 (Vibration, Axial Position, and Bearing Temperature Monitoring Systems) where it states that the operating position of the journal in the bearing must be
considered when deciding on temperature sensor locations.

"Bearing loads are a vectorial sum of the tangential and radial gear loads and the rotor weight"

API 613 also states that journal bearing loading should not exceed 500-psi unit load and the minimum oil film thickness should be at least .001 inches. Increased loads coupled with high journal speeds can result in elevated bearing temperatures. If you have hot running bearings in you gearbox please contact Miba for potential solutions.

EXAMPLE CALCULATION

As an example, we will analyze the pinion bearing loading in a gearbox. The required information is:

HP = 6000 hp (horsepower transmitted by the gearbox) N = 7000 rpm (the pinion speed)
Pd = 12.000 inches (the pinion pitch diameter)
θn = 20 degrees (normal pressure angle)
ψ = 25 degrees (helix angle)
Pinion is uploaded
Wrtr = -1200 lbs (pinion shaft weight, it is negative because the pinion is uploaded)
We can now calculate
T = 54021 in-lbs (transmitted torque)
Wt = 9004 lbs (tangential force)
Wr = 3616 lbs (radial force)
Wb = 4300 lbs (individual pinion bearing load)
Angle = 24.9 degrees (pinion load angle as measured from vertical)
This example would correspond to either figure 1 (if the pinion is being driven by the gear) or figure 4 (if the pinion is doing the driving).
If the pinion bearing is 4 inches in diameter (D) and 3 inches long (L) the bearing unit loading will be:

$$\text{loading} = \frac{Wb}{L \times D} = 358 \text{ psi}$$

CONCLUSION

One last comment needs to be made regarding pressure dam bearings: Should pressure dam bearings be installed it is important that the pressure dam is not located such that the load is into the dam. For example: If there are pressure dam bearings installed for the pinion shafts in the four gearboxes represented by the figures, then the dam would be located in the lower half of the pinion bearings in figures 1 and 4.

For a good reference on gearbox bearing loading please see the chapter "Helical, Worm, and Bevel Gears" in Joseph Edward Shigley's classic text "Mechanical Engineering Design."

Please contact Miba should you have any questions regarding gearbox loads or bearing design.

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