Backlash and Axial Movement

QUESTION

What is the relationship between angular backlash and mean or normal backlash, the axial movement of wheel gear, and mean or normal backlash for bevel and hypoid gears?

Expert response provided by Bob Wasilewski, Engineering Services Manager, Arrow Gear. In order to understand the requested relationships, we should be clear as to what the backlash values are on bevel gears, what they mean and how they are determined.

Both ISO and AGMA specify that the backlash on bevel gears is defined as:

Outer normal backlash at the tightest point of mesh.

There are several important items in that description.

First, that backlash is taken at the tightest point of mesh. The values tabulated in AGMA and ISO standards give a suggested range of backlash values for the *tightest* point. They are not the total range of backlash. Backlash at any other point on the bevel gear can and likely will be higher that the tabulated range. Any reputable bevel gear manufacturer will find the tightest point of mesh in the set, measure the normal backlash there and mark both that backlash and the mating teeth where the measurement was taken. It is important to note that that tightest point of mesh was determined in a test machine with precision bearings and minimal runout in the work holding tooling. The components in your gear box will have different runout that may end up shifting that tightest point to another set of teeth. It is always a good idea to verify that your gear set has proper backlash in installation.

Second, the backlash measurement is taken at the outer diameter of the gears, not at the mean or midface.

Third, the backlash is the normal backlash, meaning it is perpendicular to the tooth surface.

One simple way to describe that direction is to envision placing the base of a thumb tack on the tooth at the outer diameter. The point of the thumb tack will point in the normal direction. That is the direction that a measuring device should be used to measure the backlash movement. That direction is a result of the tooth's pressure angle. On straight bevels that is the only angle to consider. On hypoids, spiral bevels and Zerol bevel gears the tooth is curved and that adds the additional factor of the spiral angle at the outer end. That angle is not the same as the mean spiral angle specified in the gear set geometry, it is always greater.

To determine the angular backlash from the normal backlash some calculation is required. First, you have to calculate the transverse backlash. To do that calculation, you need some values from the gear set geometry, including some that are not often readily available. The following values are necessary:

J_n = Normal backlash
R_e = Outer cone distance
β_e = Spiral angle at R_e
R_m = Mean cone distance
β_m = Spiral angle at R_m
α_n = Normal pressure angle
r_{c0} = Cutter radius

The two values that are not always readily available are the spiral angle at the outer cone and the cutter radius. These values are not always tabulated in the gear data block on the gear set drawing but are determined for the machine calculations necessary to manufacture the gear set. You may have to get them from the gear manufacturer. Actually, if you can determine the cutter radius you can calculate a value for the outer spiral angle using the following equation:

$$\beta e \cong \arcsin \frac{2R_m r_{cO} \sin\beta_m - R_m^2 + R_e^2}{2R_e r_{cO}}$$

Using the outer spiral angle you may calculate the transverse backlash with:

$$j_{et} \approx \frac{j_n}{\cos\alpha_n \cos\beta e}$$

Where:

j_{et} = Transverse backlash

The transverse backlash, of course, is a linear distance that you can convert to angular using the pitch diameter. Transvers backlash is the value you want to use if you measure the backlash outside the gear box at a diameter equal to the pitch diameter. It is generally easier to measure the backlash on the shaft with the wheel member (larger gear).

Axial movement for a change in backlash

To calculate the axial movement for a change in backlash, calculate the amount of axial movement for *each member* using the formulas below. (If the shaft angle is 90 degrees, the ratio of wheel mounting distance change and pinion mounting distance change is equal to the gear ratio, z_2/z_1).

$$\Delta j = \Delta j_1 + \Delta j_2$$

$$\Delta j_1 = \frac{\Delta j \tan\delta_1}{\tan\delta_1 + \tan\delta_2}$$

$$\Delta j_2 = \frac{\Delta j \tan\delta_2}{\tan\delta_1 + \tan\delta_2}$$

$$\Delta a_1 = \frac{\Delta j_1}{2\tan\alpha_n \sin\delta_1}$$

$$\Delta a_2 = \frac{\Delta j_2}{2\tan\alpha_n \sin\delta_2}$$

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Where:

Δj is total change in backlash

Δj_1 is change in backlash for pinion

Δj_2 is change in backlash for wheel

Δa_1 is axial movement of pinion

Δa_2 is axial movement of wheel

z_2 is number of wheel teeth

z_1 is number of pinion teeth

α_n is pressure angle

δ_1 is pinion pitch angle

δ_2 is wheel pitch angle

When adjusting backlash for lower ratios, it might be necessary to move both wheel and pinion members to maintain acceptable tooth contact. For higher ratios the effect of pinion axial movement on backlash is small and moving the wheel alone may be sufficient. *NOTE: These formulas are for bevel gears but may also be used for hypoid gears as a first approximation.*

All of this material is described in the national standard ANSI AGMA 2008-D11 Assembling Bevel Gears. That document has a considerable amount of other information that is not only valuable to the assembler but for the gear box designer as well.

That standard is available from the American Gear Manufacturers at *www.agma.org*.

Robert F. Wasilewski is Engineering Services Manager at Arrow Gear Company and Chairman of the AGMA Bevel Gearing Committee.