Bevel & Hypoid Gears: Measuring Backlash

QUESTION

Please tell me the best method(s) for measuring backlash in bevel gears.

Expert answer provided by: Dr. Hermann J. Stadtfeld, Gleason Corp.

There are three commonly used methods to determine the backlash of a bevel or hypoid gearset:

- ***Method 1***. Indicator method on a roll tester or in the gearbox
- ***Method 2***. Metal-to-metal movement of gear cone
- ***Method 3***. Encoder backlash determination in a CNC roll tester

Method 1. The most common method is to determine the normal backlash by clamping pinion and gear in a roll tester. First, it must be certain that pinion and gear are rotated to the so called "tight spot." Because of pinion and gear runout, the difference between tight spot and loose spot may be significant. It is important to determine the minimal backlash because this is the value that must be assured for the operation of the gearset: The tight spot can be found on a manual roll tester by setting the pinion cone to the exact mounting distance and rotating the gear by hand until the first metal-to-metal contact occurs. Further rotation will show if the gear cone has to be increased or reduced in order to maintain slight metal-to-metal contact. The angular ring gear position with the largest gear cone adjustment represents the tight spot. Now, the ring gear cone is adjusted to the correct mounting distance and a dial indicator is positioned at the outside—in the middle of the profile of a convex ring gear tooth.

The indicator probe stem should be normal to the surface it is contacting. If possible, the pinion rotation should be locked before the indicator is positioned. After these preliminaries the ring gear is rotated in clockwise direction until the coast-side flanks are in firm contact and the indicator is set to zero (pinion convex and ring gear concave = coast-side). A slight rotation in counterclockwise direction until a firm contact of the drive-side flanks is achieved (pinion concave and ring gear convex = drive-side). The indicator reading after this procedure is defined as the "minimal backlash in the plane of rotation" Δt. The relevant value relating to the backlash values in the dimension sheet must then be calculated as:

$$\Delta s = \Delta t \bullet \cos ß \bullet \cos \Phi$$

Whereas:

Δs Normal backlash
Δt Backlash in the plane of rotation
$ß$ Spiral angle
Φ Pressure angle

Figure 1 visualizes the setup and indicator position in a 90° roll testing machine. The indicator shaft direction includes a 90° angle to the radius connection between probe contacting point at the flank and the center of the ring gear.

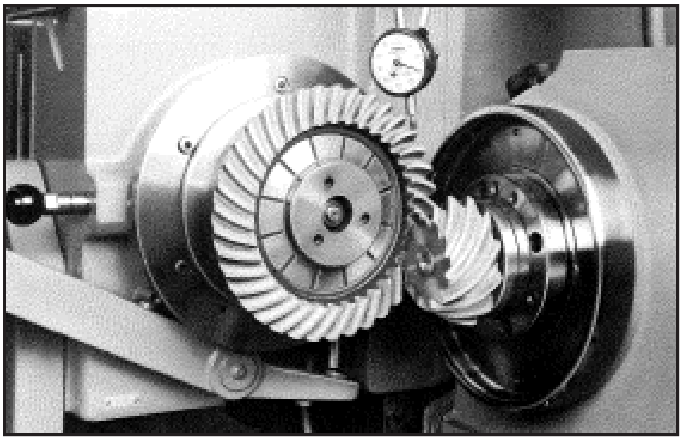

Figure 1 Measurement of normal backlash.

Method 2. Backlash adjustment is done with an axial change of the ring gear position (gear cone). The axial gear cone change between the correct mounting distance setup to the metal-to-metal condition can therefore be used to determine the normal backlash. Pinion and gear are clamped in a roll tester. Then, make certain that pinion and gear are rotated to the so called "tight spot." The tight spot can be found using a manual roll tester by setting the pinion cone to the exact mounting distance and rotating the gear by hand—while simultaneously reducing the gear cone setting with the hand-wheel—until the first metal-to-metal contact occurs. Further rotation will show if the gear cone must be increased or reduced in order to maintain a slight metal-to-metal contact. The angular ring gear position with the largest gear cone adjustment represents the desired tight spot. Assure firm double-flank contact at the tight spot and read the gear cone position on the electronic readout or on the vernier scale.

Now the ring gear cone is adjusted to the correct mounting distance.

The difference in the values of the gear cone at the tight spot, metal-to-metal position to the correct ring gear mounting distance is recorded as "Δz" and used in the following formulae in order to calculate the normal backlash:

$$\Delta s = \Delta z \bullet \sin [\arctan (n_1/n_2)] \bullet (\tan \Phi_1 + \tan \Phi_2)$$

Whereas:

Δz Axial ring gear move from nominal to metal-to-metal
n_1 Number of pinion teeth
n_2 Number of ring gear teeth
F_1 Pressure angle convex gear flank
F_2 Pressure angle concave gear flank


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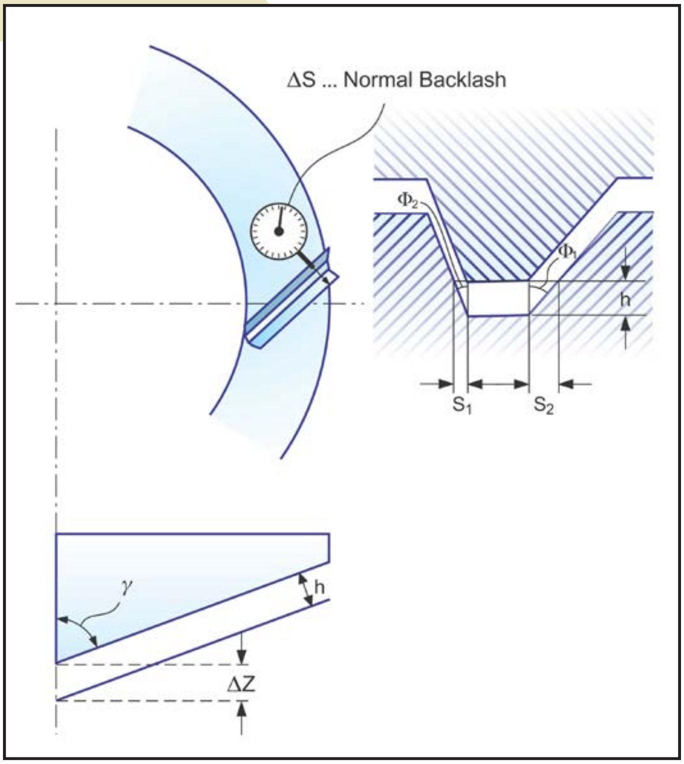

Figure 2 Relationship between withdraw and backlash.

If n_1/n_2 is below 0.3 and $\Phi_1 + \Phi_2 = 40°$, then the following simplification delivers good results:

$$\Delta s = \Delta z \bullet n_1/n_2 \bullet 0.728$$

Figure 2 shows a front view onto a ring gear with a symbolized tooth slot at the top, left. Below the front view, a top view of the ring gear with the pitch cone angle γ. and the relationship between "h" and "Δz." the simplified profile section to the right in Figure 2 relates "h" to s_1 and s_2, where the normal backlash is defined as $s_1 + s_2 = \Delta s$ in the plane shown in the profile section view.

The technique shown in Figure 2 is also used in CNC roll testing machines in order to automatically set the backlash by an axial ring gear adjustment, after the tight spot has been found.

Method 3. In contrast to Method 2, which uses a simplified, contact geometry, Method 3 is the most accurate way of determining the correct backlash. Method 3 can only be practiced on roll testing machines with single-flank recording capabilities. After pinion and ring gear are positioned at their correct mounting distance, the pinion is rotated in coast direction against a small ring gear torque (e.g., 0.5 Nm). The encoder signal of the ring gear spindle encoder is recorded as shown (Fig. 3, top graph). The diagram shows in the ordinate direction the motion variation in $\Delta\varphi$, and in the abscissa direction the rotational angle φ of the ring gear. Ideally, the number of pinion rotations equals the number of teeth of the ring gear (hunting tooth condition); but in fact one full ring gear revolution will deliver acceptable results. From there the pinion spindle reverses its rotational direction in order to establish drive-side contact and to rotate the same number of prior revolutions. Now, the

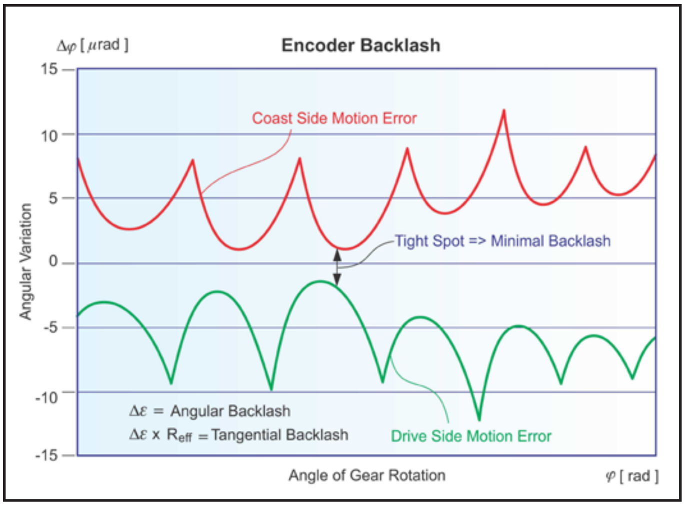

Figure 3 Encoder backlash detection method.

encoder records the drive-side motion errors — tooth pair after tooth pair. The motion error of a single tooth pair has a parabola shape. The parabolas of the different tooth pairs have a variation in the ordinate direction of the diagram featured in Figure 3. This spacing variation in the ordinate direction of the parabola extrema is caused by an interaction between pinion and ring gear runouts; ring gear runout is dominated by face runout (wobble), where pinion runout originates from the radial runout of the pinion "head" vs. the shaft.

Because the graphs for both coast-side and drive-side meshing have been recorded without an interruption of the encoder signal, the relationship of the upper and lower diagram reflects a double-flank measurement without a double-flank contact. Ordinate (vertical) distances between the two graphs are equal to the angular backlash at the rotational position of the vertical line. The roll testing machine software searches for the shortest distance between the coast- and drive-side motion error graph, and determines the "minimal backlash" (Fig. 3) that is the most relevant number for the gearset. Initially this backlash has the units in microradians, or radians, and is called "angular backlash." The calculation of normal backlash with "length units" can be simply expressed as:

$$\Delta s = \Delta\varphi \bullet R_{eff}/\cos\beta$$

Whereas:

$\Delta\varphi$ Angular backlash (rad)

R_{eff} Reference point diameter of ring gear

β Ring gear spiral angle

Dr. Hermann J. Stadtfeld — GT's bevel gear "expert of experts" — indicating setup for measuring backlash on a roll tester. Stadtfeld is Vice President, Bevel Gear Technology, R&D for Gleason Corporation (Photo by Jasmin K. Saewe for Gleason Corp).