Measuring Base Helix Error on a Sine Bar

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Introduction

Base helix error—the resultant of lead and profile errors—is the measured deviation from the theoretical line of contact (Fig. 1). It can be measured in the same way that lead error on a spur gear is measured, namely, by setting a height gage to height H based on the radial distance r to a specified line of contact (Fig. 2), rotating the gear so as to bring a tooth into contact with the indicator on the height gage, and then moving the height gage along two or more normals to the plane of action. The theoretical line of contact on a helical gear must be parallel to the surface plate, which is attained by mounting the gear on a sine bar (Fig. 3).

Advantages

The measurement of base helix is not afflicted with the errors inherent to the measurement of lead and profile. Specifically, a perfect gear mounted off-center on lead and profile measuring machines will appear to have errors in lead and profile, respectively. In practice, off-center errors can be circumvented by taking the average of measurements on two, three or four equispaced teeth—180° for even tooth numbers, 120° for tooth numbers that are a multiple of three, and 90° for tooth numbers that are a multiple of four. (Actually, measuring four equispaced teeth is superfluous, since four is a multiple of two.)

However, averaging is based on the lead and profile errors being the same on all teeth—a condition not typical of formed gearing (molded plastic, die cast, powder metal, stamped, cold-drawn). Consequently, if the averages for various sets of equispaced teeth on the same gear are significantly different, then the lead and profile measurements are not valid. Moreover, discrepant averages denote that the gear is out–of–round, i.e., that it has a multitude of unknown centers.

Also, even when the lead and profile errors are the same on all teeth, the averages for various sets of teeth on the same gear can be significantly different whenever the measured teeth are not equispaced, particularly so when the tooth number is low and prime (5, 7, 11 . . .).

Conversely, the measurement of base helix is not in error when the gear is mounted off-center (no need for averaging), or when the center is unknown. For instance, from Figure 2, it is seen that if the spur gear is slightly lower than shown, then the gear is rotated counterclockwise to bring the tooth into contact with the indicator on the height gage. The rotation places the line of contact at a slightly greater radial distance on the tooth. And the same holds true for a helical gear mounted on a sine bar.

Nomenclature

a	Distance from centerline of gear to centerline between rolls (Fig. 3)
b	Distance along base of sine bar from center of lower roll to edge of gear (Fig. 3)
d	Diameter of rolls
F	Effective face width
F_m	Measurable face width
H	Height gage setting
H_{if}	Height gage setting for r_{if}
H_{of}	Height gage setting for r_{of}
L	Distance between centers of rolls (Fig. 3)
N	Number of teeth on gear
P_n	Normal diametral pitch
r_b	Radius of base circle
r_{if}	Inside form radius
r_{of}	Outside form radius
ϕ	Transverse profile angle
ϕ_n	Normal profile angle
ψ	Helix angle
ψ_b	Base helix angle

Sine bar setup for checking base helix error. Courtesy of Koro Industries Inc., Minneapolis, MN.

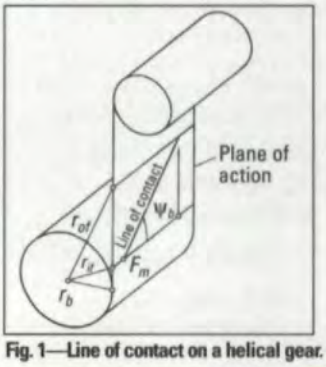

Fig. 1—Line of contact on a helical gear.

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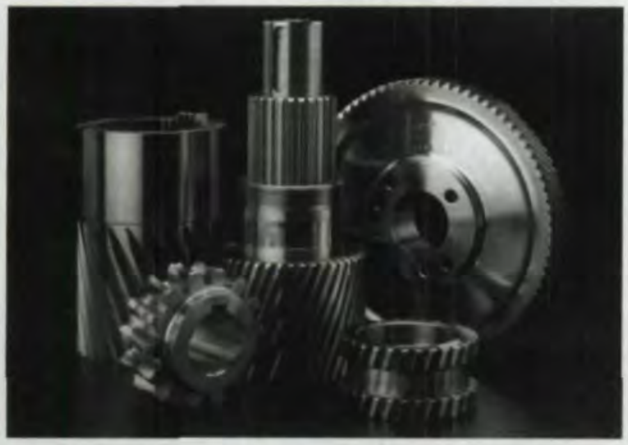

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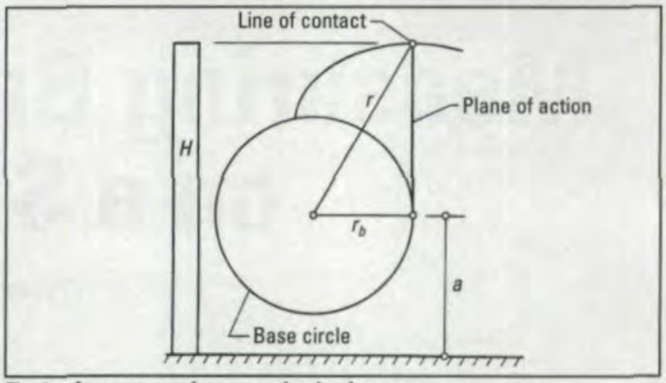

Fig. 2—Arrangement for measuring lead error on a spur gear.

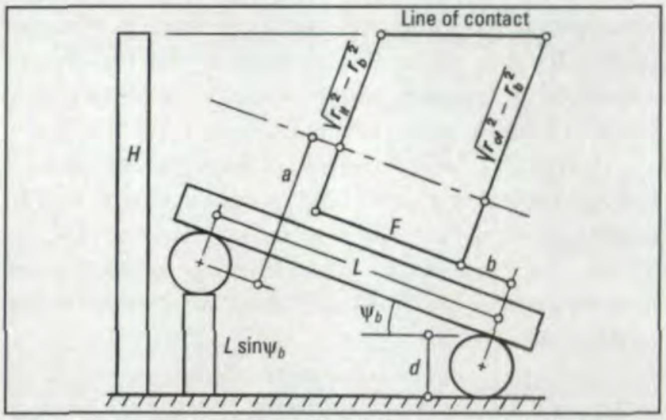

Fig. 3—Arrangement for measuring base helix error on a helical gear.

Basic Geometry

In Figure 3, F is the effective face width (minimum face width less chamfer or edge round), r_{of} is the outside form radius (minimum outside radius less chamfer or tip round), and r_{if} is the inside form radius (lowest point at which the mating gear can make contact). The distances a and b are derived from dimensions on the sine bar, gear and workholding fixture.

The radius of the base circle is (from well–known equations)

$$r_b = \frac{N\cos\phi}{2P_n\cos\psi}$$

where N is the number of teeth, P_n is the normal diametral pitch, ψ is helix angle, and ϕ is the transverse profile angle, where

$$\tan\phi = \frac{\tan\phi_n}{\cos\psi}$$

where ϕ_n is the normal profile angle.

As seen in Figure 3, when the theoretical line of contact intersects the outside and inside form radii at the ends of the effective face width, the height gage is set to height H. In this case, the effective face width is the same as the measurable face width F_m, i.e.,

$$F = F_m = \left(\sqrt{r_{of}^2 - r_b^2} - \sqrt{r_{if}^2 - r_b^2}\right) / \tan\psi_b$$

where (from the well–known equation)

$$\sin\psi_b = \sin\psi\cos\phi_n$$

where ψ_b is the base helix angle.

In general, however, the theoretical line of contact does not intersect the outside and inside form radii at both ends of the effective face width simultaneously. In particular, from Figure

3, it is seen that when the theoretical line of contact intersects the outside form radius at one end of the effective face width, the height gage is set to

$$H_{of} = \left(a + \sqrt{r_{of}^2 - r_b^2}\,\right)\cos\psi_b + b\sin\psi_b + (d/2).$$

And when the theoretical line of contact intersects the inside form radius at the other end of the effective face width, the height gage is set to

$$H_{if} = \left(a + \sqrt{r_{if}^2 - r_b^2}\,\right)\cos\psi_b + (b + F)\sin\psi_b + (d/2).$$

Thus, for these two settings of the height gage, the entire effective face width is covered, provided that $2F_m \geq F$. And the overlap v is $2F_m - v = F$, i.e., $v = 2F_m - F$. However, if $2F_m < F$, then a gap equal to $F - 2F_m$ in the middle of the face width is not covered. Even so, the middle can be covered by simply raising and lowering the value of b in the equations for H_{of} and H_{if}, respectively.

Specifically, if $2F_m < F \leq 3F_m$, then three settings of the height gage are made. The two overlaps are $3F_m - 2v = F$, i.e., $v = (3F_m - F)/2$, and the value of b is either raised in H_{of} or lowered in H_{if} by $\Delta b + v = F_m$, i.e., by $\Delta b = (F - F_m)/2$.

Likewise, if $3F_m < F \leq 4F_m$, then four settings of the height gage are made. The three overlaps are $v = (4F_m - F)/3$, and the value of b is raised and lowered in H_{of} and H_{if}, respectively, by $\Delta b = (F - F_m)/3$.

The following example illustrates the procedure:

Given that

N	= 4
P_n	= 16
ϕ_n	= 20°
ψ	= 35°
r_{of}	= 0.2607
r_{if}	= 0.1434
a	= 1.9847
b	= 1.5102
F	= 0.7500
d	= 0.7422

Then, from $\tan\phi = \tan\phi_n/\cos\psi$, the transverse profile angle $\phi = 23.95680°$, so $r_b = 0.139451$. And from $\sin\psi_b = \sin\psi\cos\phi_n$, the base helix angle $\psi_b = 32.6146°$, so $H_{of} = 3.0424$, $H_{if} = 3.2892$ and $F_m = 0.29200$.

Since $2F_m < F \leq 3F_m$, a third setting of the height gage is made. The two overlaps are $v = (3F_m - F)/2 = 0.063$, and the $\Delta b = (F - F_m)/2 = 0.2290$. So, in H_{of}, the b becomes $1.5102 + 0.2290 = 1.7392$, which results in $H_{of} = 3.1658$. ○

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