Selection of a Proper Ball Size to Check an Involute Spur or Helical Gear Tooth

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Abstract:

The selection of a properly sized ball or pin to use in the check of dimension over or between balls or pins is not an easy task. If the ball size is taken from standard tables of Van Keuren Pins for standard pitches, and if the proportion of the tooth being checked is not standard, interference with some feature of the gear tooth may result, giving an erroneous reading for the tooth thickness. This article gives a procedure for selecting a properly sized ball or pin to check an involute tooth of any proportion. A set of standard sizes for both inch and metric balls or pins is suggested.

Introduction

A much-used method for checking the tooth thickness of an involute gear tooth is to measure the dimension over two balls placed in most nearly opposite spaces in the case of external gears, and the dimension between the balls in the case of internal gears. This measurement is then checked against a pre-calculated dimension to denote an acceptable part.

From this point, references will be to external gears only. It is confusing if the text is correct for both external and internal gears because the words "over" and "between" are continually interchanged when addressing the dimension over or between balls. Confusing, also, are references to major diameter of the external and to minor diameter of the internal, and to the the root of the external and the major circle of the internal.

However, calculations for external and internal gears are the same if a minus one factor is entered at certain points in the equations for internal gears. The formulas shown will properly calculate either external or internal gears and splines.

The dimension over balls is a measure of the thickness of a theoretically true involute tooth generated from the base circle used in the equations at the ball contact point. The ball contact point is the point on the tooth where the stated measuring ball contacts the tooth on both sides of the tooth space. For standard gears the size of the measuring ball is usually chosen so the ball contact point is near the gear pitch circle.

Tables of sizes over balls have been published for standard gears using standard increments based on constants for external gears and internal gears, the ball sizes being determined by dividing the constant by the diametral pitch of the gear set. These ball sizes are satisfactory for purely standard gears. But for gears with teeth which are of non-standard proportions, the pitch circle is sometimes not near the middle of the tooth height and is sometimes off the tip of the gear tooth or below the gear tooth root. In the case of non-standard gears, a measuring ball size which contacts the gear tooth somewhere near the midpoint between the form circle and the outside circle must be chosen.

Exact Ball Size

The exact measuring ball size needed to contact this point is calculated by using Equations (2), (3) and (4).

The size of the measuring ball determined by Equation (4) would be different for every gear tooth designed with nonstandard proportions and if allowed to stand, would create a difficult, if not unmanageable, system of measurement. Keeping the ball contact point at the mid-height of the tooth is not a critical factor so long as the ball contacts the involute surface, and the problem has been resolved by changing the measuring ball size as determined by Equation (4) to a size found in a predetermined standard set of measuring ball sizes.

Standard Ball Sizes

Any set of standard ball sizes may be used to determine the final ball size. The size increments must be small enough so that the ball contact point does not move too far radially on the gear tooth when the ball size is changed from the exact size determined by Equation (4) to one of the standard increments. Experience has shown that results will be somewhat better if the exact ball size is changed to the next higher standard ball increment, thereby moving the ball con-

tact point toward the gear outside circle. However, rounding to the nearest standard size or moving to the next larger or the next smaller size is a matter of choice. Any method will yield satisfactory results if the proper checks are made for interferences with important tooth features.

Experience has also shown that within the range of balls normally used for measuring gears, a 1/64" increment for the sizes of balls is satisfactory and actually gives more selections than are needed. Since the balls are not outrageously expensive, this selection is satisfactory for inch sizes.

The R40 series from ISO recommendation R-3 has been selected as the standard set of metric pins for measuring ISO 4156 and ANSI B92-1980 standard metric splines. A good feature of this selection of sizes is that the size increment increases as the size of the pin (ball) increases. The R40 series gives very satisfactory results for metric ball sizes for measuring gears.

Interference

When a standard size ball is substituted for an exact ball size, the contact point moves from the exact mid-point of the tooth. This change must not cause the ball to interfere with any feature of the gear tooth. To insure this, calculate the radius to the standard ball contact point, the radius over the balls and the radius under the balls.

The following features of the gear tooth must be checked. **The root surface of the tooth.** To get a good measurement of the gear tooth thickness, the ball must rest on the involute tooth side surfaces. It is very difficult to tell in some cases whether the ball is resting on the root surface or the involute sides of the tooth when measuring a gear. It is much better to check this by calculation when determining the dimension over balls so as not to leave this responsibility to the shop personnel when the gear is being cut. The check here is to compare the radius under the balls with the gear root radius. If interference occurs, the ball size must be moved to the next higher standard increment and the calculations for interference repeated.

The ball contact point must not be below the gear involute form point. Equations (5), (6) and (7) assume that the involute form extends from an infinitely large diameter to the base circle; whereas, it actually only extends from the tooth tip to the form point. Therefore, a separate check must be made to be sure the ball contact point is not below the form point. Again, if this interference occurs, the solution is to move the ball size to the next higher increment.

The ball contact point also must not be outside the gear outside circle; otherwise the ball will rest on the corners of the teeth at the gear outside circle. This will result in an erroneous reading. If the balls are found to be resting on the corners of the teeth, change the ball size to the next lower standard increment and repeat the checks for interference.

The radius over the balls should not be less than the gear outside circle radius because the anvils of the measuring micrometer may rest on the corners of the gear teeth. This problem is solved by increasing the ball size to the next higher increment.

A situation can occur where the ball size is being moved up and down in an effort to avoid an interference only to have interference occur at some other point. When that happens, the ball size should be moved back to the original exact size found by Equation (1). If that ball is resting on the root surface, a calculation is made to determine how much

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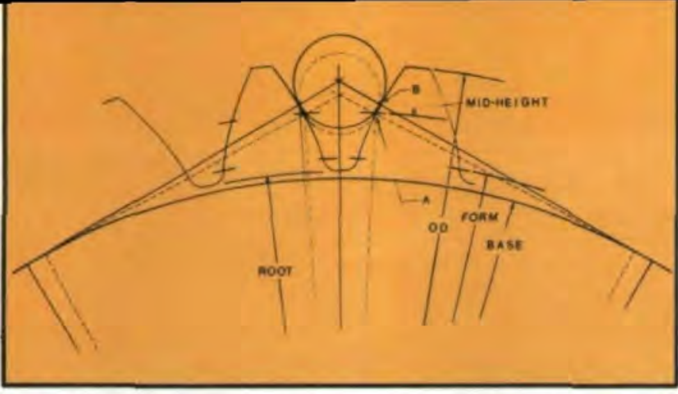


Fig. 1—In selecting the measuring ball size for a full depth gear tooth, the next standard increment larger than the exact size is usually satisfactory.

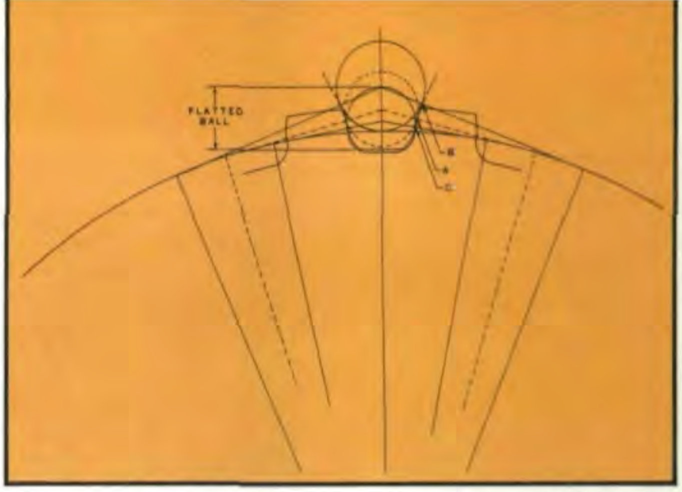
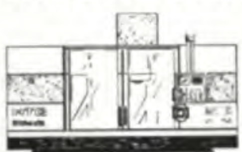


Fig. 2—In this example, the first standard increment larger than the exact ball contacts outside the outside circle limit; the next size smaller contacts the root circle. The ball must be flattened to get a good measurement. This happens with stub tooth gears with low pressure angle.

the ball must be flattened to clear the root surface. From Equation (2) it can be noted that the exact ball size contact point will not be below the form point, nor will it be outside the gear outside circle, but the ball may be resting on the gear root surface. Even a standard ball may contact the root of the tooth. This condition must always be checked, whether using a standard ball or an exact ball size.

Fig. 1 illustrates the process of selecting the ball size for measuring a full depth gear. The dashed lines are the exact ball size as determined by Equation (4). Point A is the ball contact point for this ball and is chosen midway between the outside circle and the form circle by Equation (2). The solid lines represent the standard ball, and Point B is the ball contact point for the standard ball. Note that the standard ball clears the root of the gear tooth, and the radius over the ball is outside the outside circle of the gear. This ball would be satisfactory to check this gear. Finally, the dimension over the balls is calculated from Equation (10) or (11).

It can become a burdensome task to make the calculations outlined here only to discover interference at some point and have to do everything over again. The occurrance is unlikely in the case of full depth gears of the most often used pressure angles, but choosing a satisfactory standard ball size for gears and splines of unusual proportions can be a difficult task. Fig. 2 illustrates the type of gear or spline tooth which might pose a problem. The involute in Fig. 2 is very short. When



the ball size is changed from the exact size represented by the dashed lines at Point A, the contact point moves off the tips of the teeth at Point B. The ball size is moved to the next lower standard increment, which is below the exact size. The contact Point C is below the center of the tooth, but is in the satisfactory range.

Sometimes when the involute surface is very short, Point B is outside the outside circle, and Point C is below the form point. In this case, the exact ball size is used. In Fig. 2 the standard ball at Point C contacts the root of the gear so a flattened dimension is calculated.

A computer program can be written which can accomplish this task very quickly and make all the checks necessary to guarantee good results.

One might question why a gear or spline tooth like the one shown in Fig. 2 would ever be designed, but the task of the computer program is not to decide what is reasonable. So long as the input data is valid, the computer program should determine a proper ball size and the dimension over those balls.

Fig. 3 – This photograph shows an actual master gear which has proportions similar to those shown in Fig. 2. The method outlined chose a measuring ball size without difficulty.

Fig. 3 shows a real master gear for which the data was presented to a computer program written according to the system outlined above for choice of a measuring ball. The program picked a standard inch ball and calculated a checking dimension over balls without difficulty.

Summary

Following is a summary of the steps to follow in picking

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CIRCLE A-19 ON READER REPLY CARD

a measuring ball size and finding the dimension over balls.

1. Find the normal base tooth thickness from Equation (1).
2. Find the midpoint of the tooth between the form point and the outside circle from Equation (2).
3. Calculate an exact ball size to contact this point from Equation (3) and (4).
4. Change the ball size from the exact size to a standard size either larger or smaller.
5. Check for interferences with important features of the gear tooth using Equation (5), (6), (7), (8) and (9).
6. Move the ball size in the appropriate direction if there are interferences. Repeat the checks.
7. Change the ball size back to the exact ball size and check for interferences if a satisfactory standard ball cannot be found. Calculate the flattened size if the ball contacts the root.
8. Finally, calculate the dimension over balls using Equation (10) or (11).

Equations

BTN is the normal tooth thickness at the base circle. If the tooth thickness is given at any other point on the tooth, BTN must be found. Use Equation (1).

$$BTN = BD * Cos\ (BHA) * \frac{(TTDD}{(Cos\ (HADD) * DD)} + K * Inv(Acos\ (BD/DD))) \qquad (1)$$

Equation (2), (3) and (4) are for choosing the exact ball size.

$$PACP = Acos\ \frac{((2 * BD)}{(OD + FD))} \qquad (2)$$

$$K * Inv(PACP) \Big] + PACP$$

$$D = K * ((Inv\ (PACB) + \frac{K * \pi}{Z}) * Cos\ (BHA) * BD - K * BTN) \qquad (4)$$

After the standard ball size has been selected use Equations (5), (6), (7), (8) and (9) to determine if the standard ball size is satisfactory.

$$PACB = Ainv \left[\frac{K * (BTN + DS)}{(Cos\ (BHA) * BD)} - \frac{K * \pi)}{Z} \right] \qquad (5)$$

$$RCB = \frac{BD}{2 * Cos\ (PACB)} \qquad (6)$$

$$RCP = \sqrt{ \left[(RCB * Sin\ (PACB)) - \frac{K * DS}{2 * Cos\ (BHA)} \right]^2 + \frac{(BD)^2}{2} } \qquad (7)$$

$$ROB = RCB + \frac{DS}{2} \qquad (8)$$

$$RUB = RCB - \frac{DS}{2} \qquad (9)$$

When the final selection of ball size is satisfactory, use Equation (10) or (11) to find the dimension over balls, depending on whether the number of teeth is even or odd.

If Z is odd:

$$DBALL = 2 * RCB * Cos(90/Z) + K * DS \qquad (10)$$

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THE INTERRELATIONSHIP OF TOOTH . . .

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TERMS

The following is a list of terms and definitions as used in Equation (1) through (11).

- Ainv – Perform the arcinvolute function.
- Acos – Perform the arccosine function.
- Asin – Perform the arcsine function.
- Sin – Perform the sine function.
- Cos – Perform the cosine function.
- Inv – Perform the involute function.
- BD – Diameter of the gear base circle.
- BTN – Normal tooth thickness at the gear base circle.
- CP – Contact point of the ball and the tooth side.
- D – Exact ball diameter to contact the tooth at the midpoint between the outside circle and the form point.
- DBALL – Dimension over the balls.
- DD – Diameter of the circle to any designated point on the involute surface.
- DS – Diameter of the standard ball.
- FD – Diameter of the gear form circle.
- HADD – Helix angle at diameter DD.
- K – Designator to determine external or internal – K is + 1 for external gears; K is – 1 for internal gears.
- OD – Diameter of the gear outside circle.
- PACB – Transverse pressure angle at the center of the ball.
- PACP – Transverse pressure angle at the ball contact point.
- RCB – Radius to the center of the ball.
- RCP – Radius to the contact point.
- ROB – Radius over the ball.
- RUB – Radius under the ball.
- TTDD – Normal tooth thicknes at diameter DD.
- Z – Number of teeth on the gear.

$$PACB = K * \left[\frac{\pi}{Z} - \left[\frac{(\ BTN}{Cos\ (BHA) * BD} \right] + \right. \qquad (3)$$

If Z is even:

$$DBALL = 2 * RCB + K * DS \qquad (11)$$

Measurement Over 1 Wire

$$M_1 - R_W + (d_w/2) \qquad (12)$$

Chordal Addendum Specification

$$a_c - a + (T_{Mc}{}^2 \cos^2\Psi) \ / \ (4\ d_M) \qquad (13)$$

Chordal Tooth Thickness Specification

$$t_c - T_{Mc} - (T_{Mc}{}^3 \cos^4) \ / \ (6\ d_M{}^2) \qquad (14)$$

Measurement Over 2 Wires
(Even Number of Teeth)

$$M_2 - D_w + (d_w/2) \qquad (15)$$

(Odd Number of Teeth)

$$M_2 - 2\ R_w[\cos(90/N)] + d_W/2 \qquad (16)$$

Span Measurement Specification

$$M_s - D \cos\Phi[\pi/(2N) + inv\Phi] + (n - 1)(\pi/P_d \cos\Phi) - (T_{Ms}) \cos\Phi \qquad (17)$$

Tooth Thickness and Space Width

$$\pi/P_d - t + s \qquad (18)$$

Change in Arc Tooth Thickness vs. Change in Center Distance

$$\Delta t - 2 \tan \Phi\Delta C \qquad (19)$$