Selection of Bevel Gear Cutter. Best results in cutting a bevel gear tooth are obtained if the gear cutter is selected not for the number of teeth that the bevel gear is to have, but rather for the teeth of an *imaginary spur gear* of an entirely different diameter than the bevel gear, and calculated by means of the following formula:

$$D_I = \frac{P_d}{\cos b} \qquad [3]$$

where:

D_I = pitch diameter of an imaginary spur gear, inches.
P_d = pitch diameter of bevel gear at the large end, inches.
b = pitch angle, degrees.

Since:

$$D_I = \frac{P_c N_c}{\pi}$$

$$P_d = \frac{P_c N_g}{\pi}$$

where:

P_c = circular pitch, inches.
N_c = number of teeth in imaginary spur gear.
N_g = number of teeth in bevel gear.

Substituting the latter expressions for D_I and P_d in Formula 3, the following formula is obtained, which permits calculating the number of teeth for which the gear cutter is selected.

$$N_c = \frac{N_g}{\cos b} \qquad [4]$$

where:

N_c = number of teeth of imaginary spur gear for which gear cutter is selected.

N_g = number of teeth in actual gear.
b = pitch angle, degrees.

In the present example, $N_g = 30$ and $b = 45°$.

Hence:

$$N_c = 43$$

Therefore, the cutter selected for this job is an arbor-mounted, high speed steel *No. 3 gear cutter* (Table, page 21) having a 3½ in. diameter and 6 diametral pitch, and made for milling gears with from 35 to 54 teeth.

The same cutter can be used for milling a mating gear of the *same size and pitch,* but a different cutter must be selected if the mating gear is of a *different size.* The teeth should preferably be milled by following the sequence of operations shown in Figure 25.

First Operation—Gashing the Teeth. In the first operation, the teeth are gashed after centering the bevel gear blank on the No. 3 gear cutter. This cutter is used in all subsequent operations.

By raising the knee, the blank is set for the depth of cut of 0.3595 in., equal to the full depth at the large end of the gear. Each consecutive tooth is then positioned for milling by plain indexing.

The number of complete turns and fraction of a turn of the index crank, and the circle of holes to be used for indexing, are obtained by means of Formula 1 on page 13, with $N = 40$ and $D = 30$, which is the number of teeth to be cut in the bevel gear. Hence:

$$t = \frac{40}{30} = 1\frac{1}{3} = 1\frac{18}{54}$$

Using the standard index plate (page 73), the 30-hole circle would be satisfactory for this indexing operation. However, the 54-hole circle is selected because it will be useful when making the setup for the subsequent operations.

Consequently, to index for each tooth, the index crank will be rotated one complete turn and 18 spaces on the 54-hole circle.

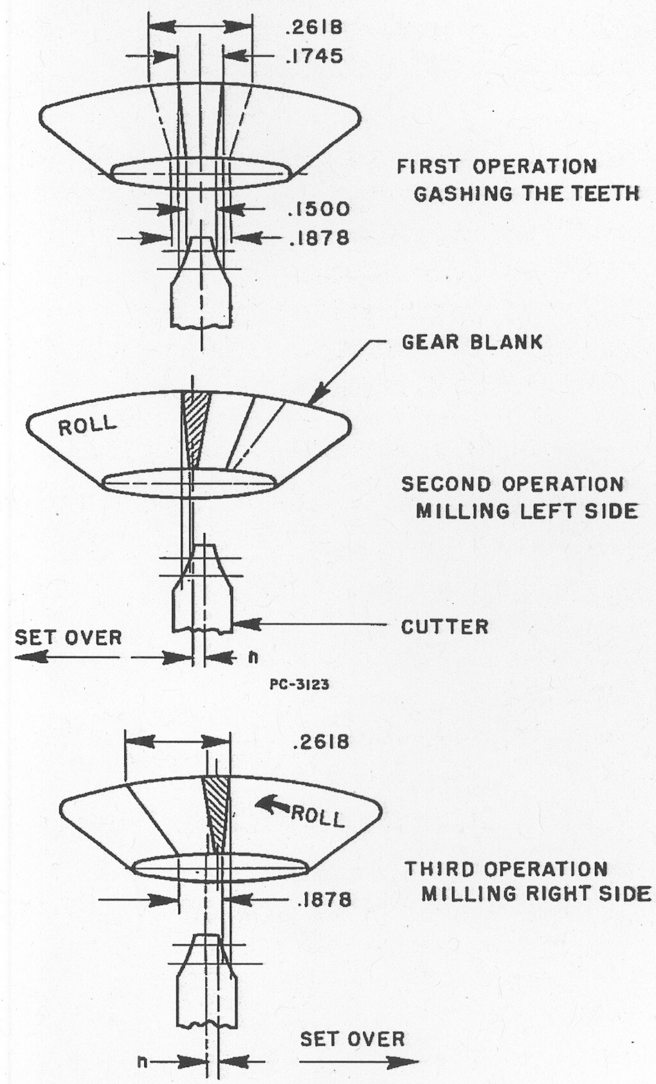

Figure 25

Sequence of Operations when Milling the Teeth of a Bevel Gear

Second and Third Operations—Milling Sides of Teeth. The width of the gashes produced by the cutter in the first operation, measured at the pitch line is 0.1745 in. and 0.150 in. at the large and the small ends of the gear, respectively. The correct dimensions for the finished gear are 0.2618 in. and 0.1878 in., respectively. In order to obtain these dimensions, an additional amount of stock must be removed on each side of the tooth space, as indicated by shading in Figure 25.

Determining the Angle of Roll. For this purpose, the blank must be rotated or rolled on its axis through an angle C, so that either line AB or line CD (view **X** in Figure 26 — traces of the pitch line along the gear tooth face width) is placed in a direction parallel to the line EF. The latter connects the points corresponding to the dimensions of the gashes (Figure 25) at the pitch line, at the large and small ends of the gear. Then point A, for example, will have moved from a distance d_2 to a distance G from the centerline M (view **Y** in Figure 26), and the distance d_1 between points A and B in view **X** of Figure 26 will change to the distance d between points E and F. But d is half the difference between the chordal thicknesses T_L and T_s of the gear cutter (Figure 28), corresponding to the pitch line, at the large and small ends of the gear, respectively. From the geometry of Figure 26 (view **Y**), the distance G can be expressed as follows:

$$G = C_r \frac{d}{W}$$

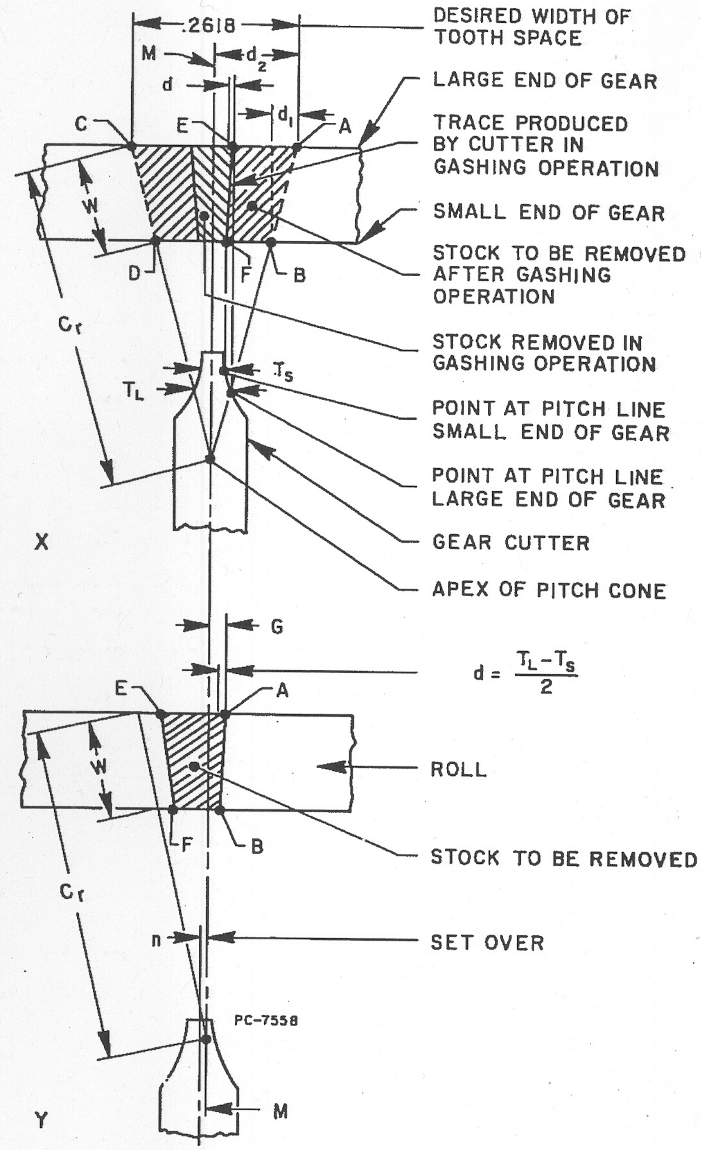

Figure 26

Geometric Relation Between Gear and Cutter to Determine Angle of Roll

But:

$$d = \frac{T_L - T_s}{2}$$

Hence:

$$G = C_r \frac{T_L - T_s}{2W} \qquad [5]$$

where:

G = distance between centerline of gear blank and point at pitch line of gear at large end, inches.

C_r = pitch cone distance, inches.

T_L = chordal thickness of gear cutter tooth at pitch line, at *large* end of gear, inches.

T_s = chordal thickness of gear cutter tooth at pitch line, at *small* end of gear, inches.

W = width of gear tooth face, inches.

The amount of gear blank roll, from the position in view **X** to that shown in view **Y** (Figure 26), is the difference between the circular distances d_2 and G of point A from centerline M of the blank. The distance d_2 is one-half of 0.2618 in., or one-quarter of the circular pitch P_c, and the distance G is obtained from Formula 5 above.

The corresponding angle of roll C in degrees is therefore obtained by dividing this difference by the pitch radius or one-half the pitch diameter of the large end of the gear, and then multiplying the result by the constant 57.3, which is the degrees of an arc corresponding to one radian. This is expressed in the following formula:

$$C = \frac{57.3}{P_d}\left(\frac{P_c}{2} - \frac{C_r}{W}(T_L - T_s)\right) \qquad [6]$$

where:

C = angle of roll, degrees.

P_d = pitch diameter at large end of gear, inches.

P_c = circular pitch at large end of gear, inches.

C_r = pitch cone distance at large end of gear, inches.

T_s, T_L = chordal thickness of gear cutter tooth corresponding to pitch line at small and large ends of gear, respectively, inches.

57.3 = degrees per radian.

W = width of gear tooth face, inches.

Calculating the Angle of Roll. All of the values to be used in Formula 6 are known, with the exception of the quantities T_s and T_L. These are obtained by direct measurement of the gear cutter tooth employed. Dimensions for the present example are given in Figure 28.

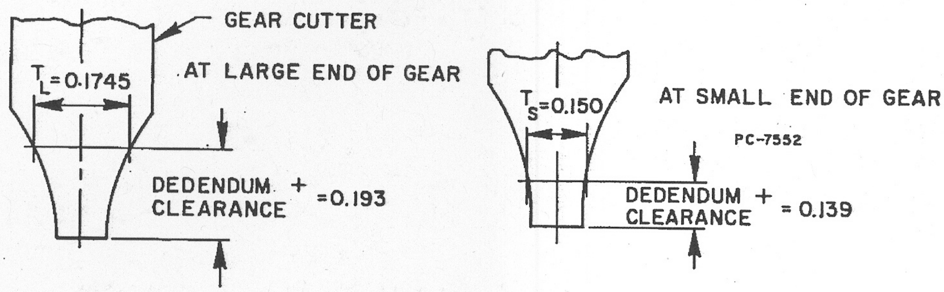

Figure 28

Chordal Thickness of the Gear Cutter, Corresponding to the Pitch Line at the Small and Large Ends of the Gear, Respectively

Substituting the known values in Formula 6:

$$C = \frac{57.3}{5}\left(\frac{0.5236}{2} - \frac{3.535}{1}(0.1745 - 0.150)\right)$$

$$= \frac{57.3}{5}\left(0.2618 - 3.535 \times 0.0245\right)$$

$$= 11.46\left(0.2618 - 0.0866\right)$$

$$= 11.46 \times 0.175$$

$$= 2.007^\circ$$

or very nearly 2°.

Indexing for the Angle of Roll. The angle of roll of 2° is obtained by plain indexing from the centered position of the blank. The number of spaces to index is obtained by dividing the angular distance between divisions by 9°, or the angular rotation of the spindle corresponding to one turn of the index crank, thus:

$$t = \frac{2}{9} = \frac{2 \times 6}{9 \times 6} = \frac{12}{54}$$

By indexing 12 spaces on the 54-hole circle, the blank will be rotated on its axis by the amount required to position one side of the teeth for producing the required tooth thickness.

After rolling the blank 2°, the subsequent teeth are, however indexed from this new position by turning the index crank one full turn and 18 spaces on the 54-hole circle, as in the case of the gashing operation. The *direction of roll* is not important, since the roll is reversed for milling the opposite sides of the teeth after all the teeth have been milled on one side. The only consideration is that *the direction of roll and the set-over must be made in opposite directions* (Figure 25).

Determining the Set-Over. After rotating the blank on its axis to the angle C, it must be set over by an amount n from the centered position. This is done to locate the blank so that the cutter will follow along the line AB, which is now parallel to the line EF produced by the cutter (view Y, Figure 26). The set-over n is also calculated from the dimensions of the gear and cutter tooth, by means of the following formula:

$$n = \frac{T_L}{2} - \frac{T_L - T_s}{2}\left(\frac{C_r}{W}\right) \qquad [7]$$

Calculating the Set-Over. The set-over n is calculated by substituting the known values in Formula 7:

$$n = \frac{0.1745}{2} - \frac{(0.1745 - 0.1500)\ 3.535}{2}$$

$$= 0.0873 - \frac{0.0245 \times 3.535}{2}$$

$$= 0.0873 - 0.01225 \times 3.535$$

$$= 0.0873 - 0.0433$$

$$= 0.044 \text{ in.}$$

If the blank has been rolled 2° in a *counter-clockwise* direction (when looking at the spindle end of the Dividing Head), the machine table is moved out, or *away from the column,* 0.044 in.

Conversely, if the blank has been rolled 2° *clockwise* (when looking at the spindle end of the Dividing Head), the table is moved in *toward the* column of the machine 0.044 in., to offset the work by this amount with respect to the center position used in the gashing operation.

To set for milling the opposite side of the teeth after one side has been completed, the table is moved twice the amount of the set-over, or 0.088 in., and the blank is rolled twice the angle of roll, or 4°.

After milling two or three complete teeth, their thickness at the pitch line at the large and small ends of the gear should be measured. These measurements should be equal to the given tooth thickness at these ends. if not, the calculations and the set-over should be checked for possible errors.

Accuracy of Tooth Profile. The objective of the operation is to mill the gear teeth to the required thickness *at the pitch line* along the face width. The tooth form, however, will not be accurate throughout the length of the tooth face, especially at the small end of the gear.

Here the flank of the teeth on the addendum part of the profile may not curve sufficiently to avoid a slight interference with the mating teeth. This results from the fact that the gear cutter is made for a tooth form which is correct for the *large end of the teeth.* In any other section, it may vary as indicated by the broken lines shown in Figure 30.

Gears milled in accordance with the method described in the foregoing will be found to mesh satisfactorily. If necessary, however, a small amount of metal in the form of a triangular shape can be removed from the top of the teeth down to the pitch line at the small end, tapering off at the large end of the teeth, as indicated by the broken lines in Figure 30. This is done by rotating the blank through a small angle on the Dividing Head spindle, and then taking light cuts until satisfactory meshing conditions are obtained.

This method of milling of bevel gears is especially convenient where the pitch cone radius is unusually large and regular gear cutting equipment does not have the range to accommodate the gear to be cut.

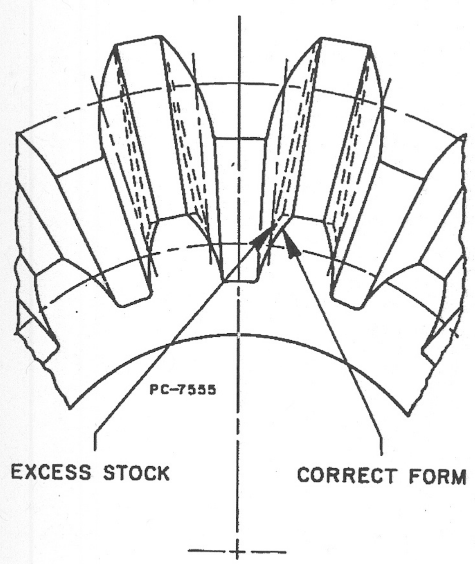

Figure 30

Effect of Bevel Gear Cutter Contour on the Tooth Shape

MILLING HELICAL GEARS

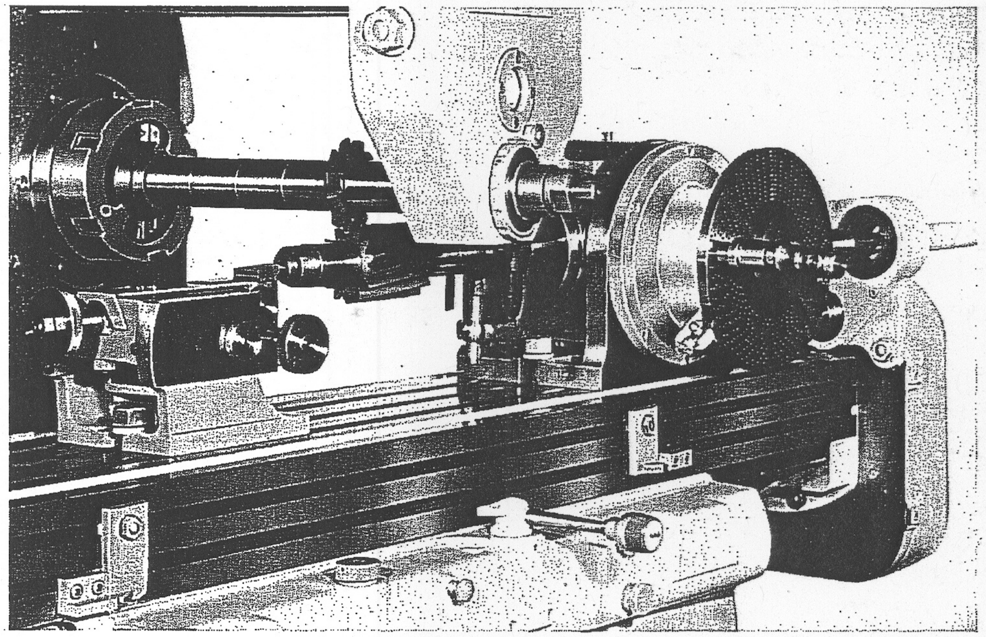

Figure 31
Milling a Helical Gear Tooth

Helical gears are gears which have the teeth cut along a helical surface. They are usually milled by using standard involute cutters of the arbor-mounted type.

In order to mill helical gears, it is necessary to *rotate* and at the same time *feed* the workpiece while milling. One of the most generally used attachments for this type of work is the Universal Dividing Head, driven from the table lead screw of the milling machine by means of change gears.

The change gears permit varying the ratio between the table feed rate and the revolutions per minute of the workpiece, and consequently the lead of the helical surface.

The Dividing Head indexing mechanism is used in spacing the helical teeth around the periphery of the workpiece as required.

The machine used for milling helical surfaces is usually a *universal general purpose type milling machine.* This permits swiveling the table, and consequently the workpiece located between centers of a Dividing Head and tailstock, to the required angle of swivel.

The same results may also be obtained if a plain general purpose machine is employed. In this case, however, additional equipment will be required. This consists of a Universal Milling Attachment which permits swiveling the cutter to the required angle of swivel.

When specifying the helix angle of helical gear teeth, the angle C (Figure 32) is preferred because this is also the angle used in setting up the blank for the milling operation. In other cases, as in the case of lead screws, the angle E is used to specify the helix angle of the threads. To avoid errors, it is therefore necessary to indicate clearly to which helix angle the given value should apply.

From the geometry of Figure 32, these formulas are obtained.

$$E + C = 90 \qquad [8]$$

$$L = \pi D \tan E \qquad [9]$$

$$L = \pi D \cot C \qquad [10]$$

where:

E and C = helix angles, degrees.

L = lead of helix, inches.

D = diameter of the cylinder or blank, inches.

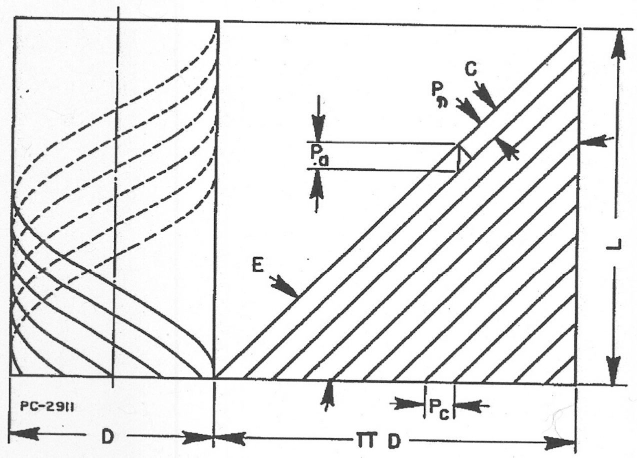

Figure 32

Axial, Circular and Normal Pitch of Equally Spaced Teeth

If a helical gear is rolled on a plane surface, the traces of the teeth will line up in equally spaced parallel straight lines. *The axial distance P_a between consecutive teeth is the axial pitch, P_n is the normal pitch and P_c is the circular pitch of the teeth.* The circular pitch, normal pitch and axial pitch are measured as shown in Figure 32, at the pitch line of the gear.

The *normal pitch* measures the thickness of the gear cutter tooth, and the tooth thickness and tooth space of the gear at the pitch line.

The *circular pitch* is calculated by substituting the known pitch diameter of the gear for the diameter D, and the number of teeth in the gear for N, hence:

$$P_c = \frac{\pi P_d}{N} \qquad [11]$$

where:

P_c = circular pitch, inches.
P_d = pitch diameter of gear, inches.
N = number of teeth.

The normal and axial pitches P_n and P_a can be obtained from the circular pitch P_c and the helix angle, as follows:

$$P_n = P_c \cos C$$

or: [12]

$$P_n = P_c \sin E$$

and:

$$P_a = P_c \tan E$$

or:

$$P_a = P_c \cot C$$

where:

P_n = normal pitch, inches.
P_a = axial pitch, inches.
P_c = circular pitch, inches.
E and C = helix angles, degrees.

Combining Formula 11 and Formula 12:

$$P_n = \frac{\pi P_d}{N} \cos C \qquad [13]$$

but the normal diametral pitch is:

$$P_{nd} = \frac{N}{P_d \cos C} \qquad [14]$$

The *diametral pitch* P_{nd} of helical gears is specified by numerical values such as 5, 7 or 10 in the same way as the diametral pitch for spur gears. By combining Formulas 13 and 14, the following normal pitch formula results:

$$P_n = \frac{\pi}{P_{nd}} \qquad [15]$$

This is similar to the formula for spur gears. In the latter, the circular pitch is the normal pitch of the helical gear teeth.

Helical Gears with Shafts at Right Angles

Two helical gears with shafts *at right angles to each other* have different helix angles. Each angle is the complement of the other (Figure 34), hence:

$$C_1 + C_2 = 90 \qquad [16]$$

The center distance of the gears is the semi-sum of their respective pitch diameters, as expressed by solving Formula 14 for P_d and applying it to each gear. The result is the following center distance formula:

$$S = \frac{1}{2\,P_{nd}} \left(\frac{N_1}{\cos C_1} + \frac{N_2}{\cos C_2} \right) \qquad [17]$$

but from Formula 16:

$$C_2 = 90 - C_1$$

therefore:

$$S = \frac{1}{2\,P_{nd}} \left(\frac{N_1}{\cos C_1} + \frac{N_2}{\sin C_1} \right) \qquad [18]$$

where:

S = center distance between the two gears, inches.

P_{nd} = normal diametral pitch of gears.

N_1, N_2 = number of teeth in the gears

C_1, C_2 = helix angles of the two gears, degrees.

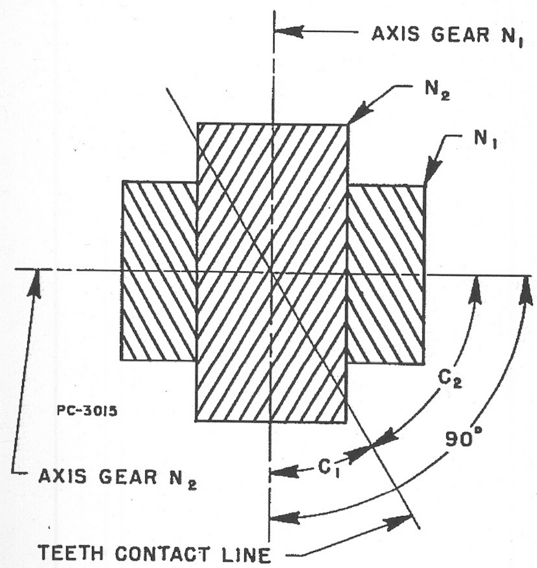

Figure 34

Helical Gears with Shafts at Right Angles

Helical Gears with Parallel Shafts

When the shafts are *parallel* the angles C_1 and C_2, in Formula 16 become *equal,* because the helix angle is the same for both gears. The center distance Formula 18 changes to the following:

$$S = \frac{1}{2\,P_{nd}\cos C} \left(N_1 + N_2 \right) \qquad [19]$$

Helical Gears with Shafts at a Angle of Less Than 90°

Helical gears may have shafts *at an angle of less than* 90°. In such cases, the center distance between the meshing gears is determined by means of Formula 17, as in the case of gears with shafts at right angles.

Selection of The Cutter for Milling Helical Gears

Spur gear cutters for milling helical gears are selected for the *hypothetical number of teeth in the section at right angles to the helix,* rather than the actual number of teeth to be cut. This section is an ellipse (Figure 35). If the length of this ellipse is divided by the normal pitch in the gear, the result is the number of teeth for which the cutter should be selected.

The major and minor axes, a and b respectively, of the ellipse can be expressed in terms of the pitch diameter P_d and helix angle C, as follows (Figure 35):

$$a = \frac{P_d}{2 \cos C}$$

[20]

$$b = \frac{P_d}{2}$$

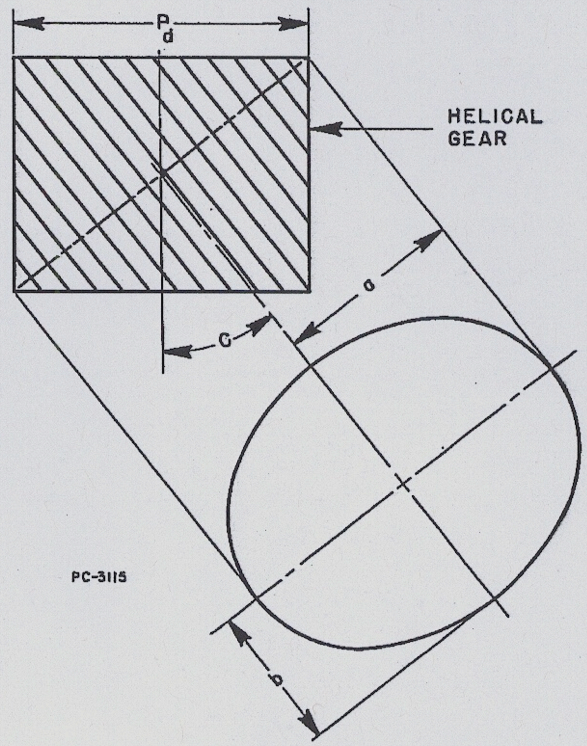

Figure 35

Eliptical Section of a Helical Gear, Used for Determining the Hypothetical Number of Teeth for Which the Gear Cutter is Selected

but the approximate length of the corresponding ellipse is:

$$M = \pi \, (a + b)$$

Substituting the expressions for a and b in Formula 20, the following result is obtained:

$$M = \frac{P_d \, (1 + \cos C)}{2 \cos C}$$

Now, by dividing M by the normal pitch P_n, the result is the hypothetical number of teeth N_c in the normal section:

$$N_c = \frac{M}{P_n} = \frac{\pi \, P_d \, (1 + \cos C)}{2 \, P_n \cos C}$$

Using the expression for P_n obtained from Formula 15 (page 33) and the expression of P_d obtained by solving Formula 14 (page 33), the preceding Formula can now be written as follows:

$$N_c = \frac{N\ (1 + \cos C)}{2 \cos^2 C} \qquad [21]$$

This formula gives the hypothetical number of teeth which is used for selecting the gear cutter.

Another formula commonly used is the following:

$$N_c = \frac{N}{\cos^3 C} \qquad [22]$$

This formula is obtained by considering the radius of curvature R of the elliptical section normal to the helix (Figure 35), at a point corresponding to the minor axis b. Hence:

$$R = \frac{a^2}{b}$$

Substituting for a and b in this formula the expressions given in Formula 20:

$$R = \frac{P_d}{2 \cos^2 C}$$

also:

$$2\,\pi\, R = \frac{\pi\, P_d}{\cos^2 C}$$

Dividing this formula by Formula 14 (page 33):

$$\frac{2\,\pi\, R}{P_n} = \frac{\pi\, P_d}{P_c \cos^3 C}$$

but:

$$\frac{2\,\pi\, R}{P_n} = N_c \text{ and } \frac{\pi\, P_d}{P_c} = N$$

After substituting these values in the preceding formula, the latter becomes equal to Formula 22.

Formula 22 gives a slightly higher number of teeth than Formula 21. In the above formulas:

N_c = hypothetical number of teeth for which the gear cutter should be selected.

N = actual number of teeth in the gear.

C = helix angle, degrees.

Milling Helical Gears for Parallel Shafts

Example: Milling a pair of helical gears for use on parellel shafts. The center distance is 8 in.; the gear ratio 2:1, the normal diametral pitch 5. The width of the gears is 1½ in. The teeth have the same helix angle but opposite "hands" of helix.

Selection of Setup. Helical gears are milled with the same equipment as used in milling helical and plain milling centers. This equipment may consist of either a *universal general purpose type milling machine* with a Dividing Head and the Dividing Head driving mechanism, and an arbor to mount the gear cutter; or a *plain horizontal general purpose type milling machine* equipped with a Universal Milling Attachment.

When the latter equipment is used, the gear cutter, rather than the machine table, is set at the angle required to place it in the plane of the tangent to the helix of the teeth to be cut. In helical gears, the value of the helix angle is calculated from or related to the pitch diameter.

Number of Teeth and Helix Angle. If N is the number of teeth in the small gear, the number of teeth in the large gear will be $2N$. Substituting $N_1 = N$, $N_2 = 2\,N$, $P_{nd} = 5$, $C_1 = C_2 = C$, and $S = 8$ in. in the center distance Formula 18 (page 34), the formula as it applies in the present example is as follows:

$$8 = \frac{2\,N \times N}{2 \times 5 \times \cos C}$$

or:

$$80 = \frac{3\,N}{\cos C} \quad [a]$$

In this formula, there are two unknowns: the number of teeth N in the small gear and the helix angle C of both gears. When one of these factors is assumed, the other can be calculated. The value of the helix angle C can be established on the basis of the overlap, underlap

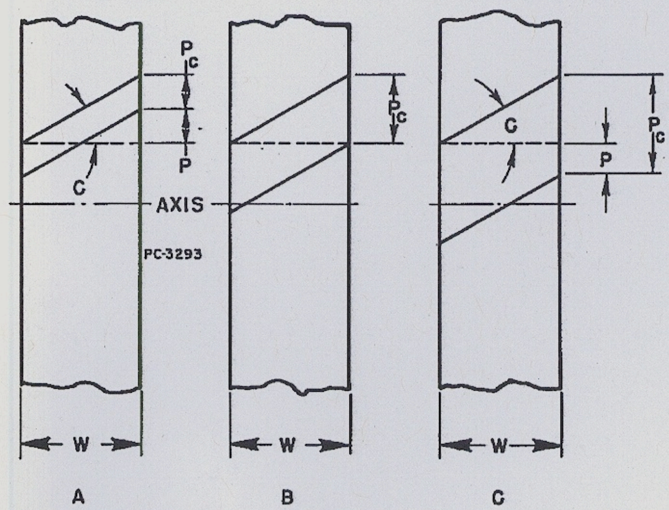

Figure 37

Overlap, No Lap and Underlap Between Teeth in Helical Gears

or no lap between the teeth in the gear, as measured in a direction parallel to the gear axis (Figure 37).

The *overlap* is the distance P (as in view **A** of Figure 37), by which the axial projection of the *end* or one tooth overlaps the *beginning* of the next tooth; hence, from the geometry of view **A**, Figure 37:

$$P_c = W \tan C - P \qquad [23]$$

where:

P_c = circular pitch, inches.
P = overlap, inches.
W = with of the gear, inches.
C = helix angle, degrees.

Expressing the overlap P as a percentage K of the circular pitch:

$$P = K\,P_c$$

Formula 23 can be written thus:

$$P_c = \frac{W \tan C}{1 + K} \qquad [24]$$

When $K = 0$, the teeth has *no lap*, as in view **B** of Figure 37.

When the teeth have an *underlap* P, as in view **C** of Figure 37, Formula 23 changes as follows:

$$P_c = W \tan C + P \qquad [25]$$

Thus, in general, the conditions of overlap, no lap and underlap of the teeth in a helical gear can be determined by means of the following formula, which is obtained by combining Formulas 23, 24 and 25:

$$P_c = \frac{W \tan C}{1 \pm K} \qquad [26]$$

The plus sign in the denominator is used when the teeth overlap, while the minus sign is used when the teeth underlap. $K = 0$ when there is no lap.

Combining Formulas 11 (page 32) and 14 (page 33) and solving for P_c:

$$P_c = \frac{\pi}{P_{nd} \cos C}$$

Hence, substituting this expression for P_c in Formula 24 and solving for the function of C:

$$\sin C = \frac{(1 \pm K)\,\pi}{P_{nd}\,W} \qquad [27]$$

In the present example, $W = 1\frac{1}{2}$ in. and $P_{nd} = 5$, and if the teeth have no lap, $K = 0$; hence:

$$\sin C = \frac{3.1416}{5 \times 1.5}$$

$$= 0.4188$$

and:

$$C = 24° \, 46'$$

Substituting this value of C in Formula a (page 37), and solving for the number of teeth N of the small gear, the following result is obtained:

$$N = \frac{80 \times \cos 24° \, 46'}{3}$$

$$= \frac{80 \times 0.908}{3}$$

$$= 24.2$$

Assuming 24 teeth for the small gear, the large gear will then have $2\,N = 48$ teeth. Recomputing the helix angle, from center distance Formula 19 (page 34), the correct value of the angle C is $25° \, 50'$. This helix angle is also the angle of swivel of the machine table.

Selecting the Gear Cutters. If the gear cutter for the *small gear* is selected by means of Formula 21 (page 36), with $N = 24$ and $C = 25° \, 50'$:

$$N_c = \frac{24\ (1 + \cos 25° \, 50')}{2 \cos^2 25° \, 50'}$$

$$= \frac{24 \times 1.9}{2 \times 0.81}$$

$$= 28$$

A No. 4, 5 diametral pitch gear cutter (Table, page 21) made to cut 26 to 34 teeth is the cutter to use for cutting teeth of the small gear.

The *large gear* has 48 teeth and the same helix angle as the small gear. Hence, using Formula 21 (page 36):

$$N_c = \frac{48\ (1 + \cos 25° \, 50')}{2 \times \cos^2 25° \, 50'}$$

$$= \frac{48 \times 1.9}{2 \times 0.81}$$

$$= 56$$

Here it is found that a No. 2, 5 diametral pitch gear cutter which cuts a range of teeth from 55 to 134 should be used for milling the teeth of the large helical gear.

In this case, the same results would be obtained by determining the value of N_c by means of Formula 22 (page 36).

Formulas 21 and 22 give results which are satisfactory under general conditions, but should be considered as an approximation subject to corrections, especially when milling gears to close tolerances.

Computing the Lead. The lead is calculated by means of Formula 10 (page 32) using the pitch diameter of the gear and the value of the helix angle at this diameter. Combining Formula 10 and Formula 14 (page 33):

$$L = \frac{\pi N}{P_{nd} \sin C} \qquad [28]$$

For the small gear, $N = 24$, $P_{nd} = 5$ and $C = 25° 50'$. Hence:

$$L = \frac{3.1416 \times 24}{5 \times \sin 25° 50'}$$

$$= \frac{3.1416 \times 24}{5 \times 0.435}$$

$$= 34.668 \text{ in.}$$

For the large gear, the lead $= 2 \times 34.668 = 69.336$ in.

Change Gears for the Dividing Head. Since $L = 34.668$ in., the change gears (Page 60) for the CINCINNATI 2½″ to 100″ Standard Enclosed Dividing Mechanism are calculated as follows:

$$\frac{A \times C}{B \times D} = \frac{34.668}{10} = \frac{8667}{2500}$$

This is simplified to the fraction 52/15. This fraction has a ratio of 34.666, which gives a sufficiently close approximation to the calculated lead.

By factorizing this fraction:

$$\frac{52}{15} = \frac{13 \times 4}{5 \times 3} = \frac{(13 \times 3) \times (4 \times 12)}{(5 \times 6) \times (3 \times 6)} = \frac{39 \times 48}{30 \times 18}$$

The change gears are thus (see page 60 for change gears available):

$A = 39$ teeth $\quad C = 48$ teeth
$B = 30$ teeth $\quad D = 18$ teeth

The change gears can also be found by looking up 34.668 in. in the "Table of Leads," pages 76-92.

The change gears for the lead of the large helical gear are obtained by following a similar procedure.

Gears in the Dividing Head driving mechanism must be set to provide the proper combination between the directions of blank rotation and table feed, in relation to the "hand" of helix of the teeth to be milled, as in the case of milling cutters.

Helical gears for parallel shafts have helices of opposite "hands". Hence, after milling one gear, the setup must be altered for milling the teeth of the second gear. This includes transposing the above gears and reversing the direction of table swivel.

Angle of Table Swivel. The angle of table swivel is the same as the helix angle of the gear teeth. This is calculated at the pitch diameter of the gear, and in the present example is 25° 50′.

When the gear blank is centered on the gear cutter, the table of the machine is swiveled *clockwise* to mill a left hand helix, and *counter-clockwise* when milling a right hand helix.

If the teeth of the small gear are milled on a left hand helix, those in the large gear will be milled on a right hand helix, and the setup must be changed accordingly.

Indexing. The teeth are indexed into position by plain indexing. From Formula 1 page 13, the number of turns of the index crank to index each tooth into position for milling the *small gear* is:

$$t = \frac{40}{24} = 1\frac{16}{24}$$

and the number of turns to mill the *large gear* is:

$$t = \frac{40}{48} = \frac{20}{24}$$

The 24-hole circle is used in both cases.

If *block indexing* is used, the gear can be divided into eight blocks. After milling the first tooth, the blank is indexed by turning the index crank $40/8 = 5$ turns, to mill a tooth spaced 45° from the first tooth. This indexing is continued until the first tooth is again in the starting position.

The blank is now indexed to mill the tooth following the first tooth by indexing one full turn and 16 spaces on the 24-hole circle. This is followed by indexing 5 turns to mill each successive tooth in the blocks. This indexing is continued until all the teeth in the gear have been milled.

The same procedure is used for milling the 48 teeth in the large gear. Each tooth is positioned by indexing 20 spaces on the 24-hole circle.

Cutting Speed and Feed. The cutting speed and feed rates are selected in relation to the work and cutter materials and the type of cutter used. Gear cutters are usually made of high speed steel, and are of the form relieved type.

Milling Helical Gears for Shafts at Right Angles

Example: The milling of helical gears for *shafts at right angles* does not present any different problem than the milling of helical gears for *parallel shafts*. The two gears have different helix angles, but of the same "hand" of helix. The procedure used is shown in the following example:

Milling the teeth of helical gears for operation on shafts at right angles (Figure 43). Material: S.A.E. 3115 steel.

Gear Specifications

	Large Gear	*Small Gear*
Number of teeth	25	5
Helix angle	26° 46′	63° 14′
"Hand" of helix	Left hand	Left hand
Normal diametral pitch	8	8
Normal Pressure angle	20°	20°
Full depth of tooth	0.2696 in.	0.2696 in.
Pitch diameter	3.496 - 3.4955 in.	1.3888 in.
Lead at pitch diameter	21.7987 in.	2.200 in.
Center distance between gears	2.4424 - 2.4422 in.	

Selection of Setup. The work is performed on a *plain horizontal general purpose type milling machine,* equipped with a Universal Milling Attachment which permits swiveling or tilting the cutter to the required helix angle, and a Universal Dividing Head driven by the 2½″ to 100″ Standard Enclosed Driving Mechanism.

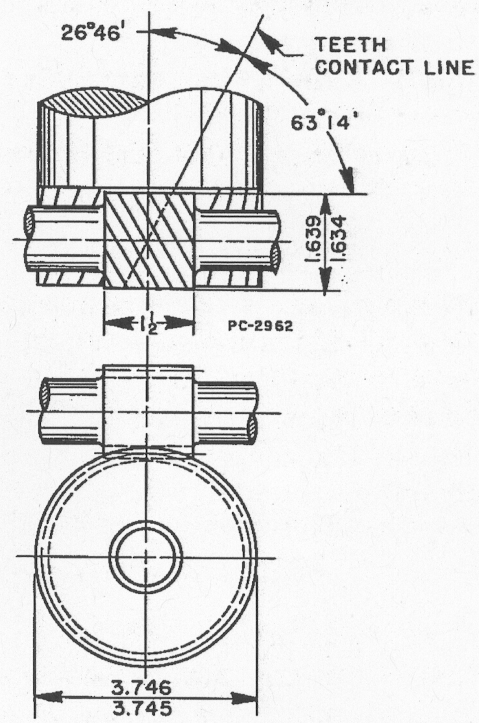

Figure 43

Helical Gears with Shafts at Right Angles

Selection of Gear Cutter. The number of teeth for which the gear cutter should be selected is obtained from Formula 20 (page 35):

$$N_c = \frac{25\ (1 + \cos 26^\circ\ 46')}{2 \cos^2 26^\circ\ 46'}$$

$$= \frac{25\ (1 + 0.893)}{2 \times 0.893}$$

$$= 30$$

This indicates that the job requires use of a No. 4, 8 diametral pitch gear cutter. (Table, page 21) made to cut a range of gear teeth from 26 to 34.

If Formula 22 (page 36) is used, the number of teeth for which the cutter should be selected is then:

$$N_c = \frac{25}{\cos^3 26^\circ\ 46'} = \frac{25}{0.893^3} = 35$$

and the cutter would be a No. 3 gear cutter made to cut from 35 to 54 teeth (Table, page 21).

Angle of Swivel for the Milling Cutter. The angle of swivel is the same as the helix angle. Hence, the spindle head of the Universal Milling Attachment is swiveled to the angle of 26° 46′, which can be read from zero mark on the graduated swivel dial of the spindle head.

The blank is centered on the cutter by means of radial and axial lines scribed on the blank, and a straight edge held against the side of the cutter.

Change Gears for Lead. The lead of the large gear as 21.7987 in. Therefore, the change gears for the 2½" to 100" Standard Enclosed Driving Mechanism are calculated as follows:

$$\frac{A \times C}{B \times D} = \frac{21.7987}{10}$$

By means of continuous fractions, it is found that the common fraction 85/39 has a ratio of 2.17948, which corresponds to a lead of 21.7948 in., or 0.0039 in. smaller than the given lead of 21.7987 in. The change gears for the driving mechanism are now determined from the new fraction:

$$\frac{A \times C}{B \times D} = \frac{85}{39} = \frac{5 \times 17}{3 \times 13} = \frac{(5 \times 6) \times (17 \times 3)}{(3 \times 6) \times (13 \times 3)} = \frac{30 \times 51}{18 \times 39}$$

hence, the change gears (page 60) are:

$A = 30$ teeth
$B = 18$ teeth
$C = 51$ teeth
$D = 39$ teeth

Selection of Circle of Holes for Indexing. The number of turns (t) of the index crank (Formula 1, page 13) to index the 25 teeth are:

$$t = \frac{40}{25} = 1\frac{15}{25}$$

One turn and 15 spaces on the 25-hole circle in the standard index plate (Table, page 73) will be required to place each tooth in position for milling.

Depth of Cut. The depth of cut is 0.2696 in., corresponding to the full depth of the teeth. This operation should be carried out by first taking a roughing cut and then a finishing cut.

Cutting Speed and Feed. The cutting speed and feed are selected in relation to the work and cutter materials and the type of cutter used. The cutting speed for the finishing cut is approximately 50 per cent higher than that used in the roughing cut.

The smaller gear teeth are cut by following the same procedure as used in milling the teeth for the large gear.

MILLING A WORM OR WORM WHEEL

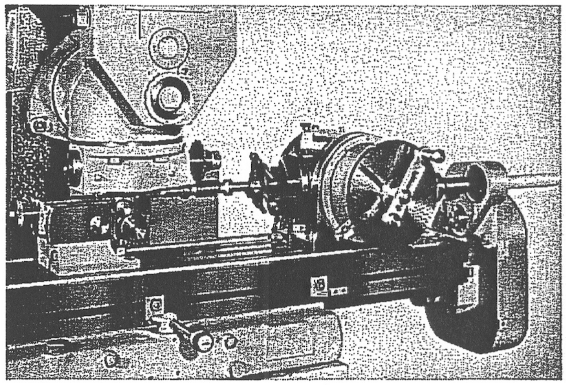

Figure 45
Milling a Worm

Worms and worm wheels are used in drives to obtain a great reduction in speed ratio between the worm and worm wheel. The worm is the *driver:* the worm wheel is the *driven member*. This type of gearing arrangement is known as an "endless screw." The ratio of the drive is independent of the relative pitch diameters of the worm and worm wheel.

The *worm* is a screw with a single thread or multiple threads, of such a form that its axial cross-section is the same as that of a rack. The teeth of the *worm wheel* are of a special form required to provide proper meshing conditions with the worm.

If the worm has a single thread, the ratio of the drive is equal to the number of teeth in the worm wheel. With a constant number of teeth in the worm wheel, the drive ratio decreases as the number of threads in the worm is increased. With double and quadruple thread worms, for example, the drive ratio becomes one-half and one-fourth, respectively, of the number of teeth in the worm wheel.

In the worm, the distance between the centers of two adjacent threads is termed the *pitch*. The *lead* is the distance which any one thread advances in one revolution of the worm. Therefore, the lead and pitch in a single thread worm are equal; in double and quadruple thread worms, the lead is, respectively, twice and four times the pitch.

Cutting Worm Wheel Teeth on a Milling Machine. Worms and worm wheels can be cut on a milling machine by means of *thread milling cutters* and *hobs*. The procedure used is illustrated in the following examples:

Gashing and Hobbing a Worm Wheel

Example: Milling a 100-tooth, right hand, cast iron worm wheel. Pitch Diameter = 7.9576 in., Circular Pitch = 0.250 in., Full Depth = 0.1716 in., Center Distance = 4.773 in., Gashing Angle = 2° 52′, Pitch Diamter of Worm = 1.5916 in. (Figure 46).

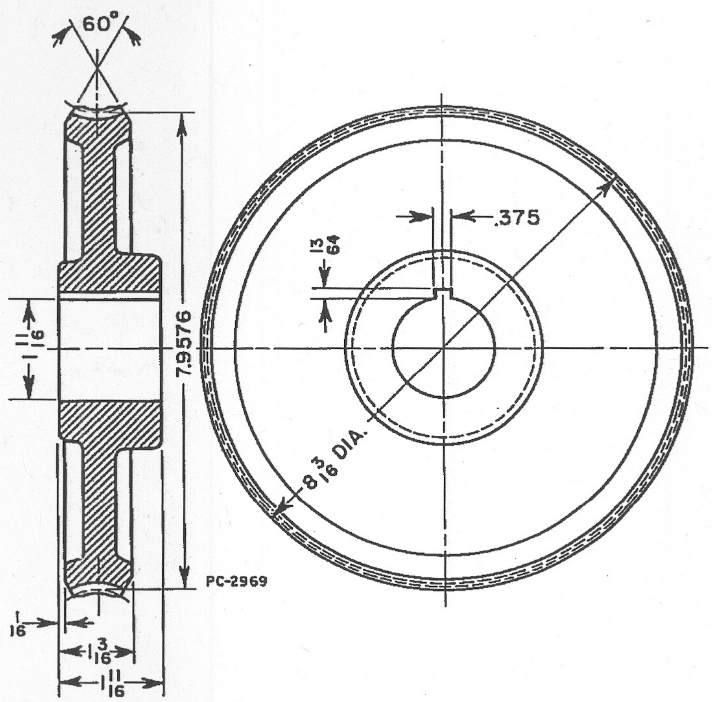

Figure 46
Dimensions of a Worm Wheel

In cutting the teeth of a worm wheel on a milling machine, two operations are required: (1) *gashing* the teeth, and (2) *hobbing* the teeth to the correct size and shape.

Selection of Setup. A *universal type milling machine* equipped with a Universal Dividing Head is used for this operation. The blank is placed between centers of the Dividing Head and tailstock.

Gashing the Teeth—Selection of Cutter. The gashing operation consists of *roughing* the gear teeth with an involute gear cutter having the same pitch and diameter as the worm.

The table of the machine is swiveled to the gashing angle of 2° 52′, in a counter-clockwise direction for a right-hand worm, after aligning the blank on the center of the gashing cutter both crosswise and longitudinally. The gashing operation is then performed by feeding the work vertically to the depth of the teeth. It is necessary, however, to leave a sufficient amount of stock for the *finishing* operation.

If not given, the gashing angle can be calculated from Formula 9 (page 32), using the known values of the lead and pitch diameter of the worm. The gashing angles for worm wheels for a variety of worms from 5/8″ to 6″ diameter and from 1/10″ to 1½″ lead may be taken directly from the Table, (pages 68 and 69).

In the present worm wheel, the pitch diameter of the worm is 1.5916 in. and the lead is 0.250 in. Hence:

$$\tan E = \frac{0.250}{3.14 \times 1.59} \; (.05)$$

and:

$$E = 2^\circ \, 52'$$

Indexing. Plain indexing is used for positioning each tooth of the worm wheel. The correct circle of holes on the index plate and number of turns of the index crank are found by means of the formula on (page 13):

$$t = \frac{40}{100} = \frac{2}{5}$$

$$= \frac{12}{30}$$

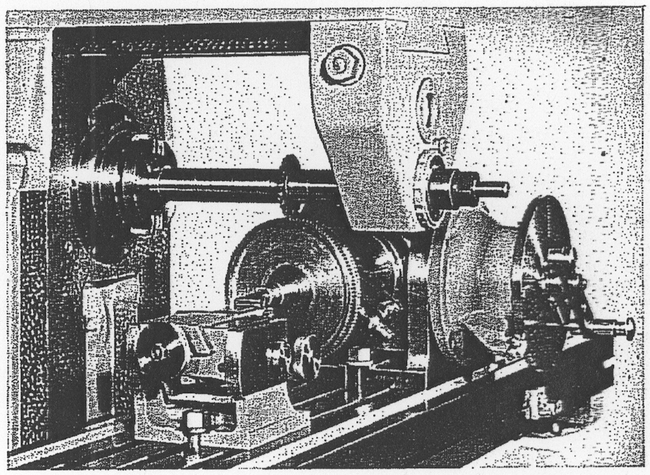

Figure 47A
Gashing the Teech of a Worm Wheel

Each tooth is positioned by indexing 12 spaces on the 30-hole circle of the standard plate. The setup for gashing the teeth on the worm wheel is illustrated in Figure 47A.

Hobbing the Worm Wheel Teeth. For the hobbing operation, the worm wheel is held between centers but free from the Dividing Head driving dog, *thus allowing the hob to drive the wheel while the teeth are cut.*

The worm wheel axis is at right angles to that of the worm. It is therefore necessary to set the table of the universal ma-

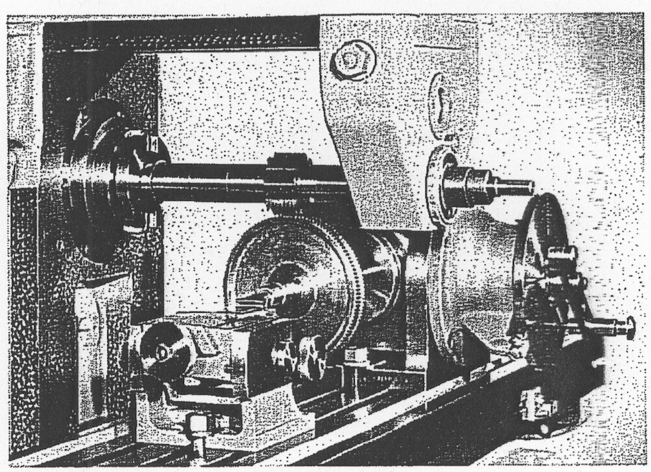

Figure 47B
Hobbing the Teeth of a Worm Wheel

chine in the usual straight position, so that the axis of the worm wheel is at right angles to the arbor on which the hob is mounted (Figure 47B).

The *hob* is made for a ¼ in. pitch, ¼ in. lead, right hand single thread. The diameter of the hob is 1¾ in., the same as the outside diameter of the worm.

The workpiece is adjusted so that the hob centers over the rim of the worm wheel. The table of the machine is locked in position to prevent its moving while the teeth are being hobbed. The work is then raised gradually until the proper depth is obtained.

If a large amount of stock is to be removed or an exceptionally good finish is required, the worm wheel is passed under the hob a number of times, bringing it into the *final depth* for the last revolution.

Milling Worms

Example: Milling a right hand, single thread worm for the worm wheel shown in Figure 46. The worm diameters are shown in Figure 48. The specifications are as follows:

Outside diameter = 1.750 in.	Lead = 0.250 in.
Pitch diameter = 1.591 in.	Pitch = 0.250 in.

Selection of Setup. The worm is placed between the centers of the Universal Wide Range Dividing Head and tailstock on a *universal general purpose milling machine.* Thread milling cutters are mounted on a Universal Milling Attachment and are swiveled to the helix angle of the worm threads. To obtain the lead of ¼ in., the Short and Long Lead Attachment is used.

Selection of Cutter. The *thread milling cutter* is selected for the given ¼ in. pitch and 29° included angle of the worm threads. Since the worm has a single thread, a

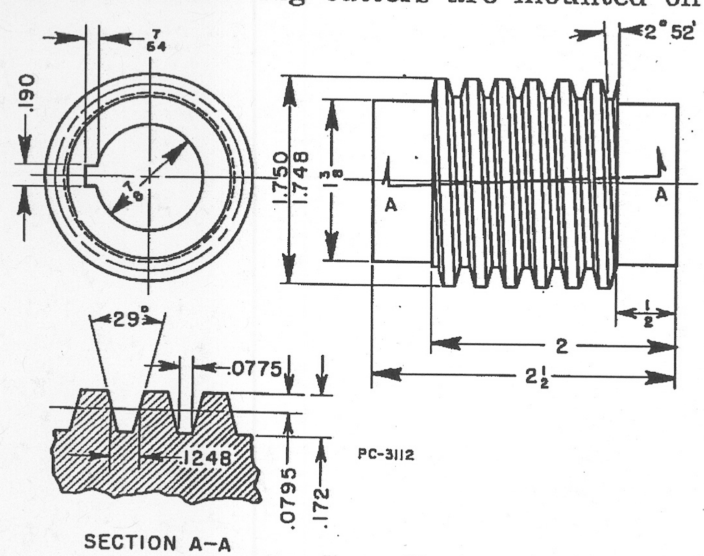

Figure 48

Dimensions of the Worm for the Worm Wheel in Figure 46