CHAPTER 14

GEARS AND GEAR CUTTING

CHAPTER LEARNING OBJECTIVES

Upon completing this chapter, you should be able to do the following:

- *Describe the materials used to manufacture gears.*
- *Explain the manufacture of gears, splines, and sprockets.*
- *Explain the process used to set up gear trains.*

This chapter covers the manufacture of spur gears, helical gears, bevel gears, stub tooth gears, worms, worm gears, splines, and sprockets.

Gears have always been a highly essential element in machinery used aboard ships and at naval shore facilities. In today's Navy, the emphasis on speed, power, and compactness in naval machinery has created special problems for the machinist cutting a gear. Today's machinists must be able to turn out a noiseless, practically unbreakable gear that transmits large amounts of power in small spaces. This requires great skill and precision.

This chapter will cover gear cutting practices on a standard milling machine. If you encounter problems when you calculate or cut gears, consult a machinist's handbook for more detailed information.

As with any shop equipment you must observe all posted safety precautions. Review your equipment operators manual for safety precautions. Also read any chapters of *Navy Occupational Safety and Health (NAVOSH) Program Manual for Forces Afloat,* OPNAV Instruction 5100.19B, that apply to the equipment.

MATERIALS USED FOR GEARS

The choice of material for a particular gear is usually based on the function of the gear. This involves factors such as the speed of operation, the type of stress, the importance of quiet operation, and the need for resistance to corrosion. The easiest way to determine what material to use for a replacement gear is to find out what material was used for the gear you must replace. In most cases, you will have the original gear to go by. If not, you may have to find the specifications or blueprints for the original gear. In some cases you should consult a machinist's handbook, which prescribes various materials. Do this to be sure the material you are using will hold up under the stresses the gear will encounter.

Gears are made from ferrous, nonferrous, and nonmetallic materials. Steel, for example, is used whenever great strength and toughness are required. Nonferrous metals such as bronze and brass are often used aboard naval ships for gears that must resist saltwater corrosion.

Monel and aluminum may be used for gears, where corrosion resistance is of primary importance. Nonmetallic gearing is frequently used where quiet operation is important. Nonmetallic gears are most effective at high-speeds. However, they do not always hold up against the wide fluctuations of load and the high shock loads encountered at low speeds. Gears made of nonmetallic materials have a lower tensile strength than those constructed of metallic materials, but their greater resiliency gives them approximately the same power-transmitting capacity as cast iron.

SPUR GEARS

A gear is made by cutting a series of equally spaced, specially shaped grooves on the periphery of a wheel (see fig. 14-1).

To calculate the dimensions of a spur gear, you must know the parts of the gear. You also must know the formulas for finding the dimensions of the parts. To cut the gear you must know what cutter to use and how

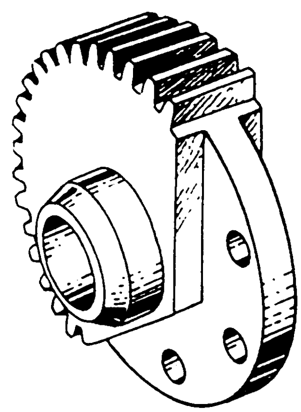

Figure 14-1.—Cutting specially shaped grooves.

to index the blank, so the teeth are equally spaced and have the correct profile.

SPUR GEAR TERMINOLOGY

The following terms (see fig. 14-2) describe gears and gear teeth. The symbols in parentheses are standard gear nomenclature symbols used and taught at MR schools.

OUTSIDE CIRCLE (OC): The circle formed by the tops of the gear teeth

OUTSIDE DIAMETER (OD): The diameter to which you will turn the blank or the overall diameter of the gear

PITCH CIRCLE (PC): The contact point of mating gears, the basis of all tooth dimensions, or an imaginary circle one addendum distance down the tooth

PITCH DIAMETER (PD): The diameter of the pitch circle. In parallel shaft gears, you can determine the pitch diameter directly from the center-to-center distance and the number of teeth.

ROOT CIRCLE (RC): The circle formed by the bottoms of the gear teeth

ROOT DIAMETER (RD): The distance through the center of the gear from one side of the root circle to the opposite side

ADDENDUM (ADD): The height of the part of the tooth that extends outside the pitch circle

CIRCULAR PITCH (CP): The distance from a point on one tooth to a corresponding point on the next tooth measured on the pitch circle

CIRCULAR THICKNESS (CT): One-half of the circular pitch, or the length of the arc between the two sides of a gear tooth on the pitch circle.

CLEARANCE (CL): The space between the top of the tooth of one gear and the bottom of the tooth of its mating gear

DEDENDUM (DED): The depth of the tooth inside the pitch circle, or the radial distance between the root circle and the pitch circle

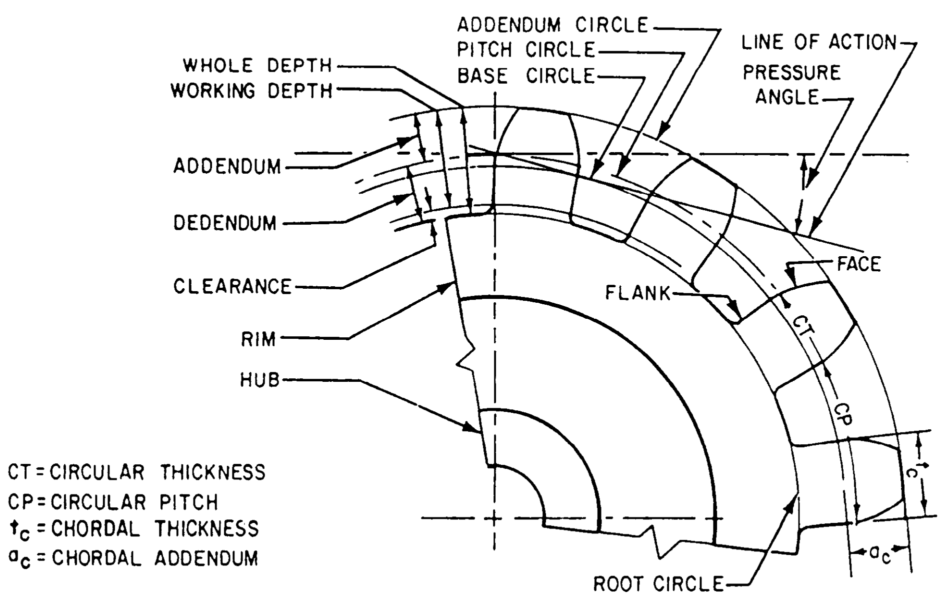

Figure 14-2.—Gear terminology.

WHOLE DEPTH (WD): The radial depth between the circle that bounds the top of the gear teeth and the circle that bounds the bottom of the gear teeth

WORKING DEPTH (WKD): The whole depth minus the clearance, or the depth of engagement of two mating gears; the sum of their addendums

CHORDAL THICKNESS (t_c): The thickness of the tooth measured at the pitch circle or the section of the tooth that you measure to see if the gear is cut correctly

CHORDAL ADDENDUM (a_c): The distance from the top of a gear tooth to the chordal thickness line at the pitch circle (used to set gear tooth vernier calipers to measure tooth thickness)

DIAMETRAL PITCH (DP): The most important calculation because it regulates the tooth size, or the number of teeth on the gear divided by the number of inches of pitch diameter

NUMBER OF TEETH (NT): The actual number of teeth of the gear

BACKLASH (B): The difference between the tooth thickness and the tooth space of engaged gear teeth at the pitch circle

The symbols the American Gear Manufacturers Association uses to describe gears and gear teeth are different from those the Navy uses. The following list will familiarize you with both sets of symbols:

	Machinery Repairman	**American Gear Manufacturers**
Spur Gear Terms	School Abbreviations	Association Abbreviations
Pitch circle	PC	(none)
Pitch diameter	PD	D
Center-to-center distance	C-C	C
Addendum	ADD	a
Dedendum	DED	d
Working depth	WKD	hk
Clearance	CL	C
Whole depth	WD	ht
Root circle	RC	(none)
Outside diameter	OD	Do
Circular thickness	CT	tc
Circular pitch	CP	P
Diametral pitch	DP	P
Number of teeth	NT	N
Root diameter	RD	DR
Chordal thickness	tc	(none)
Chordal addendum	ac	(none)

DIAMETRAL PITCH SYSTEM

The diametral pitch system was devised to simplify gear calculations and measurements. It is based on the diameter of the pitch circle rather than on the circumference. Since the circumference of a circle is 3.1416 times its diameter, you always must consider this constant when you calculate measurements based on the pitch circumference. In the diametral pitch system, however, the constant is in a sense “built into” the system to simplify computation.

When you use this system, there is no need to calculate circular pitch. Indexing devices based on the diametral pitch system will accurately space the teeth, and the formed cutter associated with the indexing device will form the teeth within the necessary accuracy. This system simplifies all calculations such as center distance between gears and working depth of teeth.

Many formulas are used to calculate the dimensions of gears and gear teeth, but we will only use those needed in this discussion. Appendix III of this manual contains a more complete list of such formulas. Appendix IV contains explanations of how you determine the formulas to calculate the dimensions of gear teeth.

Usually, you can get the outside diameter (OD) of a gear and the number of teeth (NT) from a blueprint or a sample gear. You may then use these two known factors to calculate the necessary data.

For example, use the following procedure to make a gear 3.250 inches in diameter that has 24 teeth:

1. Find the pitch diameter (PD) by using the formula:

$$PD = \frac{(NT)\,OD}{NT + 2}$$

$$PD = \frac{24 \times 3.250}{24 + 2} = \frac{78}{26} = 3.000 \text{ inches}$$

2. Find the diametral pitch (DP) by using the formula:

$$DP = \frac{NT}{PD}$$

$$DP = \frac{24}{3} = 8$$

3. Find the whole depth of tooth (WD) by using the formula:

$$WD = \frac{2.157}{DP}$$

$$WD = \frac{2.157}{8} = 0.2696 \text{ inch}$$

You can select the cutter to machine the gear teeth as soon as you compute the diametral pitch. Formed gear cutters are made with eight different forms (numbered from 1 to 8) for each diametral pitch. The number of the cutter depends upon the number of teeth the gear will have. The following chart shows which cutter to use to cut various numbers of teeth on a gear.

If, for example, you need a cutter for a gear that has 24 teeth, use a No. 5 cutter since a No. 5 cutter will cut all gears containing from 21 to 25 teeth.

Range of teeth	Number of cutter
135 to a rack	1
55 to 134	2
35 to 54	3
26 to 34	4
21 to 25	5
17 to 20	6
14 to 16	7
12 to 13	8

Most cutters are stamped to show the number of the cutter, the diametral pitch, the range for the number of the cutter, and the depth. Involute gear cutters usually run from 1 to 48 diametral pitch and 8 cutters to each pitch.

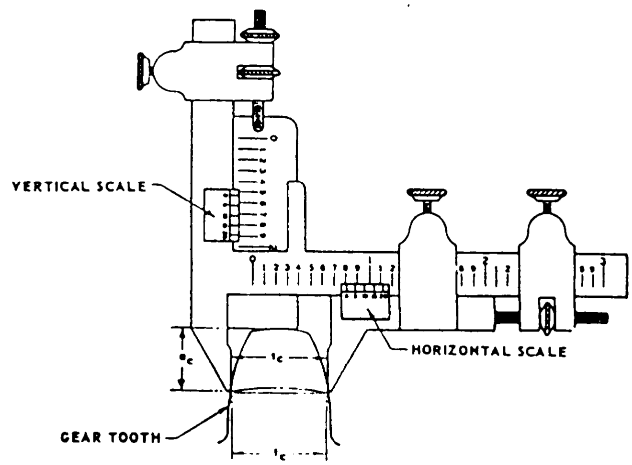

Figure 14-3.—Measuring gear teeth with a vernier caliper.

To check the dimensional accuracy of gear teeth, use a gear tooth vernier caliper (see fig. 14-3). The vertical scale is adjusted to the chordal addendum (a_c) and the horizontal scale is used to find the chordal thickness (t_c). Before you calculate the chordal addendum, you must determine the addendum (ADD) and circular thickness (C_t).

To determine the addendum, use the formula:

$$ADD = \frac{PD}{NT}$$

Using the values from the preceding example,

$$ADD = \frac{3.000}{24} = 0.125 \text{ inch}$$

To determine the circular thickness, use the formula:

$$CT = \frac{1.5708}{DP}$$

Using the values from the preceding example,

$$CT = \frac{1.5708}{8} = 0.1964 \text{ inch}$$

The formula used to find the chordal addendum is

$$a_c = ADD + \frac{(CT)^2}{4\,(PD)}$$

$$= 0.125 + \frac{(0.1964)^2}{4 \times 3}$$

$$= 0.125 + \frac{(0.0386)}{12} = 0.128 \text{ inch}$$

The formula to find the chordal tooth thickness is

$$t_c = PD \sin \left(\frac{90°}{NT} \right)$$

For example,

$$t_c = 3 \times \sin \left(\frac{90°}{NT} \right)$$

$$= 3 \times \sin 3°45''$$

$$= 3 \times 0.0654$$

$$= 3 \times 0.1962 \text{ inch}$$

(**NOTE:** *Mathematics,* Volume II-A, NAVEDTRA 10062, and various machinist's handbooks contain information on trigonometric functions.)

Now set the vertical scale of the gear tooth vernier caliper to 0.128 inch. Adjust the caliper so the jaws touch each side of the tooth as shown in figure 14-3. If the reading on the horizontal scale is 0.1962 inch, the tooth has correct dimensions; if the dimension is greater, the whole depth (WD) is too shallow; if the reading is less, the whole depth (WD) is too deep.

Sometimes you cannot determine the outside diameter of a gear or the number of teeth from available information. However, if you can find a gear dimension and a tooth dimension, you can put these dimensions into one or more of the formulas in Appendix II and calculate the required dimensions.

MACHINING THE GEAR

Use the following procedures to make a gear with the dimensions given in the preceding example:

1. Select and cut a piece of stock to make the blank. Allow at least 1/8 inch excess material on the diameter and thickness of the blank for cleanup cuts.

2. Mount the stock in a chuck on a lathe. At the center of the blank, face an area slightly larger than the diameter of the required bore.

3. Drill and bore to the required size (within tolerance).

4. Remove the blank from the lathe and press it on a mandrel.

5. Set up the mandrel on the milling machine between the centers of the index head and the footstock. Dial in within tolerance.

7. Select a No. 5 involute gear cutter (8 pitch) and mount and center it.

8. Set the index head to index 24 divisions.

9. Start the milling machine spindle and move the table up until the cutter just touches the gear blank. Set the micrometer collar on the vertical feed handwheel to zero, then hand feed the table up toward the cutter slightly less than the whole depth of the tooth.

10. Cut one tooth groove. Then index the workpiece for one division and take another cut. Check the tooth dimensions with a vernier gear tooth caliper as described previously. Make the required adjustments to provide an accurately "sized" tooth.

11. Continue indexing and cutting until the teeth are cut around the circumference of the workpiece.

When you machine a rack, space the teeth by moving the work table an amount equal to the circular pitch of the gear for each tooth cut. Calculate the circular pitch by dividing 3.1416 by the diametral pitch:

$$CP = \frac{3.1416}{DP}$$

You do not need to make calculations for corrected addendum and chordal pitch to check rack teeth dimensions. On racks the addendum is a straight line dimension and the tooth thickness is one-half the linear pitch.

HELICAL GEARS

A <u>h</u>elix is a line that spirals around a cylindrical object, like a stripe that spirals around a barber pole.

A <u>heli</u>cal gear is a gear whose teeth spiral around the gear body. Helical gears transmit motion from one shaft to another. The shafts can be either parallel or set

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Figure 14-4.—Helical gears.

at an angle to each other, as long as their axes do not intersect (fig. 14-4).

Helical gears operate more quietly and smoothly than spur gears because of the sliding action of the spiral teeth as they mesh. Also, several teeth make contact at the same time. This multitooth contact makes a helical gear stronger than a comparable spur gear. However, the sliding action of one tooth on another creates friction that could generate excessive heat and wear. Thus, helical gears are usually run in an oil bath.

A helical gear can be either right-handed or left-handed. To determine the hand of a helical gear, simply put the gear on a table with its rotational axis perpendicular to the table top. If the helix moves upward toward the right, the gear is right-handed. If the helix moves upward to the left, the gear is left-handed.

To mill a helical gear, you need a dividing head, a tailstock, and a lead driving mechanism for the dividing head (fig. 14-5). These cause the gear blank to rotate at a constant rate as the cut advances. This equipment is an integral part of a universal knee and column type of milling machine.

When a helical gear is manufactured correctly, it will mesh with a spur gear of the same diametral pitch (DP), with one gear sitting at an angle to the other. The dimensions of a helical gear would be the same as those of a comparable spur gear if the helical gear's teeth were

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Figure 14-5.—A universal horizontal milling machine equipped for helical milling. The closeup shows the workpiece mounted between the dividing head centers. A fluting cutter is mounted on the arbor.

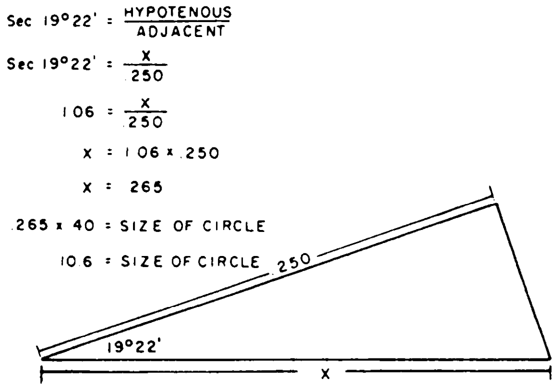

Figure 14-6.—Development of evenly spaced slots with an included angle.

not cut at an angle. One of these differences is shown in the following example:

> You will need a 10-inch circular blank to cut 20 one-quarter-inch wide slots spaced one-quarter of an inch apart parallel to the gear's axis of rotation. But you will need a 10.6-inch circular blank to cut the same slots at an angle of 19°22′ to the axis of rotation (fig. 14-6).

Helical gears are measured at a right angle to the tooth face in the same manner as spur gears with the same diametral pitch.

DIMENSIONS OF A HELICAL GEAR, REAL AND NORMAL

Every helical gear contains a theoretical spur gear. Any gear element formula used to calculate a spur gear dimension can also be used to determine an equivalent helical gear dimension. However, the helical gear dimension is known as a normal dimension. For example, the number of teeth (NT) on a helical gear is considered a normal dimension. Remember, though, all normal gear elements are calculated dimensions and therefore cannot be measured.

For example: $\frac{NT}{DP}$ = *Normal pitch diameter (NPD)*

Although most helical gear dimensions are normal dimensions, a few dimensions are real (measurable) dimensions. Examples of real dimensions are the outside diameter (OD), called the real outside diameter (ROD), and the pitch diameter, called the real pitch diameter (RPD). Two other real dimensions are the lead and the helix angle($\angle H$).

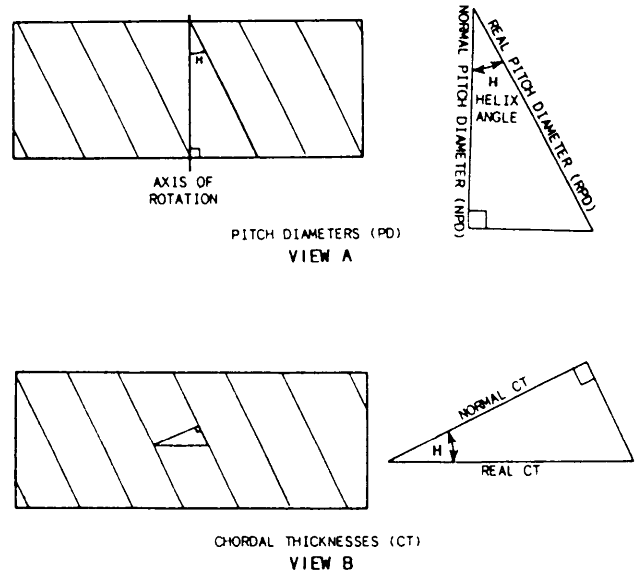

Figure 14-7.—Development of the helix angle.

The lead of a helical gear is the longitudinal distance a point on the gear travels during one complete revolution of the gear. During the gear manufacturing process, lead relates to the travel of the table.

The helix angle is the angle between a plane parallel to the rotational axis of the workpiece and the helix line generated on the workpiece. Use this angle to set the milling machine table to cut the gear. Also use it to establish the relationships between the real dimensions and the normal dimensions on a helical gear.

Determining the Dimensions of a Helical Gear

The RPD is the easiest helical gear dimension to determine. Simply subtract twice the addendum from the ROD, or

$$RPD = ROD - 2\ ADD$$

To determine the other major dimensions, you must relate real and normal dimensions trigonometrically through the helix angle. Then by knowing two of the three components of the trigonometric relationship, you can determine the third component.

Look at figure 14-7, view A, and recall that the helix angle is the angle between the gear's axis of rotation and the helix. In this view, the RPD and the NPD are related through the secant and cosine functions. That is,

$$Secant\ H = \frac{RPD}{NPD} \text{ or } Cosine\ H = \frac{NPD}{RPD}$$

In figure 14-7, view B, the triangle has been mathematically shifted so we can compare the real chordal thickness (CTR) and the normal chordal

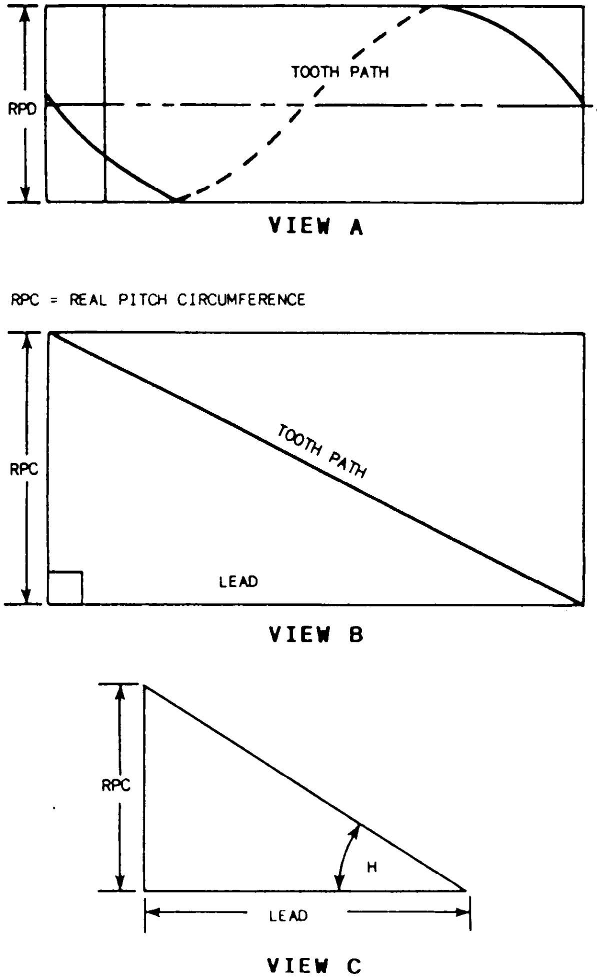

Figure 14-8.—Formulation of a lead triangle and a helix angle.

thickness (CTN). The CTR is the thickness of the tooth measured parallel to the gear's face, while the CTN is measured at a right angle to the face of the tooth. The two dimensions are also related through the secant and cosine functions. That is,

$$Secant\ H = \frac{CTR}{CTN} \text{ or } Cosine\ H = \frac{CTN}{CTR}$$

If we could open the gear on the pitch diameter (PD), we would have a triangle we could use to solve for the lead (fig. 14-8, view A).

Figure 14-8, view B, shows a triangle; one leg is the real pitch circumference and the other is the lead. Notice that the hypotenuse of the triangle is the tooth path and has no numerical value.

To solve for the lead of a helical gear, when you know the RPD and the helix angle, simply change RPD to RPC (real pitch circumference). To do that, multiply RPD by 3.1416 (π) (fig. 14-8, view C), then use the formula:

$$Lead = RPC \times Cotangent\ \angle H.$$

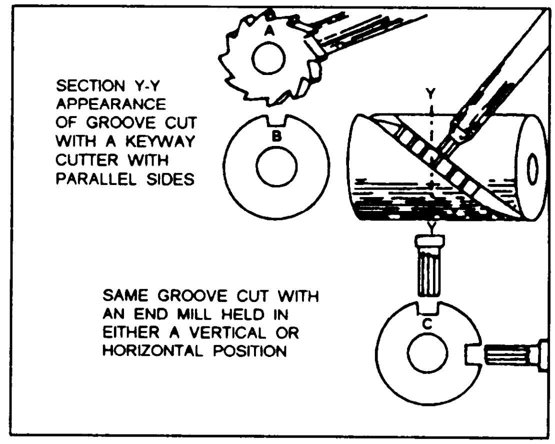

Figure 14-9.—Helix cut with two different cutters.

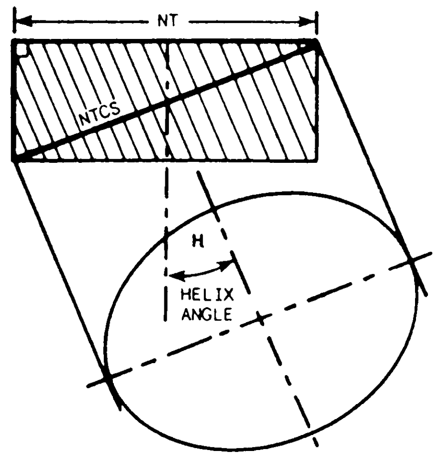

Figure 14-10.—Formation of helical gear cutter selection.

Selecting a Helical Gear Cutter

When you cut a spur gear, you base selection of the cutter on the gear's DP and on the NT to be cut. To cut a helical gear, you must base cutter selection on the helical gear's DP and on a hypothetical number of teeth set at a right angle to the tooth path. This hypothetical number of teeth takes into account the helix angle and the lead of the helix, and is known as the number of teeth for cutter selection (NTCS). This hypothetical development is based on the fact that the cutter follows an elliptical path as it cuts the teeth (fig. 14-9).

The basic formula to determine the NTCS involves multiplying the actual NT on the helical gear by the cube of the secant of the helix angle, or

$$NTCS = NT \times sec\ \angle H^3$$

This formula is taken from the triangle in figure 14-10.

Table 14-1.—"K" Factor Table

Degrees of Helix Angle	K	Degrees of Helix Angle	K	Degrees of Helix Angle	K
1	1.001	22	1.254	43	2.557
2	1.002	23	1.282	44	2.687
3	1.004	24	1.312	45	2.828
4	1.007	25	1.344	46	2.983
5	1.011	26	1.377	47	3.152
6	1.016	27	1.414	48	3.336
7	1.022	28	1.454	49	3.540
8	1.030	29	1.495	50	3.767
9	1.038	30	1.540	51	4.012
10	1.047	31	1.588	52	4.284
11	1.057	32	1.640	53	4.586
12	1.068	33	1.695	54	4.925
13	1.080	34	1.755	55	5.295
14	1.094	35	1.819	56	5.710
15	1.110	36	1.889	57	6.190
16	1.127	37	1.963	58	6.720
17	1.145	38	2.044	59	7.321
18	1.163	39	2.130	60	8.000
19	1.182	40	2.225	61	8.780
20	1.204	41	2.326	62	9.658
21	1.228	42	2.436	63	10.687

Table 14-2.—Corrected Tooth Constant

No. of Teeth	Chordal Thickness	Chordal Addenda	No. of Teeth	Chordal Thickness	Chordal Addenda	No. of Teeth	Chordal Thickness	Chordal Addenda
10	1.56434	1.06156	59	1.57061	1.01046	108	1.57074	1.00570
11	1.56546	1.05598	60	1.57062	1.01029	109	1.57075	1.00565
12	1.56631	1.05133	61	1.57062	1.01011	110	1.57075	1.00560
13	1.56698	1.04739	62	1.57063	1.00994	111	1.57075	1.00556
14	1.56750	1.04401	63	1.57063	1.00978	112	1.57075	1.00551
15	1.56794	1.04109	64	1.57064	1.00963	113	1.57075	1.00546
16	1.56827	1.03852	65	1.57064	1.00947	114	1.57075	1.00541
17	1.56856	1.03625	66	1.57065	1.00933	115	1.57075	1.00537
18	1.56880	1.03425	67	1.57065	1.00920	116	1.57075	1.00533
19	1.56901	1.03244	68	1.57066	1.00907	117	1.57075	1.00529
20	1.56918	1.03083	69	1.57066	1.00893	118	1.57075	1.00524
21	1.56933	1.02936	70	1.57067	1.00880	119	1.57075	1.00519
22	1.56946	1.02803	71	1.57067	1.00867	120	1.57075	1.00515
23	1.56958	1.02681	72	1.57067	1.00855	121	1.57075	1.00511
24	1.56967	1.02569	73	1.57068	1.00843	122	1.57075	1.00507
25	1.56977	1.02466	74	1.57068	1.00832	123	1.57076	1.00503
26	1.56984	1.02371	75	1.57068	1.00821	124	1.57076	1.00499
27	1.56991	1.02284	76	1.57069	1.00810	125	1.57076	1.00495
28	1.56998	1.02202	77	1.57069	1.00799	126	1.57076	1.00491
29	1.57003	1.02127	78	1.57069	1.00789	127	1.57076	1.00487
30	1.57008	1.02055	79	1.57069	1.00780	128	1.57076	1.00483
31	1.57012	1.01990	80	1.57070	1.00772	129	1.57076	1.00479
32	1.57016	1.01926	81	1.57070	1.00762	130	1.57076	1.00475
33	1.57019	1.01869	82	1.57070	1.00752	131	1.57076	1.00472
34	1.57024	1.01813	83	1.57070	1.00743	132	1.57076	1.00469
35	1.57027	1.01762	84	1.57071	1.00734	133	1.57076	1.00466
36	1.57030	1.01714	85	1.57071	1.00725	134	1.57076	1.00462
37	1.57032	1.01667	86	1.57071	1.00716	135	1.57076	1.00457
38	1.57035	1.01623	87	1.57071	1.00708	136	1.57076	1.00454
39	1.57037	1.01582	88	1.57071	1.00700	137	1.57076	1.00451
40	1.57039	1.01542	89	1.57072	1.00693	138	1.57076	1.00447
41	1.57041	1.01504	90	1.57072	1.00686	139	1.57076	1.00444
42	1.57043	1.01469	91	1.57072	1.00679	140	1.57076	1.00441
43	1.57045	1.01434	92	1.57072	1.00672	141	1.57076	1.00439
44	1.57047	1.01402	93	1.57072	1.00665	142	1.57076	1.00435
45	1.57048	1.01370	94	1.57072	1.00658	143	1.57076	1.00432
46	1.57050	1.01341	95	1.57073	1.00651	144	1.57076	1.00429
47	1.57051	1.01311	96	1.57073	1.00644	145	1.57077	1.00425
48	1.57052	1.01285	97	1.57073	1.00637	146	1.57077	1.00422
49	1.57053	1.01258	98	1.57073	1.00630	147	1.57077	1.00419
50	1.57054	1.01233	99	1.57073	1.00623	148	1.57077	1.00416
51	1.57055	1.01209	100	1.57073	1.00617	149	1.57077	1.00413
52	1.57056	1.01187	101	1.57074	1.00611	150	1.57077	1.00411
53	1.57057	1.01165	102	1.57074	1.00605	151	1.57077	1.00409
54	1.57058	1.01143	103	1.57074	1.00599	152	1.57077	1.00407
55	1.57058	1.01121	104	1.57074	1.00593	153	1.57077	1.00405
56	1.57059	1.01102	105	1.57074	1.00587	154	1.57077	1.00402
57	1.57060	1.01083	106	1.57074	1.00581	155	1.57077	1.00400
58	1.57061	1.01064	107	1.57074	1.00575	156	1.57077	1.00397

It can be complicated to compute the NTCS with the formula, so table 14-1 provides the data for a simplified method to cube the secant of the helix angle. To use it, multiply the NT by a factor (K) you obtain from the table.

$$NTCS = NT \times K\ (factor)$$

To determine the constant K, locate on table 14-l the helix angle you plan to cut. If the angle is other than a whole number, such as 15°6´, select the next highest whole number of degrees, in this case 16°. The factor for 15°6´is 1.127.

The following section will show you how to use the numerical value of the NTCS to compute corrected chordal addenda and chordal thicknesses.

Corrected Chordal Addendum and Chordal Thickness

As in spur gearing, you must determine corrected chordal addenda and chordal thicknesses since you will be measuring circular distances with a gear tooth vernier caliper that was designed to measure only straight distances.

In helical gearing, use the NTCS rather than the actual NT to select the constant needed to determine the chordal addendum (CA) and the chordal thickness (CT). Table 14-2 provides these constants. Remember, the numbers listed in the Number of Teeth column are not actual numbers of teeth, but are NTCS values. After you have determined the chordal addendum and chordal thickness constants, you can calculate the corrected chordal addendum by using the following formula:

$$CADD = \frac{Chordal\ addendum\ constant}{Diametral\ pitch} = \frac{CA\ constant}{DP}$$

and the corrected chordal thicknesss by using this formula:

$$CCT = \frac{Chordal\ thickness\ constant}{Diametral\ pitch} = \frac{CT\ constant}{DP}$$

As an example, calculate the corrected chordal addendum and the corrected chordal thickness for a helical gear with a DP of 10, a helix angle of 15°, and 20 teeth.

$$NTCS = NT \times K$$

$$= 20 \times 1.11 \text{ (constant from table 14-l)}$$

$$= 23$$

Table 14-3.—Maximum Backlash Allowance

DP	Backlash
4	.011
5	.009
6	.008
7	.007
8	.006
9	.006
10	.005
12	.005
14	.005

A. Maximum Backlash Allowance for Spur and Helical Gear.

DP	Backlash
4	.012
5	.012
6	.008
7	.008
8	.007
10	.007
12	.004
14	.004

B. Maximum Backlash Allowance for Bevel Gear.

NOTE: If the calculated NTCS is other than a whole number, go to the next highest whole number.

From table 14-2, an NTCS of 23 provides the following:

$$CA\ constant = 1.0268;\ CT\ constant = 1.56958$$

Therefore, $CADD = \frac{1.0268}{10} = 0.102680$ and

$$CCT = \frac{1.56958}{10} = 0.156958$$

Backlash Allowance for Helical Gears

The backlash allowance for helical gears is the same as that for spur gears. Backlash is obtained by decreasing the thickness of the tooth at the pitch line and should be indicated by a chordal dimension. Table 14-3 gives maximum allowable backlash in inches between the teeth of the mating gears.

To determine the proper amount of backlash, multiply the maximum allowable amount of backlash found in table 14-3, part A, by 2 and add the result to the calculated whole depth. In this case the maximum backlash allowance is a constant.

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Figure 14-11.—Standard universal dividing head driving mechanism connected to the dividing head, and showing the location of change gears's A, B, C, and D.

Center-to-Center Distance

We said earlier in this chapter that the main purpose of gearing is to transmit motion between two or more shafts. In most cases these shafts are in fixed positions with little or no adjustments available. Therefore, it is important for you to know the center-to-center (C-C) distance between the gear and the pinion.

If you know the tooth elements of a helical gear, you can say that when the real pitch radius of the gear (RPR_g) is added to the real pitch radius of the pinion (RPR_p), you can determine the C-C distance of the two gears (gear and pinion).

The ratio of the NT on the gear and the pinion is equal to the ratio of the PD of the gear and the pinion. This will allow you to solve for the necessary elements of both gear and the pinion by knowing only the C-C distance and the ratio of the gear and the pinion.

GEAR TRAIN RATIO

When a helix is milled on a workpiece, the workpiece must be made to rotate at the same time it is fed into the revolving cutter. This is done by gearing the dividing head to the milling machine table screw. To achieve a given lead, you must select gears with a ratio that will cause the work to rotate at a given speed while it advances a given distance toward the cutter. This distance will be the lead of the helical gear. The lead of the helix is determined by the size and the placement of the change gears, labeled A, B, C, and D in figure 14-11. Gears X and Y are set up to mill a left-handed helix. You can set a right-handed helix by removing gear Y and reversing gear X.

Before you can determine which gears are required to obtain a given lead, you must know the lead of the milling machine. The lead is the distance the milling machine table must move to rotate the spindle of the dividing head one revolution. Most milling machines have a table screw of 4 threads per inch with a lead of 0.250 inch (1/4 inch) and a dividing head (index head) with a 40:1 worm-to-spindle ratio. When the index head is connected to the table through a 1:1 ratio, it will cut a lead of 10 inches. Thus, 40 turns of the lead screw are required to make the spindle revolve one complete revolution (40 × 0.250 inch = 10 inches). Therefore, 10 will be the constant in our gear train ratio formula,

All ratios other than 1:1 require modification of the gear train.

From this formula, we can also say that the

$$\frac{\textit{Lead of the machine}}{\textit{Lead of the helix to be cut}} = \frac{\textit{Product of the driving gears tooth numbers}}{\textit{Product of the driven gears tooth numbers}}$$

Example:

Determine the change gears required for a lead of 15 inches. Assume the milling machine has a lead of 10 inches.

$$\frac{\textit{Lead of machine}}{\textit{Lead of helix desired}} = \frac{10}{15} = \frac{\textit{Driving gears tooth numbers product}}{\textit{Driven gears tooth numbers product}}$$

If you could use a simple gear train (one driving and one driven gear), a lo-tooth gear on the table screw meshed with a 15-tooth gear on the dividing-head worm shaft would produce the 15-inch lead required. However, gears of 10 and 15 teeth are not available, and the drive system is designed for a compound gear train of four gears. Therefore, the fraction 10/15 must be split into two fractions whose product equals 10/15. Do this by factoring as follows:

$$\frac{10}{15} = \frac{5 \times 2}{5 \times 3} = \frac{\textit{Driving gears tooth product}}{\textit{Driven gears tooth product}}$$

If gears with 5 and 2 teeth were possible, they would be the driving gears, and gears with 5 and 3 teeth would be the driven gears. But since this is not possible, each of the fractions must be expanded by multiplying both the numerator and the denominator by a number that will result in a product that corresponds to the number of teeth on available gears:

$$\frac{5}{5} \times \frac{8}{8} = \frac{40}{40} \text{ and } \frac{2}{3} \times \frac{12}{12} = \frac{24}{36}$$

or

$$\frac{5 \times 2}{5 \times 3} = \frac{40 \times 24}{40 \times 36} = \frac{\textit{Driving gears tooth product}}{\textit{Driven gears tooth product}}$$

Thus, gears with 40 and 24 teeth become the driving gears, and gears with 40 and 36 teeth become the driven gears.

These gears would be arranged in the gear train as follows:

Gear A (on the dividing-head worm shaft)

40 teeth (driven)

Gear B (first gear on the idler stud)

24 teeth (driving)

Gear C (second gear on the idler stud)

36 teeth (driven)

Gear D (gear on the table screw)

40 teeth (driving)

The positions of the driving gears may be interchanged without changing their products. The same is true of the driven gears. Thus, several different combinations of driving and driven gears will produce a helix with the same lead.

Before you start to figure your change gear, check your office library for a ready-made table for the selection of gears devised by the Cincinnati Milling Machine Company. These gears have been determined using the formula, $\frac{\textit{lead}}{10}$. If you have already calculated your lead, match it with the lead in the table and select the gears for that lead.

MANUFACTURING A HELICAL GEAR

At this point of the chapter, you are ready to manufacture a helical gear. In a case where you must manufacture a helical gear from a sample, you should do the following:

1. Find the DP.
2. Measure the OD. This is also the ROD.
3. Find the ADD.
4. Find the RPD.
5. Find the NT.

6. Find the NPD.
7. Find the $\angle H$.
8. Find the RPC.
9. Find the lead.
10. Find the change gear.
11. Find the NTCS.
12. Make sure the cutter has the correct DP and cutter number.
13. Find your corrected chordal addendum and chordal thickness.
14. Find your corrected whole depth (WD).
15. Determine what kind of material the sample gear is to be made of.

Now you are ready to machine your gear.

Use the following hints to manufacture a helical gear:

1. Make all necessary calculations that are needed to compute the dimensions of the gear.
2. Set up the milling machine attachments for machining.
3. Select and mount a gear cutter. Use the formula

$$Sec \angle H^3 = \frac{NTCS\,(X)}{NT}$$

4. Swivel the milling machine table to the helix angle for a right-hand helix; face the machine and push the milling machine table with your right hand. For a left-hand helix, push the table with your left hand.
5. Set the milling machine for the proper feeds and speeds.
6. Mount the change gears. Use the gear train ratio formula to determine your change gears.
7. Mount the gear blank for machining.
8. Set up the indexing head for the correct number of divisions.
9. Before cutting the teeth to the proper depth, double check the setup, the alignment, and all calculations.
10. Now you are ready to cut your gear.
11. Remove and deburr the gear.

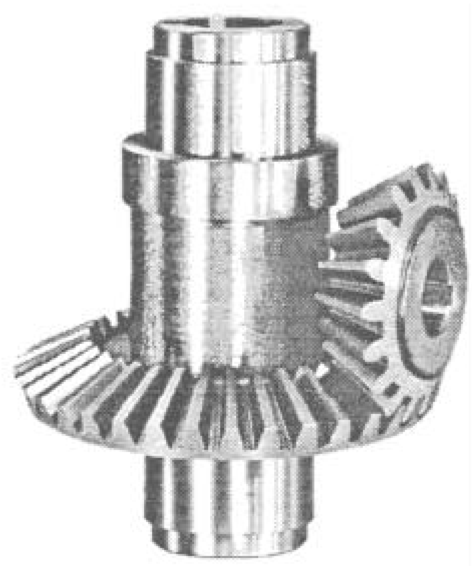
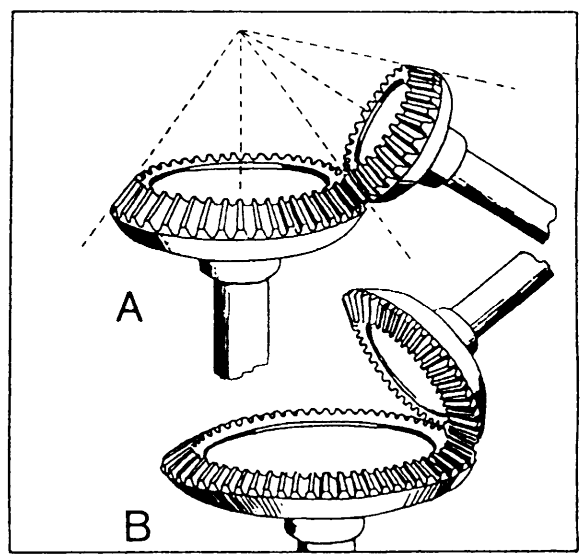


Figure 14-12.—Bevel gear and pinion.



A. With shafts less than 90° apart
B. With shafts more than 90° apart

Figure 14-13.—Other forms of bevel gears.

BEVEL GEARS

Bevel gears have a conical shape (fig. 14-12) and are used to connect intersecting shafts. Figure 14-13, view A, shows an example of bevel gears with shafts set at less than 90°. View B shows those set at more than 90°. There are several kinds of bevel gear designs. We will discuss the straight-tooth design because it is the most commonly used type in the Navy. The teeth are straight but the sides are tapered. The center line of the teeth will intersect at a given point.

Bevel gears are usually manufactured on gear-cutting machines. However, you will occasionally have to make one on a universal milling machine.

This section of the chapter deals with the angle nomenclature of a bevel gear as well as the development of the triangles needed to manufacture one.

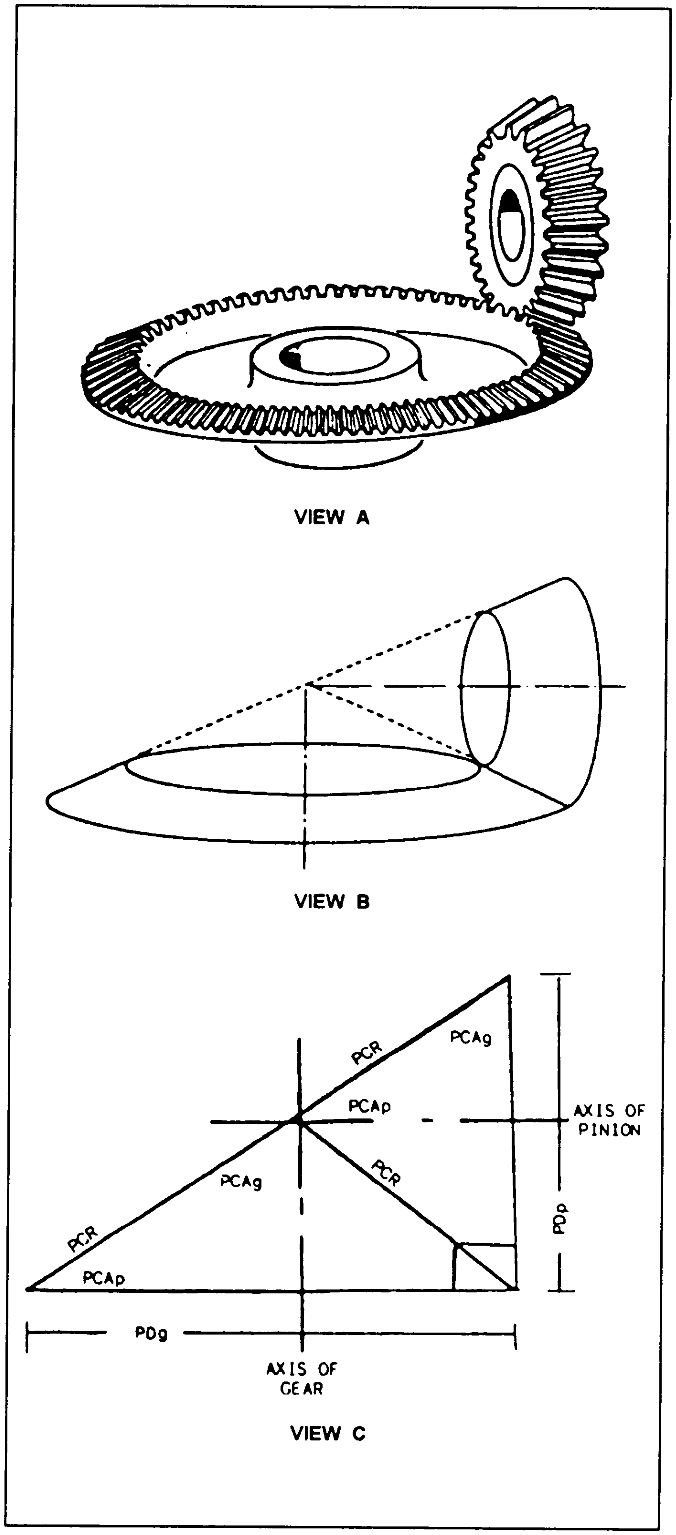


Figure 14-14.—Development of the mating gear triangle.

When two bevel gears whose shaft angles equal 90° are in mesh (fig. 14-14, view A) they form a triangle. It is called the mating gear triangle. The cones (fig. 14-14, view B) that form the basis of the bevel gears are called the pitch cones. These cones are not visible at all on the finished gear, but they are important elements in bevel gear design.

The angle that is formed at the lower left-hand corner of the triangle (fig. 14-14, view C) is called the pitch cone angle of the pinion. The altitude of the triangle is called the pitch diameter of the pinion, and its base is called the pitch diameter of the gear.

The hypotenuse of the triangle is twice the pitch cone radius.

The pitch diameter (gear and pinion), the number of teeth (gear and pinion), and the actual ratio between the gear and the pinion are all in ratio. Therefore, we can use any of these three sets to find the pitch cone angle (PCA).

Example: A 10 diametral pitch (DP) gear with 60 teeth has a pitch diameter (PD) of 6 and a 10 DP pinion with 40 teeth has a PD of 4. Therefore, the ratio of the gear and the pinion is 3:2.

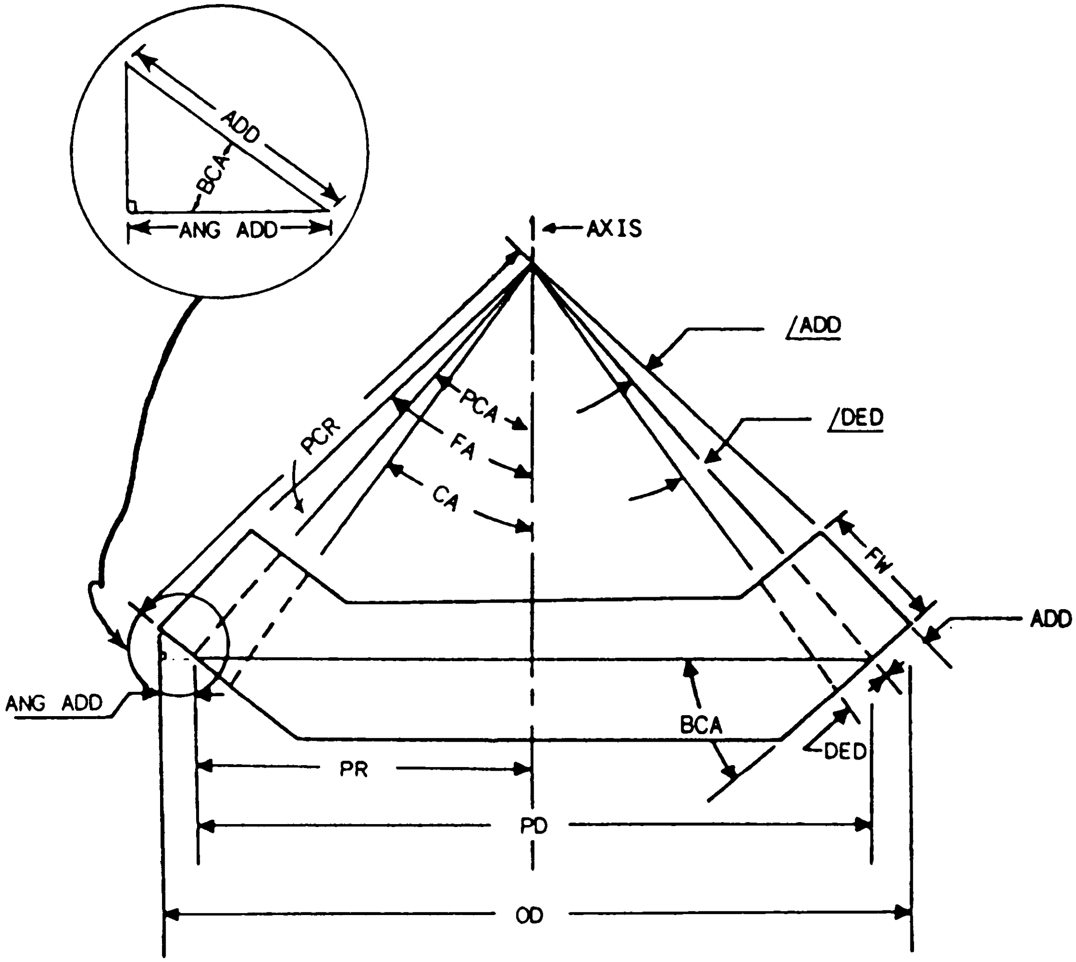
We can determine the PCA by simply substituting the known values into the formula:

$$\text{Tan } \angle PC = \frac{NT_g}{NT_p} = \frac{(60)}{(90)}$$

or

$$\frac{PD_g}{PD_p} = \frac{(6)}{(4)} = \frac{3}{2} \textit{ ratio}$$

NOTE: The pitch cone angle of the pinion (PCA_p) is the compliment of the pitch cone angle of the gear (PCA_g).



FA - Face angle
PCA - Pitch cone angle
CA - Cutting angle
ADD - Addendum angle
DED - Dedendum angle
BCA - Back cone angle
PD - Pitch diameter
OD - Outside diameter
ANG ADD - Angular addendum
FW - Face width
PCR - Pitch cone radius
PR - Pitch radius
ADD - Addendum
DED - Dedendum

Figure 14-15.—Parts of a bevel gear.

BEVEL GEAR NOMENCLATURE

The dimension nomenclature of the bevel gear is the same as that of a spur gear, with the exception of the angular addendum. Refer to figure 14-15.

1. Face angle (FA)
   a. This angle is formed by the top edge of the teeth and the axis of the gear.
   b. The gear blank is machined to this angle.
   c. The face angle is obtained by adding one addendum angle (∠ADD) to the pitch cone angle (∠PC).

2. Pitch cone angle (PCA or ∠PC)
   a. This angle is formed by a line down one addendum on the tooth and the axis of the gear.
   b. This angle cannot be measured, but it is very important in calculations.

3. Cutting angle (∠C or CA)
   a. This angle is formed by the bottom of the tooth and the axis of the gear.
   b. The index head is set at this angle when the gear is cut.

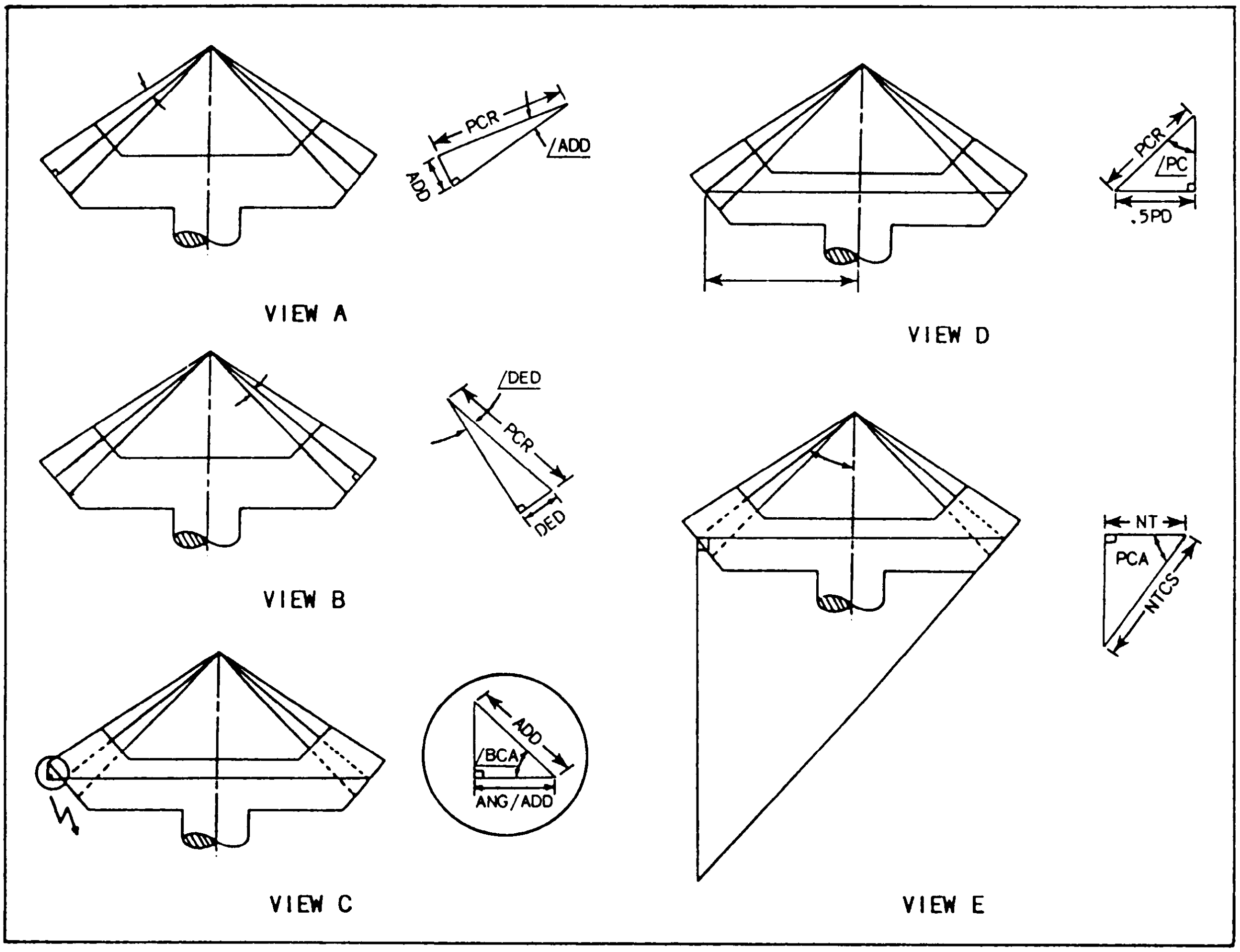


Figure 14-16.—Development of bevel gear formulas.

c. This angle is obtained by subtracting the dedendum angle ($\angle DED$) from the pitch cone angle ($\angle PC$).

4. Addendum angle ($\angle ADD$)

a. This angle is formed by the top of the tooth and a line one addendum down on the tooth.

b. This angle cannot be measured, but it is used in making calculations for the gear.

c. In the triangle shown in figure 14-16, view A, the hypotenuse is the pitch cone radius and the side opposite is the addendum.

Therefore, Cot $\angle ADD = \frac{PCR}{ADD}$.

5. Dedendum angle ($\angle DED$) (fig. 14-15)

a. This angle is formed by a line addendum down on the tooth and a drawn through the bottom tooth.

b. This angle cannot be measured, but used in calculations.

c. In the triangle shown in figure 14-16, view B, the side opposite the dedendum angle is the dedendum and the hypotenuse is the pitch cone radius.

Therefore, Cot $\angle DED = \frac{PCR}{DED}$.

6. Back cone angle (BCA or $\angle BC$)(fig. 14-15). This angle is formed by the large end of the tooth and the pitch diameter of the gear. It is equal in value to the pitch cone angle (PCA).

7. Pitch diameter (PD)—This is the diameter of the gear blank one addendum down at the large end of the gear.

8. Outside diameter (OD)

a. This is the maximum diameter of the gear.

b. The gear blank is machined to this outside diameter.

c. The outside diameter is obtained by adding the pitch diameter and twice the angular addendum.

9. Angular addendum (ANG ADD)

a. This is one-half the difference between the pitch diameter and the outside diameter.

b. In the triangle shown in figure 14-16, view C, the hypotenuse is the addendum and the side adjacent to the angle (BCA) is known as the angular addendum.

C. To obtain the angular addendum (ANG ADD), simply multiply the addendum of the gear by the cosine of angle BCA.

$$ANG\ ADD = ADD \times COS \angle BCA$$

10. Tooth dimensions (TD)

a. All tooth dimensions at the large end are the same as a spur gear of the same DP.

b. All tooth dimensions at the small end are a percentage of the large end, depending of the face width ratio.

11. Face width (FW) (fig. 14-15)

a. This is the length of the tooth.

b. The gear blank is machined to this dimension.

12. Pitch cone radius (PCR)

a. This is the length of the side of a cone formed by the bevel gear.

b. This radius is used extensively in calculations.

c. In the triangle shown in figure 14-16, view D, the hypotenuse is the pitch cone radius and the side opposite the pitch cone angle ($\angle PC$)is equal to one-half the pitch diameter (0.5 PD).

d. By using our knowledge of trigonometry, we can obtain the PCR by using the cosec of $\angle PC$ and one-half the pitch diameter.

$$PCR = cosec \angle PC \times 0.5PD.$$

13. Pitch cone radius small (PCR_s). This is the difference between the pitch cone radius and the face width. $PCR_s = PCR - FW$.

14. Face width ratio (FWR)

a. This is the ratio of the pitch cone radius and the face width. $FWR = \frac{PCR}{FW}$.

b. The small tooth dimensions are calculated from this ratio.

15. Proportional tooth factor (PTF). This is the ratio between the pitch cone radius small and the pitch cone radius. $FTF = \frac{PCR_s}{PCR}$.

16. Small tooth dimensions. Multiply any large tooth dimension by the proportional tooth faction to find the dimension of the small tooth of the gear or pinion.

17. Number of teeth for cutter selection (NTCS)

a. In the triangle shown in figure 14-16, view E, the NTCS is the hypotenuse and the side adjacent is the number of teeth of the gear.

b. The known angle in this case is the pitch cone angle, or the back cone angle.

c. To obtain the NTCS, simply multiply the secant of $\angle PC$ by the NT.

$$NTCS = NT \times Sec \angle PC.$$

d. The NTCS is taken from the number of teeth on an imaginary spur gear that has a different pitch diameter (PD) than the pitch diameter (PD) of a bevel gear.

e. When your computation for the NTCS contains a decimal number, round the computation to the next higher whole number.

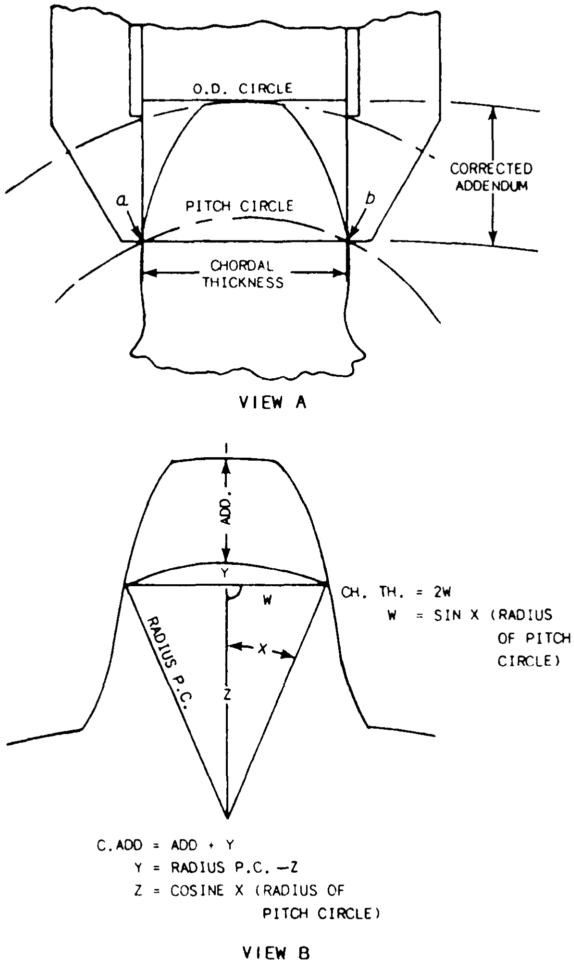


Figure 14-17.—Formulas for calculating chordal thickness.

Chordal Addendum and Chordal Thickness

Before you can measure a manufactured gear tooth accurately, you must know the chordal addendum and the chordal thickness. These dimensions are used to measure the size of the gear tooth.

Chordal addendum (corrected addendum) a_c. This is the distance from the top of a gear tooth to the chord across the gear tooth at the pitch circle (fig. 14-17, view A). It is the point at which the chordal thickness is measured.

Chordal thickness of a gear tooth (t_c). This is the distance in a straight line (chord) from one side of the tooth to the other side at the points where the pitch circle passes through the gear tooth (fig. 14-17, view A).

Use the following methods to calculate the chordal addendum and the chordal thickness:

You can calculate the dimensions by using the formulas shown in figure 14-17, view B. However, you can also use tables such as table 14-3, part B, to make bevel gear calculations. Simply substitute the constant into the following formula:

$$\frac{\textit{Chordal addendum}}{(a_C)\ (\textit{large tooth})} = \frac{\textit{Constant} \times \cos\angle PC + 1}{DP}$$

NOTE: Obtain the constant from table 14-3, part B.

The procedure used to solve the chordal thickness of the large tooth of a bevel gear is the same as that for a spur gear.

$$\textit{Chordal thickness}\ (t_C)\ (\textit{large tooth}) = \frac{\textit{Constant}}{DP}$$

To determine the chordal addendum (corrected addendum) a_c small and the chordal thickness of the small tooth, multiply the value of the large tooth by the proportional tooth factor (PTF).

Backlash Allowance of a Bevel Gear

You learned earlier that backlash is the amount by which the width of a gear tooth space, when two gears are meshed together, exceeds the thickness of the engaging tooth on the pitch circles. You must take these measurements with a device used for that purpose.

Theoretically, when gear teeth are meshed, they should run with little backlash. However, manufacturing tolerances make this impossible. There must be space between the gear teeth for lubrication and for expansion due to temperature changes at high speeds.

Just as with helical gears, bevel gears must have enough freedom between teeth so they will not bind when the gears turn. Table 14-3, part B shows the recommended backlash allowance corresponding to the gear's diametral pitch (DP).

To determine the chordal thickness with backlash at the large end of the tooth, use the following formula:

$$\textit{Chordal thickness} = \frac{\textit{Constant}}{DP} - \frac{1}{2}\ \textit{backlash allowance}$$

NOTE: Obtain the constant from table 14-3, part B.

To determine the corrected working depth (WD) with backlash at the large end of the tooth, use the following formula:

$$\frac{2.157}{DP} + (2 \times \textit{backlash allowance})$$

SELECTING A BEVEL GEAR CUTTER

To cut bevel gears on the milling machine, you must use special form relieved cutters. These cutters are similar in appearance and size to those used to cut spur gears, but they have thinner teeth. They are made to cut gears with a face width not greater than one-third nor less than one-eighth of the distance from the back of the gear to the apex of the cone.

The contour of the cutter teeth is made for the large end of the gear. The tooth shape at any other section, then, is only an approximation of the current form for that section. However, it is possible to approximate the dimensions and form of the teeth with enough accuracy to meet the repair needs aboard ship.

To get the best results in milling bevel gear teeth, select a cutter, not for the number of teeth in the bevel gear, but for the number of teeth in an imaginary spur gear. This imaginary spur gear has a different diameter than the actual bevel gear.

To determine the number of teeth in the imaginary spur gear, multiply the number of teeth in the actual gear by the secant of the pitch cone angle. That is:

$$NTCS = NT \times Sec \angle_{PC}$$

Where:

$NTCS$ = number of teeth of the imaginary spur gear

NT = number of teeth in the actual bevel gear

$\angle_{PC}$ = pitch cone angle

Suppose you plan to cut a bevel gear with 30 teeth and a 45° pitch cone angle. Using the NTCS formula, you will find the imaginary spur gear to have 43 teeth.

$$NTCS = NT \times Sec \angle_{PC}$$

$$= 30 \times Sec \angle_{45°}$$

$$= 30 \times 1.4142$$

$$= 42.4260 \text{ or}$$

$$= 43$$

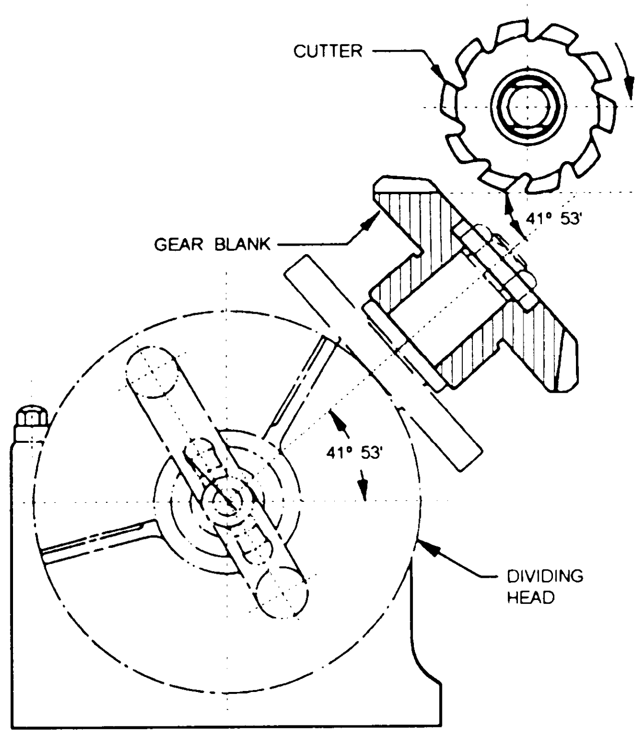


Figure 14-18.—Bevel gear set to the cutting angle by swiveling the dividing head in the vertical plane.

Therefore, by using a standard chart, you can determine the proper cutter for this gear to be a No. 3 cutter with a 6 diametral pitch.

MILLING THE BEVEL GEAR TEETH

Mount the gear blank in the dividing head with the larger end of the blank toward the dividing head. Set the gear blank to the cutting angle by swiveling the dividing head in the vertical plane (fig. 14-18). To determine the cutting angle, subtract the dedendum angle from the pitch cone angle. The cutting angle is not the same angle as the one to which the gear blank was machined in the lathe.

Milling bevel gear teeth involves three distinct operations. First, gash the teeth into the gear blank, then mill each side of the teeth to the correct tooth thickness.

In the first operation, mount the selected cutter on the milling machine arbor and center the blank on the cutter. Then bring the milling machine table up to cut the whole depth you determined for the large end of the gear. After you cut the first tooth, index the gear blank in the same manner as you would to cut a spur gear, and gash the remaining teeth.

In the second and third operations, mill the sides of the teeth that were formed in the gashing operation.

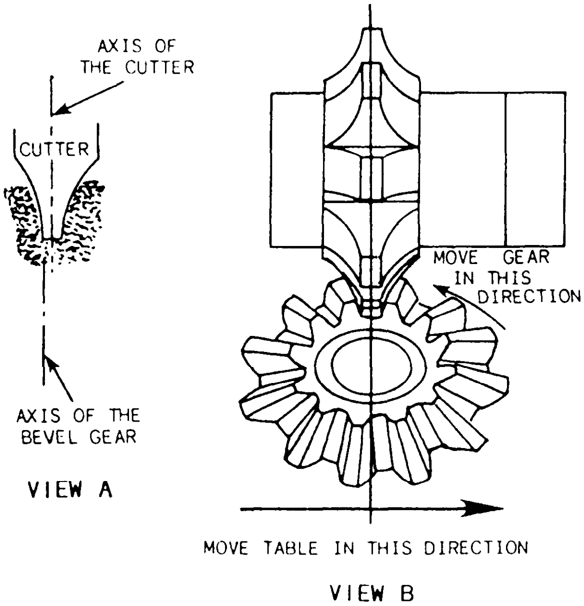


Figure 14-19.—Rolling and offsetting a bevel gear.

When you prepare to cut a bevel gear, remember that the milling machine is the only machine available to you. Therefore, you must take steps like offsetting the cutter (moving the milling machine table a calculated amount) and rolling the gear blank to cut the correct profile on the gear tooth. The following information will help you calculate the amount of offset in inches and the roll of the gear blank in degrees.

Offsetting The Cutter

To offset the cutter, move it from the axis of the gear blank a calculated distance as shown in figure 14-19, view A. Use the following formula to determine the distance:

$$Offset = \frac{CTL}{2} - \left(\frac{CTLC - CTSC}{2} \times FWR\right)$$

Where: *CTLC* = tooth thickness, large end

CTSC = tooth thickness, small end

FWR = face width ratio

Rolling The Gear Blank

After you offset the gear blank, roll it back to the center line of the small end of the tooth by turning the index crank (fig. 14-19, view B). The roll is always in the opposite direction of the offset. Determine the amount of roll by using the following formula:

$$Roll = \frac{57.3}{PD}\left[\frac{CP}{2} - \left(\frac{PCR}{FW} \times CTLC - CTSC\right)\right]$$

Where:

57.3 = constant (degrees per radian)

CTLC = tooth thickness (cutter), large end

CTSC = tooth thickness (cutter), small end

CP = circular pitch

PD = pitch diameter

PCR = pitch cord radius

FW = width

and the roll is expressed in degrees.

To accomplish the roll, you must know the amount of index crank movement, which you can find with the following formula:

$$NHR = \frac{CR \times NHC}{9^\circ}$$

Where:

NHR = number of holes to roll

CR = calculated roll in degrees

NHC = number of hole circle to index properly

9° (express in degrees—one turn of the index crank)

Use the largest hole circle available when you select your number of hole circles because the largest hole circle has less arc between holes.

After you have milled the bevel gear teeth completely, measure the tooth thickness of the pitch line of both the large and the small ends of the gear. These measurements should be equal to the dimensions you previously determined in your basic calculation. If they are not, check the setup and your calculations to identify your errors.

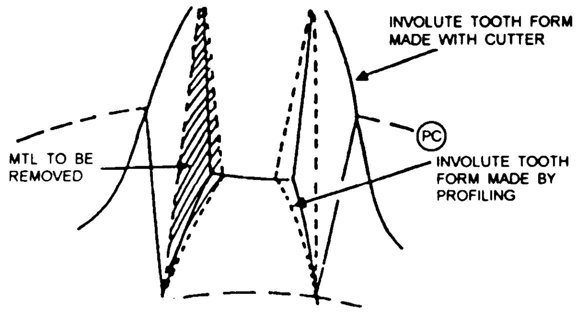


Figure 14-20.—Profiling a bevel gear.

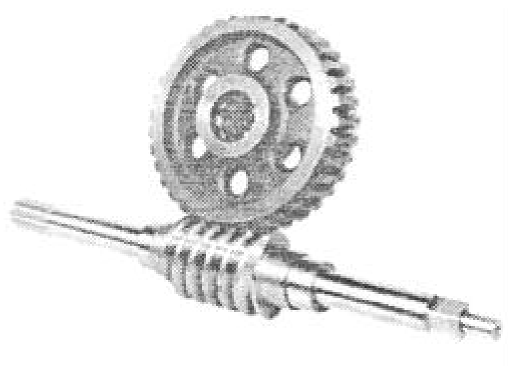


Figure 14-21.—Worm and worm gear.

Remember, you cannot machine a perfect bevel gear in a milling machine. As you learned earlier, you only use part of the cutter's contour when you machine the small end of the tooth. So, to finish the bevel gear teeth properly, you must file the contour as illustrated in figure 14-20 . This is known to a Machinery Repairman as profiling the gear.

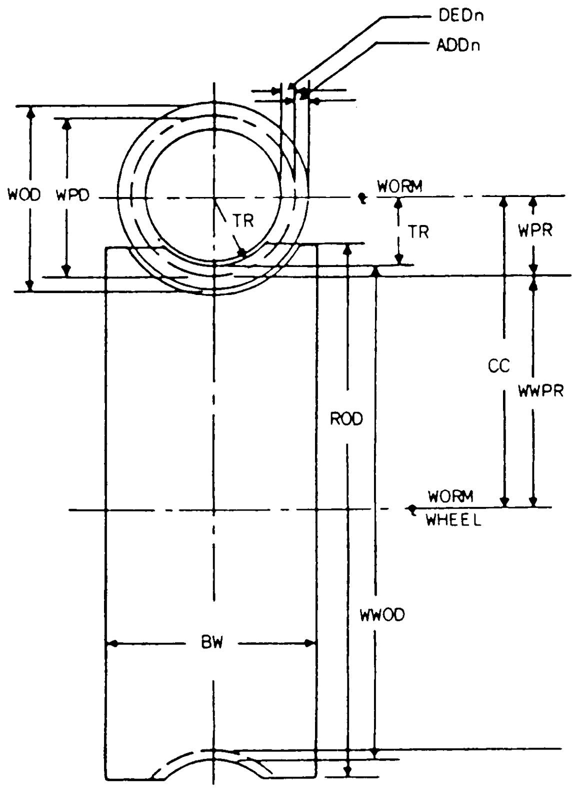
To file a tooth, start at the top of the large end of the tooth and gradually work to the pitch line at the small end.

After you have determined that the gear is properly formed, give the gear a final touch by deburring it.

WORMS AND WORM GEARS

A worm gear is sometimes called a worm wheel. It has teeth cut at an angle to the axis of rotation and radially in the gear face. The teeth are helical and conform to the helix angle of the teeth on the worm.

Worm gears are used for heavy-duty work where a large reduction of speed is required. They are used extensively in speed reducers.



WOD - Worm outside diameter
WPD - Worm pitch diameter
DEDn - Dedendum
ADDn - Addendum
TR - Throat radius
WPR - Worm pitch radius
CC - Center-to-center distance
ROD - Rim outside diameter
WWOD - Worm wheel outside diameter
WWPR - Worm wheel pitch radius
BW - Blank width

Figure 14-22.—Parts of a worm and worm gear.

A worm, sometimes called a worm thread, resembles an Acme thread. Worms can be either solid or cylinder-type mounted on a shaft. Both are installed perpendicular to the worm gear (fig. 14-21). Worms may have single, double, or triple threads. One revolution of a worm with a single thread turns the circumference of the worm gear an amount equal to the distance between identical points on two adjacent teeth, or one circular pitch, and so on.

This type of gearing is also known as an "endless screw," where the worm is the driver and the worm gear is driven. Figure 14-22 identifies the parts of a worm and a worm wheel.

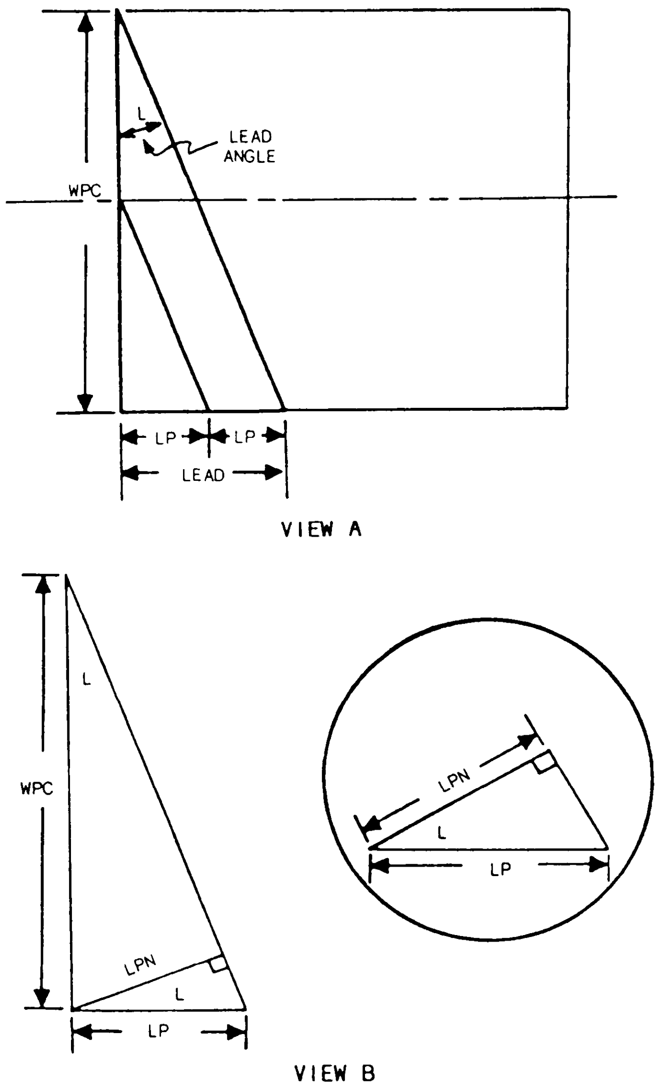


Figure 14-23.—Development of lead angle and linear pitch (normal).

WORM AND WORM WHEEL NOMENCLATURE AND FORMULA DEVELOPMENT

You will need the following terms and formulas when you plan and manufacture a worm and a worm wheel:

1. Linear pitch (LP)

   a. The distance from a point on one thread to a corresponding point on the next thread.

   b. This distance is measured parallel to the axis of the thread.

2. Lead (L)

   a. The distance traveled by a thread during one complete revolution of the worm around its axis.

   b. The lead and the linear pitch are the same on a single-start worm. On a double-start worm, the lead is twice the linear pitch, and on a triple-start worm, the lead is three times the linear pitch.

   c. The number of starts multiplied by the linear pitch equals the lead.

   $$No.\ of\ S \times LP = Lend$$

   d. The lead is needed to determine the proper gear train ratio to set the table travel on the milling machine and to perform work on the lathe machine.

3. Lead angle ($\angle L$)

   a. The angle formed by the thread and a line drawn at a right angle to the axis of the worm.

   b. It can be found by dividing the lead into the worm's pitch circle. The result is the cotangent of the lead angle (fig. 14-23, view A).

Therefore: $$\text{COT}\ \angle L = \frac{WPC}{Lead}$$

4. Tooth dimensions

   a. Linear pitch normal (LPN)

      (1) Measurement of the thread (tooth) at a right angle to its face.

      (2) It can be found by multiplying the linear pitch by the cosine of the lead angle (fig. 14-23, view B).

      $$LPN = LP \times \text{COS}\ \angle L$$

      (3) The tooth parts are the same in worm and spur gears.

b. Use the following formulas to solve for all normal tooth dimensions:

$$\textit{Addendum normal} = LPN \times 0.3183$$

$$\textit{Clearance normal} = LPN \times 0.0637 \text{ or } ADD_n \times 0.2$$

$$\textit{Dedendum normal} = LPN \times 0.382$$

$$\textit{Whole depth normal} = LPN \times 0.7$$

$$\textit{Circular thickness normal} = LPN \times 0.5$$

NOTE: All worm tooth constants are derived from a worm with a l-inch linear pitch.

5. Length of the worm (LOW)
   a. It is found by using the following formula:

   $LOW = [(NT \times 0.02) + 4.5] \times LP$

   b. The worm is longer than is required for complete meshing between the worm and the worm wheel.

6. Worm wheel pitch diameter (WWPD)
   a. You learned in spur gearing that for every tooth in the gear there is a circular pitch on the pitch circle, and for every tooth on the gear there is an addendum on the pitch diameter.
   b. By using this theory, we can derive the following formulas:

   (1) WWPC D (real)

   $$= \frac{NR \times CP \text{ or } (LP)}{\pi}$$

   $$= LP \times 0.3183 \times NT$$

   (2) $ADD\ (real) = LP \times 0.3183$

7. Throat diameter
   a. It is found by adding the worm wheel pitch diameter and twice the addendum normal.

   $WWPD + 2\,ADD_n = \textit{Throat diameter}$

   b. It is measured at the base of the throat radius.

8. Rim diameter
   a. To find the rim diameter for single- and double-start worms, multiply the linear pitch by the constant 0.4775 and add the result of the throat diameter.

$$\textit{Rim diameter} = (LP \times 0.4775) + \textit{Throat diameter}$$

   b. To find the rim diameter for three or more starts, multiply the linear pitch by the constant 0.3183 and add the result to the throat diameter.

$$\textit{Rim diameter} = (LP \times 0.3183) + \textit{Throat diameter}$$

9. Throat radius
   a. To find this radius, subtract one addendum (normal) from the pitch radius of the worm.

$$\textit{Throat radius} = \textit{pitch radius (worm)} - 1\,ADD_n$$

   b. This dimension is taken from the worm but is machined on the worm wheel blank.

10. Blank width
   a. To find the blank width for single- and double-start worms, multiply the linear pitch by the constant 2.38 and add the result to the constant 0.250.

$$\textit{Blank width} = (LP \times 2.38) + 0.250$$

   b. To find the blank width for three or more starts, multiply the linear pitch by the constant 2.15 and add the result to the constant 0.20.

Blank width (for three or more starts)
$= LP \times 2.15 + 0.20$

11. Tooth dimensions. These are the same as those of the worm. The linear pitch and the circular pitch are of equal value.

12. Number of teeth (NT). Multiply the number of starts by the ratio of the worm to the worm wheel.

Number of teeth (NT) = No. of starts x ratio of the worm to the worm wheel.

SELECTING A WORM WHEEL CUTTER

When you machine the throat radius of a worm wheel, select a two- or four-lip end mill with a radius smaller than the calculated throat radius. You need the smaller radius because as you swivel the cutter from its vertical position to a desired angle, the radius being cut increases.

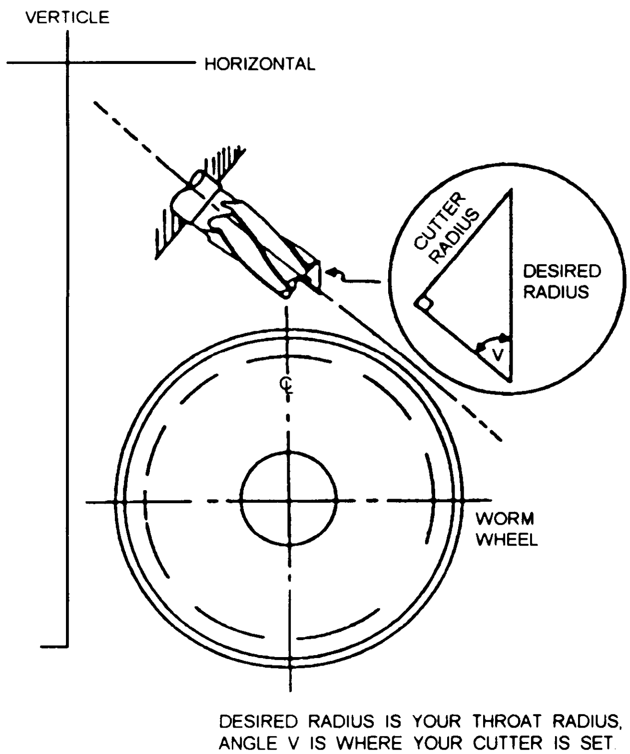


Figure 14-24.—Formation of desired radius.

As you swivel the cutter to a predetermined angle to cut the calculated throat radius, you will form a right triangle (fig. 14-24). Use this triangle to find the radius:

$$\textit{Desired radius} = \textit{Cutter radius} \times \textit{cosec} \measuredangle V$$

Where:

$$\measuredangle V = \textit{Angle at which the throat radius is cut.}$$

To determine the depth of cut, subtract the throat diameter from the rim diameter and divide by two.

$$\textit{Depth of cut} = \frac{\textit{Rim diameter} - \textit{Throat diameter}}{2}$$

CENTER-TO-CENTER DISTANCE (WORM AND WORM WHEEL)

As with other systems of gearing you have studied, worm gearing is designed to transfer motion between two planes at a fixed ratio. The majority of spur and helical gears have adjustments for the center-to-center distance and for backlash. In worm gearing, the center-to-center distance is very important. The worm gearing systems are designed to transfer as much power as possible in the smallest practical space.

This section will give you the information you need to manufacture a worm and a worm wheel using the center-to-center distance and the ratio between the worm (driver) and the worm wheel (driven).

To find the center-to-center distance of a worm and a worm wheel, add the worm pitch radius and the worm wheel pitch radius.

$$C\text{-}C = WPR + WWPR, \text{ or}$$

$$C\text{-}C = \frac{WPD + WWPD}{2}$$

WORM WHEEL HOBS

A hob is a cylindrical worm converted into a cutting tool. Hobs resemble worms in appearance and are ideal for cutting a worm wheel. The hob's teeth are cut on the outside of a cylinder following a helical path corresponding to the thread line of a worm. The cutting edges of the hob are formed when flutes are cut into the worm. For small lead angles, flutes are cut parallel to the axis; while for large lead angles (6° and above), they are cut helically at a right angle to the thread line of the worm.

As a general rule, there should not be a common factor between the number of starts and the number of flutes. Even numbers of starts (6, 8, or 10) should have odd numbers of flutes (7 or 11).

You can usually find the approximate number of gashes (flutes) if you multiply the diameter of the hob by 3 and divide this product by twice the linear pitch.

$$\textit{Number of flutes} = \frac{3 \times \textit{hob's OD}}{2 \times LP}$$

There are, however, certain modifications you may have to make. The number of gashes (flutes) has a relationship to the number of threads in the hob and to the number of teeth in the worm gear. Try to avoid a common factor between the number of threads and the number of gashes. For example, if the worm is a double-thread worm, the number of gashes should be 7 or 9 rather than 8. If the worm is a triple-thread worm, select 7 or 11 gashes rather than 6 or 9, as both 6 and 9 have a factor in common with 3.

It is also best to avoid having a common factor between the number of threads in the hob and the number of teeth in the worm gear. For example, if the number of teeth is 28, a triple thread will be satisfactory since 3 is not a factor of 28.

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Figure 14-25.—Milling machine set up for gashing and hobbing of a worm wheel.

The cutter you select to gash the hob should be 1/8 to 1/4 inch thick at the periphery, depending on the pitch of the hob thread. The width of the gash at the periphery of the hob should be about 0.4 times the pitch of the flutes. The depth of the gash should be about 3/16 to 1/4 inch below the root of the thread.

There are three types of hobs:

- Shell. This has a straight bore with a keyway to hold the arbor that drives the hob.

- Straight shank This is the integral part of the shaft. It is used between centers.

- Tapered shank. This has a milling machine taper (Brown and Sharpe). The outside end is supported by either a line or a dead center.

Since the hob is a cutting tool, the top of the tooth on the hob is a dedendum. The bottom of the hob tooth forms the top of the worm wheel tooth and must be given a clearance. Therefore, it also equals a dedendum of the gear you are cutting. The working depth of the hob (cutting portion) is the addendum plus the dedendum of the gear you are cutting.

The nomenclature of the hob is the same as that of the worm; chordal thickness (normal), linear pitch, lead, pressure angle, and pitch diameter. The outside diameter of the hob has two clearances, and both are larger than the worm's outside diameter:

$$WPD + 2\ DED$$

Hobs can be bought commercially, or made by a machinist. If you order a hob, furnish drawings or blueprints of both the worm and the worm wheel and any information such as bore size for the shell-type hob.

CUTTING WORM WHEEL TEETH ON A MILLING MACHINE

You can cut the teeth of a worm gear on a milling machine, usually in two operations. The first is called gashing the teeth (fig. 14-25, view A). Seat an involute spur-gear cutter of the correct pitch and number according to the number of teeth and pitch of the worm gear. Set the milling machine table at an angle equal to the lead or helix angle of the worm thread. Be sure to center the gear blank under the cutter. To perform the operation, raise the table a distance equal to the whole depth of the tooth. Use the graduated vertical feed dial to get a uniform depth for each tooth. Index each tooth, using the dividing head with a dog clamped to the mandrel to drive the gear blank.

The second operation is called hobbing (fig. 14-25, view B). First, mount the hob on a cutter arbor. Then set the table back to zero, or at a right angle to the machine spindle. Remove the dog so the gear blank can rotate freely. Line up the gear blank so the hob meshes with the gashed slots. When you start the machine, the rotating hob will rotate the gear blank. As the hob and gear blank rotate, raise the table gradually until the teeth are cut to the correct depth. To get the correct center-to-center distance, use the worm that you will use with the worm gear before you remove the worm gear from the milling machine.

STUB TOOTH GEARS

Stub tooth gears are widely used throughout the automotive industry in transmissions because their great strength enables them to transmit maximum power. Cranes and rock crushers are examples of high-torque equipment that use stub tooth gears. This type of gear has a 20-degree pressure angle and is short and thick. A stub tooth gear compared to other gears has a shorter addendum (ADD). This results in a stronger tooth, but causes the gears to operate with more noise.

Stub tooth gears come in two forms. One form has straight teeth, like spur gears. The other form has teeth similar to those on helical gears. Gears with helically shaped teeth are used when smooth operation is required.

The basic rule for spur, helical, and bevel gears, "for every tooth on the gear, there is a circular pitch (CP) on the pitch circle" also applies to stub tooth gearing systems.

We will discuss two stub tooth gearing systems: the American Standard System and the Fellows Stub Tooth Gears System.

AMERICAN STANDARD SYSTEM

This system bases tooth dimensions on specific formulas:

1. The tooth depth or whole depth (WD) equals 1.8 divided by the diametral pitch (DP).

$$WD = \frac{1.8}{DP}$$

2. To find the outside diameter (OD), add 1.6 to the number of teeth and then divide by the diametral pitch (DP).

$$OD = \frac{NT + 1.6}{DP}$$

3. To find the addendum (ADD), divide 0.8 by the diametral pitch (DP).

$$ADD = \frac{0.8}{DP}$$

4. To find the clearance (CL), divide 0.2 by the diametral pitch (DP).

$$CL = \frac{0.2}{DP}$$

5. When the addendum (ADD) is added to the clearance (CL) the result is the dedendum (DED).

$$DED = ADD + CL$$

6. All circular measurements of a stub tooth gear, including the number of teeth and the pitch diameter, are the same as those of a spur gear. To find the pitch diameter, divide the number of teeth (NT) by the diametral pitch (DP).

$$PD = \frac{NT}{DP}$$

7. To find the circular pitch (CP), divide ! (3.1416) by the diametral pitch (DP).

$$CP = \frac{3.1416}{DP}$$

8. To find the circular thickness (CT), divide 1.5708 by the diametral pitch (DP).

$$CT = \frac{1.5708}{DP}$$

FELLOWS STUB TOOTH GEAR SYSTEM

This system was introduced by the Fellows Stub Tooth Gear Company. It uses a 20-degree pressure angle and is based on the use of two diametral pitches (DP). In the formulas we will use, the numerator (DPL) is the circular measurement which consists of the pitch diameter (PD) and the number of teeth (NT). The denominator (DPS) is the radial measurement.

There are eight standard pitches in this system. They are 4/5, 5/7, 6/8, 7/9, 8/10, 9/11, 10/12, and 12/14.

The formulas for the basic dimensions are as follows:

1. $\textit{Addendum}\ (ADD) = \dfrac{1}{DPS}$
2. $\textit{Outside diameter}\ (OD) = \dfrac{NT}{DPL} + \dfrac{2}{DPS}$
3. $\textit{Whole depth}\ (WD) = \dfrac{2.25}{DPS}$
4. $\textit{Clearance}\ (CL) = WD - 2\,ADD$
5. $\textit{Dedendum}\ (DED) = ADD + CL$
6. $\textit{Circular pitch}\ (CP) = \dfrac{3.1416}{DPL}$
7. $\textit{Circular thickness}\ (CT) = \dfrac{1.5708}{DPL}$
8. $\textit{Number of teeth}\ (NT) = DPL \times PD$

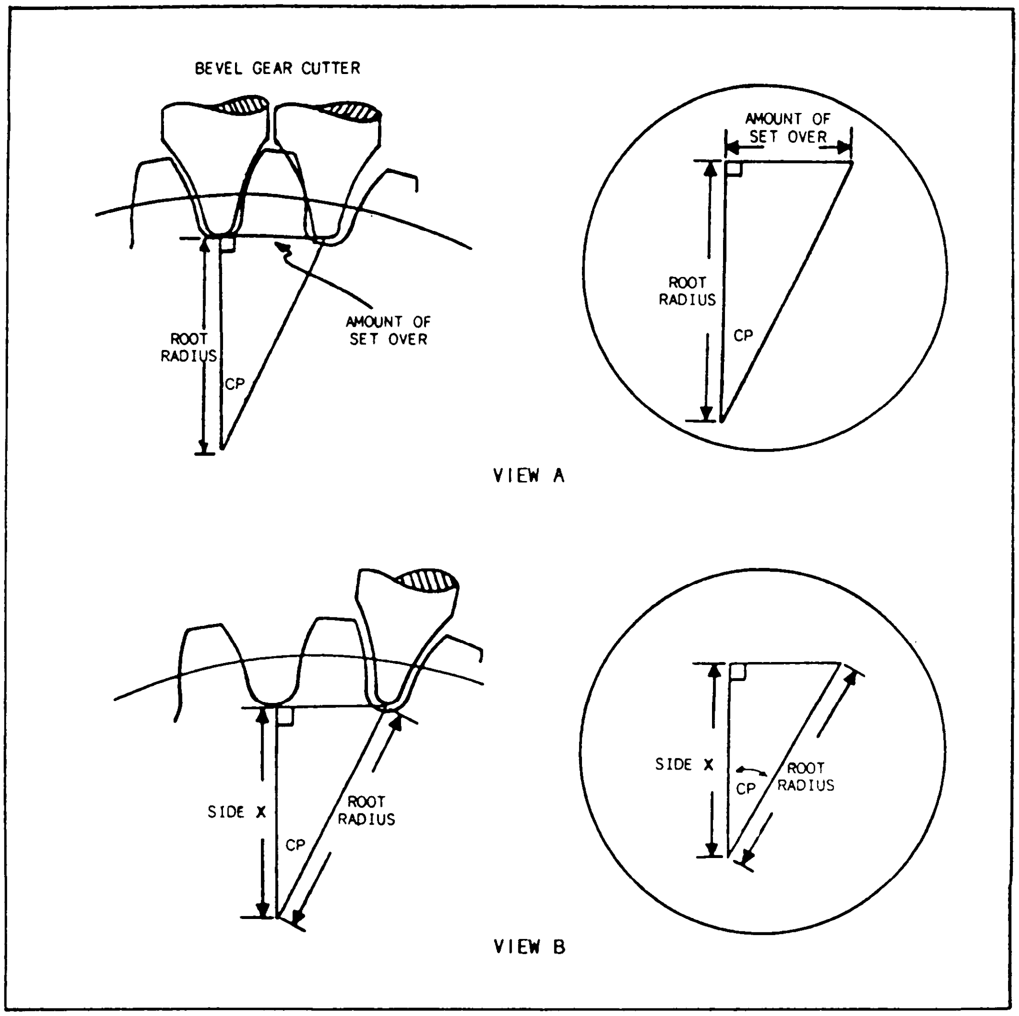

Figure 14-26.—Development of setover and depth increase.

9. Diametral pitch (DP)

a. $$TPL = \frac{NT}{OD - (\frac{2}{DPS})}$$

b. $$DPS = \frac{NT}{OD - (\frac{NT}{DPL})}$$

METHOD OF MANUFACTURE

If you buy a stub tooth gear cutter, you can manufacture a straight or helical stub tooth gear by using the procedure you use for spur and helical gears. If you use a fly cutter, use the old gear as a pattern to grind a single-point tool bit to the desired shape.

A properly fitted gear must have a setover and a depth increase. You should calculate these after you select a cutter. The only way to select a cutter is by sight. Get a large selection of bevel gear cutters, then match one of them to the side of a good tooth.

To find the amount of setover, first establish the circular pitch angle ($\angle CP$). One circular pitch equals 360°. Therefore, you can divide 360° (one circular pitch) by the number of teeth (NT) to find the circular pitch angle ($\angle CP$). You can solve for the amount of setover by using the triangle in figure 14-26, view A.

$$Setover = Root\ radius \times \mathrm{Tan}\angle CP$$

Where the root radius is the outside diameter (OD) divided by 2 minus the whole depth (WD).

$$Root\ radius = \frac{OD}{2} - WD$$

To find the amount of depth increase, set up the triangle shown in figure 14-26, view B. In this triangle, side X is equal to the root radius multiplied by the cosine of the circular pitch angle ($\angle CP$).

$$\textit{Side X} = \textit{Root radius} \times \text{Cos} \angle CP$$

To find the depth increase, subtract side X from the root radius: *Depth increase = Root radius - Side X.* The cutting procedure is as follows:

1. Center the cutter on the gear blank.

2. Offset the calculated setover away from the column. The direction of the offset is optional.

3. Move the cutter down to the whole depth of the tooth, plus the calculated amount of depth increase in increments to suit the machine and the setup. Cut the teeth all the way around the blank until one side of the tooth is complete.

4. Move the cutter back to the center line and offset toward the column face the calculated amount of setover. Cut to the full depth of the tooth plus the amount of depth increase. At this time, you are ready to debur your stub tooth gear.

SPLINES

A splined shaft has a series of parallel keys formed integrally with the shaft. These mate with corresponding grooves cut in a hub or fitting. This is in contrast to a hub or fitting with a series of keys or feathers fitted into slots cut into the shaft. This latter construction weakens the shaft to a considerable degree because of the slots cut into it and, as a consequence, reduces its torque-transmitting capacity.

Splined shafts are generally used in three types of applications: (1) to couple shafts when relatively heavy torques are to be transmitted without slippage; (2) to transmit power to sliding or permanently fixed gears, pulleys, and other rotating members; and (3) to attach parts that may require removal for indexing or a change in angular position.

Splines with straight-sided teeth have been used in many applications. However, the use of splines with involute teeth has increased steadily. Splines with involute teeth are becoming more popular for these reasons: (1) involute spline couplings have greater torque-transmitting capacity than any other type; (2) they can be produced with the same techniques and equipment used to cut gears; and (3) they have a self-centering action under load, even when there is backlash between mating members.

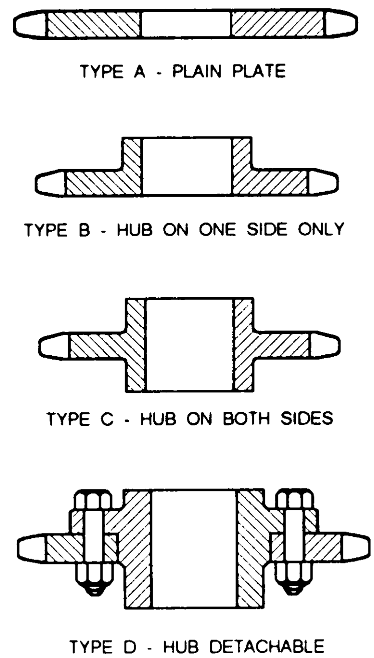

Figure 14-27.—Types of sprockets.

These splines or multiple keys are similar in form to internal and external involute gears. The general practice is to form external splines by hobbing, rolling, or on a gear shaper, and internal splines either by broaching or on a vertical shaper. The internal spline is held to basic dimensions, and the external spline is varied to control the fit. Involute splines have maximum strength at the base; they can be accurately spaced and are self-centering. This equalizes the bearing and stresses, and they can be measured and fitted accurately.

The American National Standard covers involute splines with tooth numbers ranging from 6 to 60 with a 30 or 37.5-degree pressure angle, and from 6 to 100 with a 45-degree pressure angle. When you select the number of teeth for a given spline application, remember these points: (1) There are no advantages in using odd numbers of teeth. (2) The diameters of splines with odd tooth numbers, particularly internal splines, are troublesome to measure with pins since no two spaces are diametrically opposite each other.

SPROCKETS

Webster's dictionary defines a sprocket wheel as "a wheel with cogs or sprockets to engage with the links of a chain." Most sprockets are one of the four types shown in figure 14-27. The following material briefly explains the classes and the manufacture of sprocket wheels (called sprockets here). If you want more in-depth information, refer to the current edition of *Machinery's Handbook.*

CLASSES OF SPROCKETS

There are two classes of sprockets; commercial and precision. The choice is a matter of drive application judgment. Commercial sprockets are adequate for the usual moderate to slow speed commercial drive. When you have a combination of extremely high speed and high load, or when the drive involves fixed centers, critical timing, register problems, or close clearance with outside interference, precision sprockets may be more appropriate.

MATERIAL FOR SPROCKETS

Cast iron is commonly used in large sprockets, especially in drives with large speed ratios. It is adequate because the teeth of the larger sprockets are subject to fewer chain engagements in a given time. For severe service, cast steel or steel plate is preferred.

The smaller sprockets of a drive are usually made of steel. With this material, the body of the sprocket can be heat-treated to produce toughness for shock resistance, and the tooth surfaces can be hardened to resist wear.

Stainless steel or bronze may be used for corrosion resistance; and formica, nylon, or other suitable plastic materials may be used for special applications.

MANUFACTURE OF SPROCKETS

Cast sprockets have cut teeth, and the rim, hub face, and bore are machined. The smaller sprockets are generally cut from steel bar stock and are finished all over. Sprockets are often made from forgings or forged bars, and the finish depends on specifications. Many sprockets are made by welding a steel hub to a steel plate. This process produces a one-piece sprocket of desired proportions and one that can be heat-treated.