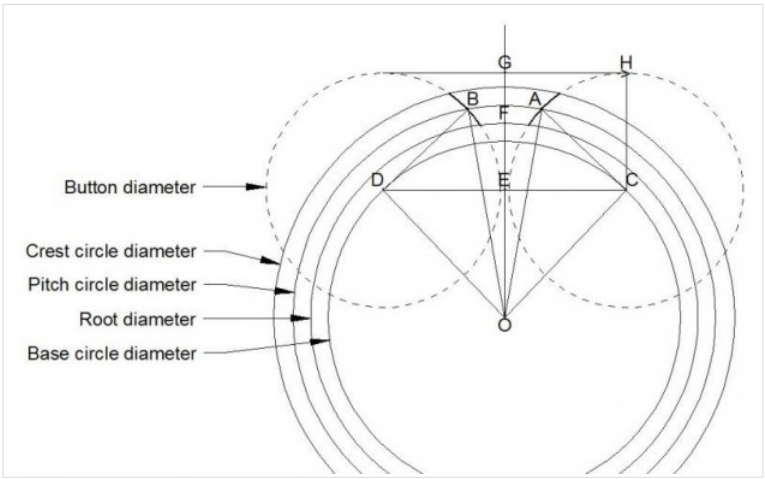


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Designing gear cutters



Making gears requires making a cutter with the appropriate profile. The amateur machinist usually does this using the button method developed by Ivan Law and further improved by John Stevenson. They have both given tables for the button diameter, button spacing and infeed required to produce the cutter. This method relies on the fact that the involute curve can be closely approximated to a circle over the limited distance of a gear tooth.

I can find relatively little information on the methods used to create the tables of button diameter, button spacing and infeed for the button method and on this page I have developed generalised equations for these parameters based on the geometry. With these equations it is straightforward to design cutters for any gear given the number of teeth, the module and the pressure angle.

Some definitions

Number of teeth (N). This is simply the number of teeth on the gear.

Pitch circle diameter (pcd). This is the diameter of an imaginary circle running through the gear teeth that is used to calculate the tooth profile.

Module (M). This is the pitch circle diameter divided by the number of teeth. Thus $pcd = NM$.

Crest circle diameter (ccd). This is the circle that touches the extremities of all the teeth. This is the outside diameter of the disc from which the gear is made. The $ccd = (N+2)M$

The root circle diameter (rcd). This is the circle that touches the base of all the teeth. The rcd is equal to the ccd minus twice the full depth of the teeth(D) + clearance (f). The full depth of the tooth + clearance is usually expressed as D+f and this is the depth the gear cutter must be fed into the gear blank when cutting the teeth. By convention $D+f = 0.6866 \times \text{circular pitch} = 0.6866 (PI) NM/N = 2.157M$. Thus the root circle diameter = $(N+2)M - 4.314M = (N-2.314)M$

The base circle diameter (bcd). This is the circle that is used to generate the involute profile of the teeth.

Pressure angle (p). This is the angle AOC in the diagram above. A line drawn from the intercept of the gear tooth with the pitch circle forms a tangent to the base circle at the pressure angle.

Angular pitch. (ap). This is the angle between any point on one tooth to a similar point on the next tooth.It is given by $360/N$ in degrees or $2(PI)/N$ in radians where $PI = 3.142$. The angle BOA in the diagram above is equal to 1/2 the circular pitch.

Button diameter (bd). This is the diameter of the button used to form the cutter. The button radius AC extends from the pitch point A on the tooth to a tangent C on the base circle.

Geometry

In the diagram the line AC is a tangent to the base circle and it is thus at right angles to the radius OC.

Calculation of the base circle diameter.

$OC = AO \cos p$

but $OC = 1/2 \text{ bcd}$ and $AO = 1/2 \text{ pcd}$

Thus

$\text{bcd} = \text{pcd} \cos p$

$\text{bcd} = NM \cos p$

Calculation of the button diameter.

$AC = AO \sin p$

but $AC = 1/2 bd$ and $AO = 1/2 pcd$
Thus

$$bd = pcd \sin p$$

$$bd = NM \sin p$$

Calculation of the button separation.

The triangle CEO is a right angled triangle.

Hence:

$$CE = CO \sin (\text{angle COE})$$

$$CE = CO \sin (\text{angle AOC} + \text{angle AOG})$$

$$CE = CO \sin (p + \pi/4)$$

$$CE = CO \sin (p + 360/4N)$$

$$CE = CO \sin (p + 90/N)$$

But $CE = 1/2$ the button separation and $CO = 1/2 bcd$

Hence:

$$\text{The button separation } bs = bcd \sin (p + 90/N)$$

$$\text{but } bcd = NM \cos p$$

Thus

$$bs = NM (\cos p) \{\sin (p + 90/N)\}$$

Calculation of infeed.

I measure infeed from the outer edge of the buttons ie. point G.

The infeed (inf) is the distance GF ie from point G to the root circle.

$$GF = CH - EF = CH - (FO - EO)$$

$$CH = 1/2 \text{ button diameter}$$

$$FO = 1/2 \text{ root circle diameter}$$

$$EO = 1/2 bcd \cos (p + 90/N)$$

$$\text{but } bcd = pcd \cos p$$

Hence

$$EO = 1/2 NM (\cos p) \{\cos (p + 90/N)\}$$

Hence:

$$\text{inf} = 1/2 \text{ button diameter} - 1/2 \text{ root circle diameter} + 1/2 NM (\cos p) \{\cos (p + 90/N)\}$$

$$\text{inf} = 1/2 [NM \sin p - (N-2.314)M + NM (\cos p) \{\cos (p + 90/N)\}]$$

$$\text{inf} = 1/2 M [N \sin p - (N-2.314) + N (\cos p) \{\cos (p + 90/N)\}]$$

Summary

There are thus three equations for expressing the button diameter (bd), button spacing (bs) and infeed (if) in terms of the number of teeth (N), the module (M) and the pressure angle (p)

$$bd = NM \sin p$$

$$bs = NM (\cos p) \{\sin (p + 90/N)\}$$

$$\text{inf} = 1/2 M [N \sin p - (N-2.314) + N (\cos p) \{\cos (p + 90/N)\}]$$

Results

Some typical results for pressure angles of 20 degree and 14.5 degrees are shown below.

Gear cutters - button method							
Module		1					
Pressure angle		20	degrees	0.3490659	radians		
No of Teeth	Pitch circle diameter mm	Crest circle diameter mm	Root circle diameter mm	Base circle diameter mm	Button diameter mm	Button spacing mm	Infeed mm
135	135.000	137.000	132.686	126.859	46.173	44.772	16.091
55	55.000	57.000	52.686	51.683	18.811	19.056	7.083
35	35.000	37.000	32.686	32.889	11.971	12.624	4.827
26	26.000	28.000	23.686	24.432	8.893	9.727	3.809
21	21.000	23.000	18.686	19.734	7.182	8.116	3.242
17	17.000	19.000	14.686	15.975	5.814	6.825	2.786
14	14.000	16.000	11.686	13.156	4.788	5.855	2.442
12	12.000	14.000	9.686	11.276	4.104	5.207	2.210

Gear cutters - button method							
Module		1					
Pressure angle		14.5	degrees	0.2530727	radians		
No of Teeth	Pitch circle diameter mm	Crest circle diameter mm	Root circle diameter mm	Base circle diameter mm	Button diameter mm	Button spacing mm	Infeed mm
135	135.000	137.000	132.686	130.700	33.801	34.195	13.631
55	55.000	57.000	52.686	53.248	13.771	14.799	6.118
35	35.000	37.000	32.686	33.885	8.763	9.947	4.235
26	26.000	28.000	23.686	25.172	6.510	7.762	3.384
21	21.000	23.000	18.686	20.331	5.258	6.547	2.910
17	17.000	19.000	14.686	16.459	4.256	5.574	2.528
14	14.000	16.000	11.686	13.554	3.505	4.842	2.240
12	12.000	14.000	9.686	11.618	3.005	4.352	2.045

Note: Cutters for gears are normally produced in eight different sizes. These sizes cover the range from a 12 tooth gear to a rack. The cutters listed in the tables above cover this range. Thus the 12 tooth cutter covers the range 12-13 teeth, the 14 tooth cutter covers the range 14 - 16 teeth, the 17 tooth cutter covers the range 17-20 teeth, the 21 tooth cutter covers the range 21 - 25 teeth, the 26 tooth cutter covers the range 26 - 34 teeth, the 35 tooth cutter covers the range 35 - 54 teeth, the 55 tooth cutter covers the range 55 - 134 teeth and the 135 cutter covers the range 135 teeth to a rack.

The calculations are simply carried out using a spreadsheet as shown in the table above. Any values of number of teeth, module and pressure angles can be input.

A copy of the spreadsheet can be obtained, on request, using the contact form on the home page

Note added 30 October 2015

My thanks to Damian Poirier for pointing out a small error on this page which has now been corrected. The error does not affect the calculation or the results above.