BASIC SPUR GEAR MILLING 7

Don Brymer continues his series on milling

In this article we will look at basic involute spur (straight tooth) gear cutting in the milling machine using form relieved gear milling cutters.

This method of gear cutting does not produce the most accurate of gear tooth forms but few modellers will have any type of gear generating machine tools in their workshops. The reason for the inaccurate tooth forms is that a different cutter is required for each different number of gear teeth. As this is not possible, gear milling cutters are produced to cut a range of similar shaped teeth. Gear cutters are generally made to the correct form of the smallest number of teeth in the range the cutters are formed to cut and closely approximate the others in the range. In the average set of gear cutters for a particular tooth profile (say 2.5 module or 10 DP) there are eight cutters that cut from a rack to 12 teeth.

No. 1 = 135 teeth to a rack
No. 2 = 55 teeth to 134 teeth
No. 3 = 35 teeth to 54 teeth
No. 4 = 26 teeth to 34 teeth
No. 5 = 21 teeth to 25 teeth
No. 6 = 17 teeth to 20 teeth
No. 7 = 14 teeth to 16 teeth
No. 8 = 12 teeth to 13 teeth.

Should more accurate tooth forms be required, cutters are available in half numbered series (1½, 2½ etc) for cutting gears with tooth numbers that are between the numbers of the standard cutters.

Common gear tooth forms

The most common gear tooth standards used are;

1) Diametral Pitch tooth form (imperial, e.g. 20 DP).
The Diametral Pitch of a gear is a ratio between the number of teeth in a gear and the gear's pitch circle diameter (also referred to as reference circle diameter) and can be expressed as;

$$DP = \frac{\text{No. of teeth}}{\text{Pitch circle diameter}}$$

In the DP system the circular pitch of adjacent teeth measured around the pitch circle diameter is equal to π (3.1416) divided by the diametral pitch.

2) ISO metric module tooth form (metric, e.g. 3 Module).
The Module Pitch of a gear is a ratio between the pitch circle diameter of the gear and the number of teeth of the gear and can be expressed as;

$$\text{Module} = \frac{\text{Pitch circle diameter}}{\text{No. of teeth}}$$

In the module system the circular pitch of adjacent teeth measured around the pitch circle diameter is equal to the Module multiplied by π.

Gear tooth pressure angles

If you are milling new gears to replace damaged gears, as well as the tooth form the pressure angle must be known to enable correct cutter selection and will usually be 14½deg. or 20deg.

The pressure angle of a gear can be found by

$$PA = \left(\frac{\text{Base circle diameter}}{\text{Pitch circle diameter}}\right)^{\cos^{-1}}$$

The 20deg pressure angle has widely been adopted for standard gearing as the tooth profile has less interference between mating teeth particularly for gears of less than 20 teeth. Gear teeth of 20deg. pressure angle are somewhat thicker and shorter than 14½deg. tooth forms. The 14½deg. pressure angle is more often used in older systems and has an advantage of producing less radial load during gear train operation than the 20deg. pressure angle forms.

Spur gear tooth elements and definitions.

(see **figures 1 and 2**)

- Addendum is the radial distance from the reference circle to the tip of the tooth.
- Dedendum is the radial distance from the reference circle to the root diameter of the tooth. The Dedendum equals the addendum plus working clearance.
- Whole tooth depth is the radial distance from the tooth tip to the tooth root.
- Flank is the surface between the reference circle and the tooth root.
- Face is the contact surface between the reference circle and the tooth tip.
- Chordal thickness is the tooth thickness measured at the reference circle across the chord of the arc.

Photo 1. A selection of gear cutters.

- Chordal height is the radial distance between the chord of the arc and the tooth tip.
- Circular pitch is the distance from a point on a tooth to the corresponding point on an adjacent tooth measured at the reference circle.

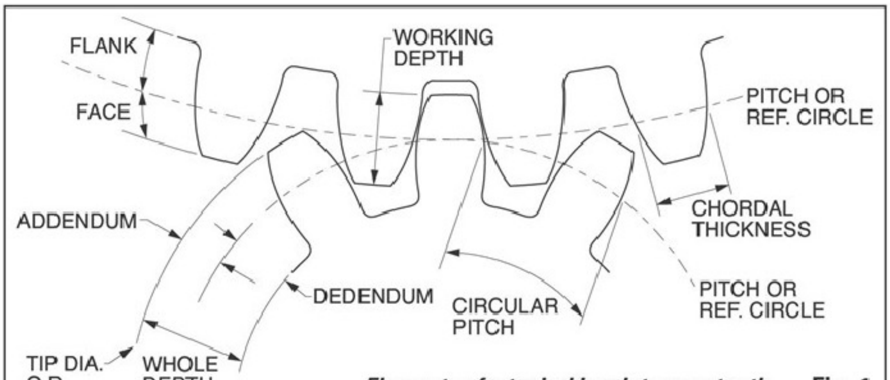
Gear tooth calculations

(See **table 1**)

Possibly one of the most important calculations is that of the gear tip diameter (diameter of the blank). It is important that the gear blank is never oversize, any tolerance must be always a uni-directional negative tolerance.

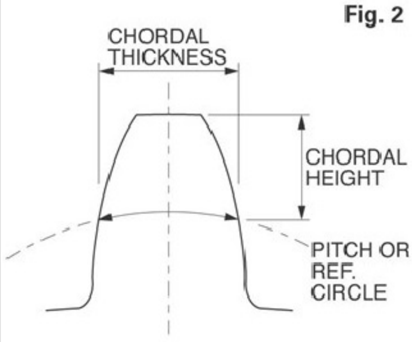
A practical example of milling a 35 tooth gear in both Module and DP forms.

MODULE CALCULATIONS	DP CALCULATIONS
Module No. 3	8 DP
Tip diameter	
Tip Ø = (35 + 2) x 3	Tip Ø = $\frac{35+2}{8}$
Tip Ø = 111.00mm	Tip Ø = 4.625″
Pitch circle diameter	
PD = 3 x 35	PD = $\frac{35}{8}$
PD = 105.00 mm	PD = 4.375″
Tooth whole depth	
WD = 2.25 x 3	WD = $\frac{2.157}{8}$
WD = 6.75 mm	WD = 0.270″
Chordal height	
$CH = \frac{105}{2}\left[1-\cos\left(\frac{90^\circ}{35}\right)\right] + 3$	$CH = \frac{4.375}{2}\left[1-\cos\left(\frac{90^\circ}{35}\right)\right] + 0.125$
CH = 3.053 mm	CH = 0.127″



Elements of a typical involute gear tooth. **Fig. 1**

Fig. 2



Chordal height and chordal thickness.

Table 1 Spur gear cutting formula 20º PA.		
To find	**Module Formula**	**DP formula**
Addendum **(A)**	$A = M$	$A = \frac{1}{DP}$
Dedendum **(D)**	$D = M \times 1.25$	$A = \frac{1.25}{DP}$
Clearance **(CL)**	$CL = M \times 0.25$	$CL = \frac{0.157}{DP}$
Whole depth **(WD)**	$WD = m \times 2.25$	$WD = \frac{2.157}{DP}$
Number of teeth **(N)**	$N = \frac{PD}{M}$	$N = PD \times DP$
Module **(M)**	$M = \frac{OD}{N+2}$	N/A
Diametral Pitch **(DP)**	N/A	$DP = \frac{N}{PD}$
Pitch or reference circle diameter **(PD)**	$PD = M \times N$	$PD = \frac{N}{DP}$
Tip diameter **(OD)**	$OD = (N + 2) \times M$	$OD = \frac{N+2}{DP}$
Circular pitch **(CP)**	$CP = M \times \pi$	$CP = \frac{\pi}{DP}$
Face width **(FW)**	FW = 2.5 to 3 x CP	FW = 2.5 to 3 x CP
Chordal thickness **(CT)**	$CT = PD \times \left[\sin\left(\frac{90}{n}\right)^{\circ}\right]$	$CT = PD \times \left[\sin\left(\frac{90}{n}\right)^{\circ}\right]$
Chordal height **(CH)**	$CH = \frac{PD}{2}\left[1 - \cos\left(\frac{90}{N}\right)^{\circ}\right] + A$	$CH = \frac{PD}{2}\left[1 - \cos\left(\frac{90}{N}\right)^{\circ}\right] + A$

Table 2 Extract from a span measurement chart 20º PA.		
No. of teeth in gear	**Constant "M"**	**No. of teeth spanned**
28	10.7246	4
29	10.7386	4
30	10.7526	4
31	10.7666	4
32	10.7806	4
33	10.7946	4
34	10.8086	4
35	10.8226	4
36	10.8366	4

Chordal thickness

$CT = 105 \times \left[\sin\left(\frac{90^{\circ}}{35}\right)\right]$ $\quad CT = 4.375 \times \left[\sin\left(\frac{90^{\circ}}{35}\right)\right]$

$CT = 4.71$ mm $\quad CT = 0.196''$

Backlash, for fixed centre gearing

When 14½deg. P.A. is used the extra depth of cut for each gear is equal to half the required backlash. In a gear and pinion drive apply all backlash to the gear.

When 20deg. P.A. is used the extra depth of cut for each gear is equal to the required backlash x 0.73. In a gear and pinion drive apply all backlash to the gear at 1.46 x required backlash.

Indexing movement

$$\text{Turns} = \frac{40}{35} = 1\frac{5}{35} = \text{1 turn and 5 holes on a 35 hole circle.}$$

Measurement of teeth

If the teeth can be measured with a gear tooth vernier while being cut, the vernier is set to the calculated chordal height and locked, while the chordal thickness is measured by adjusting the vernier to the gear tooth being measured to which backlash is subtracted if required. If a gear tooth vernier is not available then the "span" method of measurement is used, **Fig. 3**. To use this method a standard set of vernier callipers and a reference chart are all that is required. From the chart select either 14½deg. or 20deg. pressure angle figures. Select the number of teeth in the gear and find the constant (M) and the number of teeth the measurement is read over. If the gear is module form the constant (M) is multiplied by the module number, if DP form the constant (M) is divided by the DP. Subtract half the backlash from the measurement if required (see table 2).

For the above example of 35 teeth, the constant is 10.8226 and is measured over four teeth.

For the module form 10.8226 x 3 = 32.468 mm and the DP form 10.8226 ÷ 8 =1.353".

Cutting a gear

1) Calculate all the required variables and turn the gear blank to size.
2) Mount the dividing head with the required indexing plate.
3) Test the parallelism of the dividing head to the table movement.
4) Set the indexing pin and sector arms to the required positions.
5) Mount the cutter in a suitable position with the arbor support/s as close as possible to the cutter.
6) Mount the work via a suitable method.
7) Centralise the cutter to the work (see earlier article). If the cutter is not centralised correctly the teeth will have long and short flanks.
8) Test index the entire gear by nicking each cut position.
9) Set the depth of cut to suit the tooth size and machine condition, leave enough allowance for a finishing cut and cut the number of teeth as calculated for the span measurement. Measure to ensure the span measurement is oversize.
10) If span measurement is greater than required, rough out the entire gear. Be conscious of the heat of the cut, use a copious supply of coolant. If coolant is not available use a suitable neat cutting oil and try cutting a small number of teeth, index approximately 180deg. cut the same number of teeth, index 90deg. and cut, then index 180deg. and cut again. Finally cut any teeth remaining being careful with the indexing movements. Use the nicking as an indexing check.
11) Index approximately 180deg. from the original starting position to commence the finishing cuts.
12) Adjust the depth of cut to the calculated depth and cut the number of teeth to measure the span distance. Check and adjust as required and finish cut the gear.
13) When finished, check the span distance in a number of places around the gear.

Measuring the span distance of a gear.

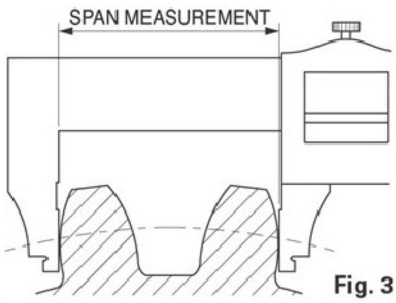


Fig. 3

Cutting a short rack

1) Set up the milling machine as above with cutter No. 1 of the required profile.
2) Set a machine vice at 90deg. to the machine column to take the place of the dividing head.
3) Mount the rack blank in the vice ensuring that it is parallel with the machine table.
4) Position a dial indicator on one end of the rack blank to index the cross slide movement.
5) The transverse pitch of the rack is equal to the circular pitch of the mating gear.
6) Set the depth of cut to allow a finishing cut and rough out the first tooth.
7) Finish the first tooth to the calculated whole depth before indexing to the second tooth. The reason for this method of cutting is to eliminate any error that may occur if the rack is moved back to the starting position for finishing cuts.
8) As the flanks of a rack are essentially straight, the angle of the flank of rack teeth is equal to the pressure angle of the gear.

As with a lot of machining operations the preparation and setting up can take longer than the actual machining, but the calculations, setting up and machining of your own gears will save a lot of money and should give you a lot of satisfaction. Good secondhand gear cutters are very well priced and available from the regular advertisers that advertise in MEW. If you have not tried gear milling in your home workshop give it a go. What have you go to loose? ■