Making Milling Cutters
for cutting gear wheels
by D. J. Unwin

IT IS MUCH more satisfying when building a model or clock involving gearing to cut the gears oneself.

Whilst commercial gearing is usually produced by a generation process, quite satisfactory results can be obtained by cutting each tooth separately with a form cutter on the lathe or milling machine using a dividing device to space the teeth. Methods of doing this and the necessary gearing calculations are fully described in the M.A.P. Handbook by Alfred W. Marshall, "Gearwheels and Gear Cutting". If you intend to make any. gearing, it can be thoroughly recommended and will explain the various terms used.

The cutter used must be of the correct form to produce a tooth of the right shape. These are available commercially but are rather expensive. However, they are not difficult to produce on the lathe using simple form tools and the method of production was described in M.E. Aug. 21, 1970. It is also much more satisfying to carry out the whole job personally.

There are two types of gear tooth forms which we are most likely to need to cut, the Involute form for ordinary power transmission and the Ogival type for clock work. As slightly different method are needed to produce the forms, I will describe them separately and deal with the involute gear cutter first.

The Involute Form

The basis for producing the cutter is the single curve approximation to the involute gear shape, the calculations for which were originally published by the Brown and Sharpe Co. of U.S.A. It is also given in "Gears for Small Mechanisms" by W. 0. Davis in which an additional correcting factor for gears with less than 20 teeth is described. This has been included in the values given in the tables of sizes given for making the form tools which are used to shape the gear cutters.

Fig. 1 shows details of the form tool. It consists of a piece of mild steel bar with two accurately spaced holes into which are clamped two turned hardened pins which form the cutting edges.

The diameter of the pin, the in-centre distance, the amount of in-feed and the blank width are obtainable from Table 1. The cutting depth of the finished gear cutter is also given. A choice of two pressure angles is given. That normally used is 20 deg., but if a pinion with very few teeth is required, 30 deg. pressure angle gives a stronger tooth without undercutting at the root.

The tables are given for 1 D.P. and to get the actual dimensions required to make a cutter it is only necessary to divide all the values by the required D.P. number (Diameter Pitch). i.e. 20 deg. pressure angle.

Cutter No. 3-35 to 54 teeth 50 D.P.

then 'd' dia. of pins	0.239 in.
'c' centre of pins	0.253 in.
'f' in-feed	0.062 in.
'w' width of blank	0.08 in.

In those cases when the pin diameter 'd' exceeds the centre distance 'c' a flat will need to be ground or filed on them. It may also be necessary to grind off the front to clear the mandrel in certain circumstances. In the case of the small pitches, width 'w' may become rather small to provide a sufficiently stiff blank. This can be avoided by stepping the blank as shown in Fig. 4. In fact I usually keep a small stock of turned but unformed blanks and produce the edge thickness in this way.

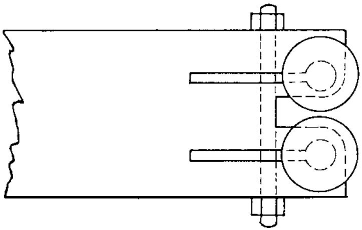
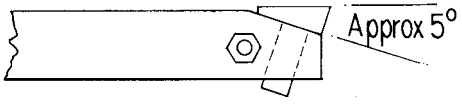


Fig .1.



Form tool for Involute Gear Cutters.

The shank of the tool can be any convenient piece of b.m.s. but long enough to clamp in your toolpost, about 5/16 in. or 3/8 in.thick and wide enough to accommodate the holes for two pins without being weak enough to bend under the cutting strain. The centre distance between the two pin holes should be as accurate as possible and to ease accurate setting up they should be perfectly square with the side. To achieve this they can be "jig-bored" by clamping the bar on an angle plate fixed to the tool-

TABLE 1

INVOLUTE CUTTER PROPORTIONS

For 1 DP or 1 Module

30 deg. PRESSURE ANGLE (Cos θ = 0.866)

CUTTER No.	RANGE OF TEETH	PIN DIA. d	PIN CENTRES C	FEED IN f	BLANK WIDTH W
1	135-R	67.5	59.5	3.20	4.0
2	55-134	27.5	25.0	2.85	4.0
3	35-54	17.5	16.3	2.67	4.0
4	26-34	13.0	12.4	2.54	4.0
5	21-25	10.5	10.25	2.41	4.0
6	17-20	8.5	8.5	2.31	4.0
7	14-16	7.0	7.2	2.18	4.0
8	12-13	6.0	6.36	2.06	4.0
9	10-11	5.0	85.6	1.98	4.0

TABLE la

INVOLUTE CUTTER PROPORTIONS

For 1 DP or 1 Module

20 deg. PRESSURE ANGLE (Cos θ = 0.93)

CUTTER No.	RANGE OF TEETH	PIN DIA. d	PIN CENTRES C	FEED IN f	BLANK WIDTH W
1	135-R	46.17	44.80	3.934	4.0
2	55-134	18.81	19.07	3.415	4.0
3	35-54	11.97	12.64	3.098	4.0
4	26-34	8.89	9.75	2.875	4.0
5	21-25	7.18	8.147	2.710	4.0
6	17-20	5.81	6.864	2.543	4.0
7	14-16	4.788	5.905	2.387	4.0
8	12-13	4.100	5.267	2.251	4.0
9	IO-11	3.42	4.632	2.108	4.0

post. The index of the cross-slide can be used to measure the centre distance and the holes which are centred, drilled and reamed by holding the tool in the chuck and using the top-slide to provide the feed. The size of holes is unimportant provided that it allows a shank on the pin of sufficient diameter not to break when cutting.

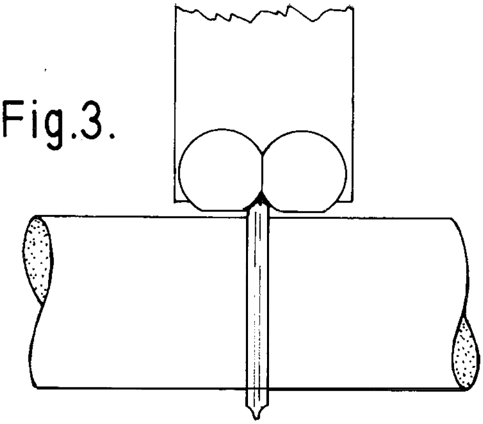


Fig.3.

Showing flats on pins,

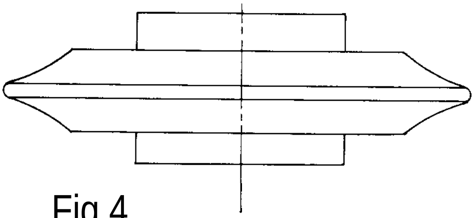


Fig.4.

Stepped blank for small pitches.

The cross hole for the clamping bolt, say 4 or 2 BA, depending on size of the tool, can be drilled and the slots for clamping sawn by hacksaw or milled. Turn the pins from cast steel or silver steel, making the shanks a good fit in the shank. Take care to get the diameter ‘d’ accurate. Harden and temper to light straw, then polish up the larger diameter in the lathe. Clamp them both in the shank and lightly grind across the tops to get them level and sharp, then finish up to a good finish on a flat oilstone to remove all burrs.

The tool is now ready to be used to produce the form milling cutter. Whilst these can be single point fly cutters for light alloy or brass, I strongly

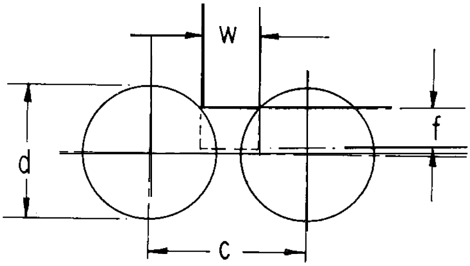


Diagram for TABLE.I.

recommend making multi-tooth cutters. Once made these cutters can be used for any future job regardless of material.

Prepare the cutter blank, including turning the edge to the correct width ‘w’, as described in my earlier article. Set up the form tool, taking care to ensure that it is perfectly square with the axis of the lathe. If the holes have been carefully drilled, then the side of the shank can be used. If not, the front edges of the pins must be set parallel to the axis by carefully lining them up to a parallel mandrel.

When correctly set up, each of the two pins must be located precisely with respect to the blank so that they are both just touching on each corner (Fig. 7). The cross-slide index collar figure is then noted or set to zero, the lathe started up on a slow speed and the tool carefully fed in the required amount ‘f’. When completed on each tooth our form tool has finished its task and we can go ahead and complete the milling cutter.

Before hardening, mark the cutter with-the D.P. number, the cutter number, the range of teeth and the cutting depth.

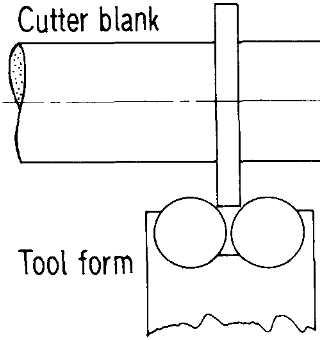


Fig.7.

Lining up the form tool on the blank.

It is worth noting that the tables can be used when it is required to make a metric module cutter; I have made several such cutters for repair jobs. All that is necessary is to remember that the gear module is the reciprocal of D.P., i.e. the metric module is defined as the $\frac{PCD,}{N}$ PCD being in mm. Therefore by multiplying the values in the table by the metric module needed, the result is the required dimension IN MILLIMETRES

i.e. 0.5 module
Cutter No. 3, 35-54 teeth
20 deg. Pressure angle
‘d’ Dia. of pin = 5.985 mm
‘c’ Centre of pin = 6.32 mm
‘f’ In feed = 1.549 mm
‘w’ Thickness = 2.000 mm

Alternatively if you prefer to work in inches

TABLE 2

OGIVAL CLOCK TOOTH PROPORTIONS

For 1 DP or 1 Module

PINION l/3 OGIVE

D!?	1	34	40	42	44	48	52	
a	0.74	0.022	0.019	0.018	0.017	0.016	0.014	
b	1.75	0.052	0.044	0.042	0.040	0.037	0.034	
s	1.99	0.059	0.050	0.048	0.045	0.042	0.038	
r	0.77	0.023	0.019	0.018	0.017	0.016	0.015	
a + b	2.49	0.074	0.063	0.060	0.057	0.033	0.048	
e	1.15	0.034	0.028	0.027	0.026	0.0239	0.022	
N	6	7	8	9	10	11	12	13
0 deg.	30	25.5	22	20	18	16	15	13.8

a, A Addendum = $\frac{0.74}{dp}$ b, B Dedendum = $\frac{1.75}{dp}$

e, E Tooth width = $\frac{1.15}{dp}$ r, R Radius = $\frac{0.77}{dp}$

s, S Space width = $\frac{1.99}{dp}$ d dia. of blank = $\frac{N + 1.48}{dp}$

0 Angle of radial sides = $\frac{180}{N}$ N Number of teeth

TABLE 3

OGIVAL CLOCK TOOTH PROPORTIONS

For 1 DP or 1 Module

GEAR

DP	1	34	40	42	44	48	52
A	**1.35**	**0.040**	**0.034**	**0.032**	**0.031**	**0.028**	**0.026**
B	**1.55**	**0.045**	**0.039**	**0.037**	**0.035**	**0.032**	**0.030**
S	1.57	0.046	0.039	0.038	0.036	**0.033**	**0.030**
R	**1.57**	**0.046**	**0.039**	**0.038**	**0.036**	**0.033**	**0.030**
A + B	2.90	0.085	0.073	0.069	0.066	**0.060**	**0.056**
E	**1.57**	**0.046**	**0.039**	**0.037**	**0.0356**	**0.0326**	**0.030**
Cutter No.		**5**	**4**	**3**	**2**	**1**	
N		**21/25**	**26/34**	**35/54**	**55/134**	**135/ Rack**	
0 deg.		9	6.9	5.1	3.3	1.3 Parallel for Practical Purposes	

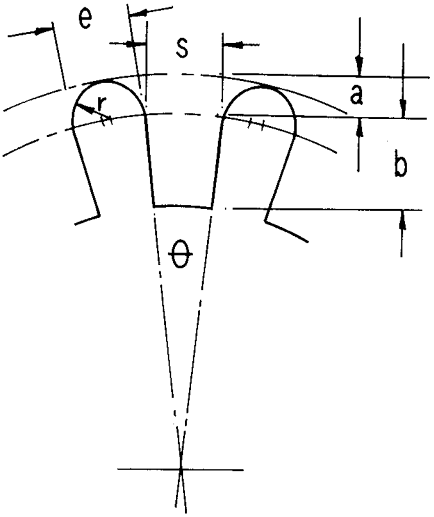


Diagram for TABLE .2.

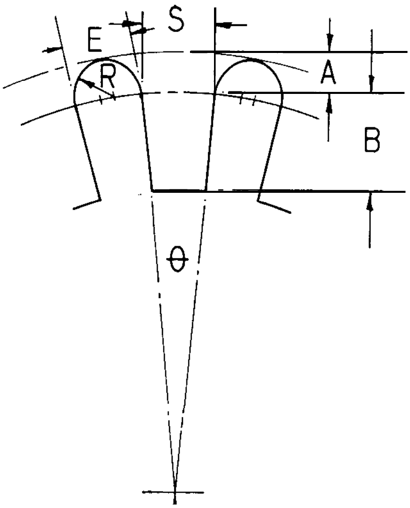


Diagram for TABLE.3.

throughout, convert the required metric module to English D.P. by dividing 25.4 by the D.P.

i.e. $\frac{25.4}{0.5} = 50.8$ then carry on by dividing these values as before. Remember the dimensions will now be in INCHES.

We will now deal with the Ogival clock tooth form.

For clock work, in which the train is usually stepping up, and where low friction is more important than a constant velocity ratio, the 'Ogival' approximation to the epicycloidal tooth is often used. There are a number of variants, but the one I have used successfully is the 1/3 Ogive in which the tooth form is not dependent on the gear to pinion ratio. If any reader should prefer to use any other form such as BS.978, the same methods of making the form tools for making the cutters can be applied. Unlike involute gear cutters, I use single point fly cutters for gears, which are almost invariably of brass, whilst using multi-point cutters for pinions which are usually of mild steel or cast steel.

Table 2 gives the proportions of shape for 1 DP (or 1 module) pinion. As in the case of involutes, to get the values required:
Divide by the DP, dimensions in inches. ***Multiply*** by the module, dimensions in mm ***if*** metric ***module.***

Note that in this case the flank angle 0 should be chosen to suit the number of teeth the cutter is going to be used to cut. Table 3 gives the same values for gearwheels.

In addition to the basic proportions, I have also given the values for a few common DP's used in clock work. It will be seen that even in the case of the larger teeth sizes such as 34 DP, typical of the size used on a clock great wheel, the radii R and r are quite small. This, together with the need for radial flanks, demands a different approach from that used to make involute shapes.

Taking the coarser pitches of gears say from 40 DP, I made pin form tools similar to those used for involutes. The main difference was that the pins consisted of short pieces of hardened silver steel of the required diameter (2R or 2r) and no attempt was made to achieve the correct centre distance. The holes to receive the pins were drilled about 1/2 in. apart at an angle of about 5 deg. from the vertical, in such a manner that both side and front clearance are given to the cutting edge. (See Figs 8 and 9, next issue.)

The blank, either a piece of square cast steel for a fly cutter for cutting gears, or a prepared disc for a multi-tooth cutter for making pinions, is mounted in the lathe and the pin form tool mounted in the tool holder with the two cutting edges parallel to the lathe axis. Using the appropriate cutting pin, one side is carefully machined to the correct depth (r + b). The amount to be machined from the side of the blank is given by:

$$\frac{\text{Blank thickness} - S}{2}$$

After completing the first side, machine the other side using the opposite cutting point. By careful measurement of the blank, and use of the top-slide indexes, the correct thickness S can be achieved, although it can be checked by direct measurement using a micrometer. If anything, be slightly undersize, not oversize.

To be continued.