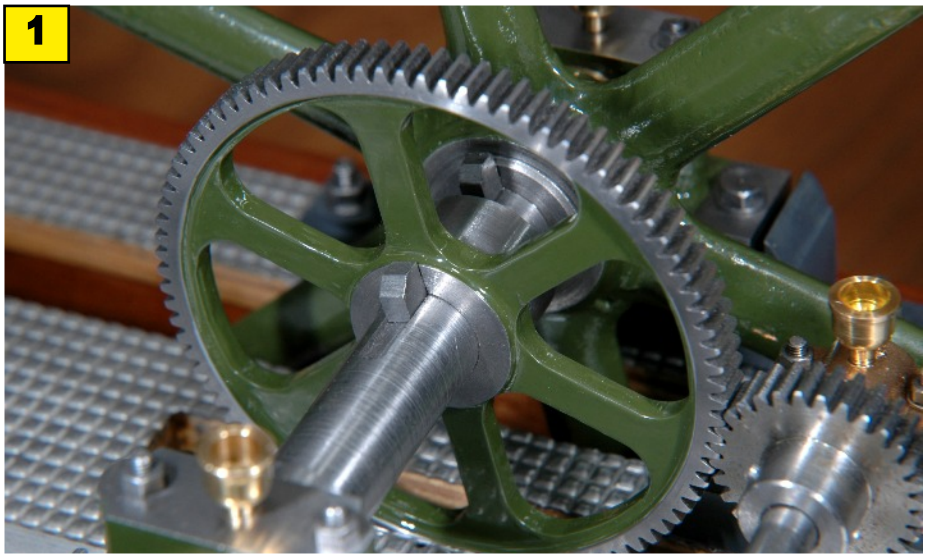
Spoked Wheels Without Castings

David Haythornthwaite examines the methods of drawing out and machining spoked wheel from solid blanks.

I am currently building an ME beam engine, and the output drive for this model involves a 90 tooth spur gear. A casting was provided in Gunmetal, which would look totally out of place, with yellow teeth, in the finished model. I decided to convert an existing steel gearwheel into a spoked wheel and the process proved to be an interesting exercise in both drawing and in machining which could be informative for many readers. The same process would apply to making flywheels from cast iron blanks as opposed to using castings.



The Finished gear Wheel Keyed Onto The Shaft

The Project In Hand

The Gearwheel as Supplied

Why cut the wheel in the first place?

The kit of castings came with a gunmetal casting of a spoked wheel and the plans suggested that this be turned with a smooth rim, smaller than the finished spur gear. The suggestion on the plan was that a commercial gearwheel should be purchased and the centre should be taken out so that just the rim of the gear could be fixed onto the turned casting with adhesive. Measuring up the job illustrated that I would have to remove the innards of the gear wheel. Leaving a rim that was only 3.5 mm thick radially, and the thought of holding that in the four jaw chuck without distorting it made my blood run cold. I therefore gear-cut the provided spoked casting with teeth to make a spoked spur gear. Despite this being my first attempt at gear cutting, the gearwheel turned out very well, but the fact that it was the colour of brass offended me as it would never have been that colour in the prototype. I had originally bought a blank gearwheel with the castings, so after a little thought, I decided to convert it into a spoked wheel. I have seen this model made with a solid gearwheel, but it does not look right in my opinion.

Setting out the proportions in a drawing

The gearwheel, as supplied looked as shown in **Photo. 3** and was 73 mm in diameter. The central hole needed to be increased to ½" diameter (12.7mm) to fit the crankshaft of the engine. The thickness of the wheel was 6mm and I decided that it should be thinned down to 3 mm by taking 1.5 mm of each side, leaving the rim at the full 6 mm width and the hub would be turned down to 19 mm diameter and axially would be left at full thickness. I needed six

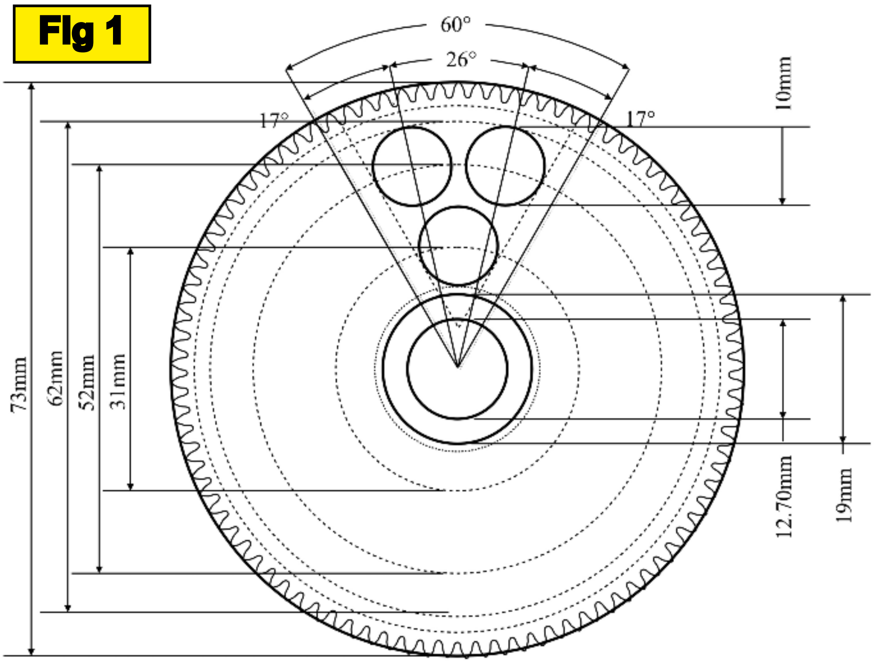
spokes so obviously these would be at 60° to each other.
Whether, like me, you prefer to create a drawing on a computer, or whether you prefer the old ways with pencil and paper is immaterial, the main point is that it is best to draw out the proposed layout of the wheel and to work out where the corners of the cut-outs are to be placed. I started by drawing a circle - the full diameter of the blank (73 mm) and then drawing the main bore (12.7 mm) and the outer circumference of the central bush (19 mm). I then drew circles inside the outer circumference and outside the hub to show the limits of where the wheel was to be recessed. With a flywheel, you would probably leave the rim much deeper than I have done on the gearwheel so as to leave the majority of the weight on the circumference.
Once the recessed area has been outlined by these two circles, it then remains to establish graceful proportions for the cut-outs and the first step in this is to create two radii lines from the centre of the circle at an angle determined by the number of proposed spokes in the wheel.

3 Spokes	-	120 Deg.
4 Spokes	-	90 Deg.
5 Spokes	-	72 Deg.
6 Spokes	-	60 Deg.

Etc. Etc.

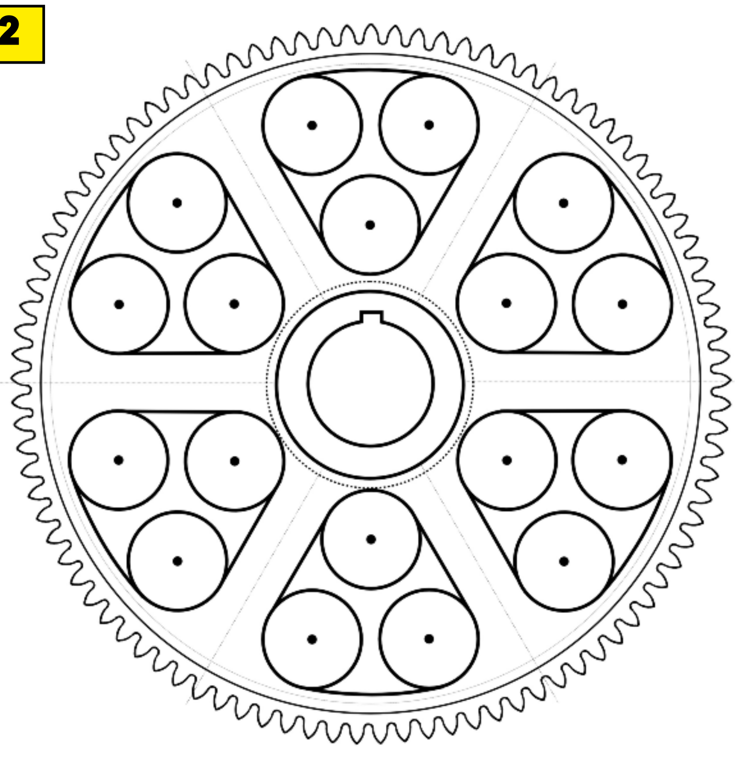
In my case I wished to have six spokes and you will see that the lines have been drawn in **Fig. 1** at 60° to each other.
These radial lines represent the centre of the radial spokes in the wheel and the next task is to decide how thick you wish the radial spokes to be in the finished wheel, and what radius of corner you wish to make in the cut-outs. Those readers who are clock makers, may laugh at these choices as it is probably second nature to them and in fact the cut-outs in clock wheels usually meet the circumference of the cut-out at a sharp angle, but I prefer a flywheel to have a nice radius on the outer edge of the spokes. In full size it would also make the flywheel stronger and less liable to cracking. As an aside, I worked in a Lancashire mill where in earlier years, a twenty foot, rope-drive, flywheel on the steam engine did break up, broke free, and motored through the weaving shed. Before my time, but the scars on the building were still there! However, - back to models. Whatever width you wish to make the spokes, (mine were 5.5 mm), then draw two lines parallel to the radius lines at half the spoke thickness (2.75 mm)

Fig 1



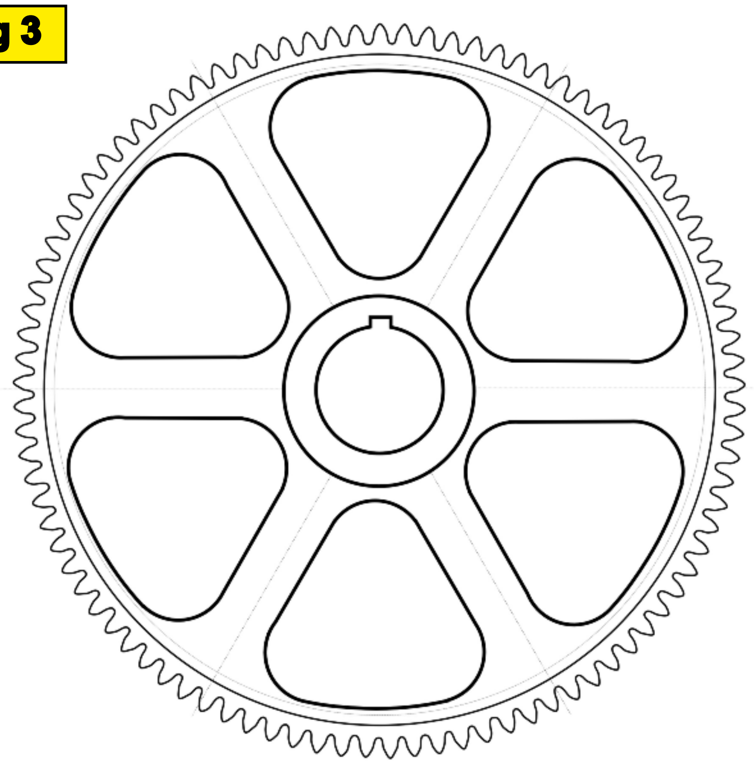
Setting Out The Hole Positions

Fig 2



Creating a Drilling Template

Fig 3



Final Appearance

away from the radii. These can be seen dotted in **Fig. 1**. I also drew a circle of 62 mm diameter to show me where the outer partial circumference of the cut-outs would be.

Having decided that the corners of the cut-out would be 5 mm radius, I knew that I would be using a 10 mm drill to form the corners, so the first task was to draw a circle 10 mm diameter and situate it in the "V" created by the two dotted spoke lines so that it touched both lines. This turned out to be 15.5 mm from the centre of the wheel and so a circle was drawn 31 mm diameter to represent the pitch circle of the 6 holes to be drilled.

A similar procedure was used to create the outer two corners of the cut-out. These 10 mm circles were situated touching the dotted spoke lines and also touching the 62 mm diameter circle already drawn. Radial lines were drawn through the centres of these two corner holes to the centre of the wheel and the angle measured. On my wheel, the holes were 26° apart and therefore 17° from the centre of the spokes, as shown in **Fig.1**.

If it is intended to drill and cut the cut-outs by hand methods, then the angles of these holes is immaterial, but I intended to drill and mill the cut-outs on the Rotary table, so it was necessary to know the precise angles involved. I intended my spokes to have parallel sides, so my dotted "spoke side" lines were parallel to the spoke centre line. If it is wished to taper the spokes towards the outer circle, then the dotted lines should be drawn at a suitable angle to the spoke centres and the same procedure carried out for the location of the corner holes.

Once happy with the location of the corners of the cut-out, the three 10 mm holes are connected by straight lines on the sides of the spokes and by an arc on the wheel circumference side of the cut-out. Finally I copied the shape 5 times round the wheel at 60° intervals. This left me with a drawing as shown in **Fig.2** which I then used as a template for machining. I also removed the 10 mm circles as shown in **Fig.3** to ensure that I was happy with the appearance. This is where drawing by CAD comes into it's own. I use Draw Plus X5 (Ref.1) for my drawings, which isn't exactly CAD but it is fine for my drawing needs.

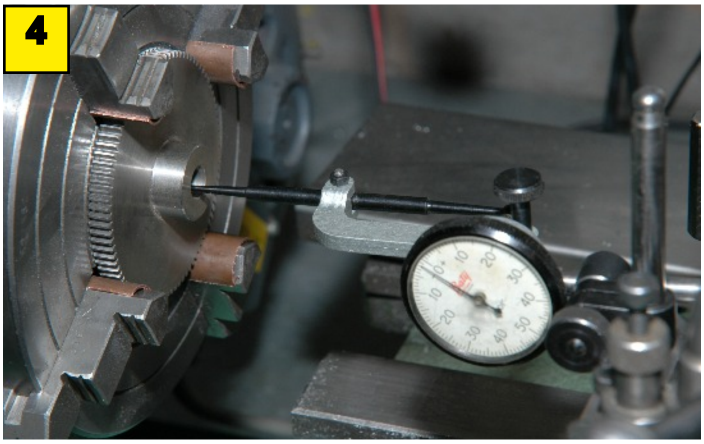
Machining Methods

The recessing (thinning the disc) must be done on the lathe, but cutting the cut-outs depends upon the equipment available and also upon the skill and preferences of the operator. I imagine that those readers who have made many clocks will prefer to cut out the shape by hand using a piercing saw or a scroll saw. The thickness of the spokes on my wheel was left at 3mm which is probably on the limit of a piercing saw. I am better with machinery than hand tools so the following is a description of how I proceeded.

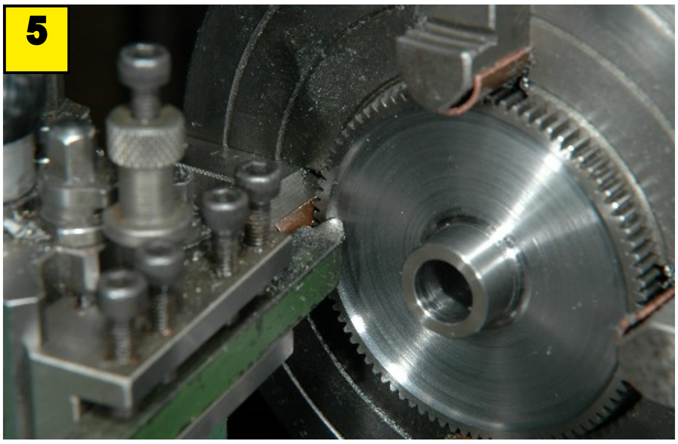
Lathe Work

First the gear wheel was centred in the four jaw chuck, and as this was a gear wheel, I protected the teeth by inserting semi-circular copper pieces over the chuck jaws, which I cut from ½" domestic plumbing pipe. The wheel was pressed against the body of the four jaw chuck, using a large tailstock rotating centre to hold the existing central hole true. The jaws were tightened up gently one at a time in the order 1,3,2,4 and the position checked by rotating the headstock. It looked pretty good, but I checked the position as shown in **Photo.4** and it was around 2 thou (0.05mm) out of centre. As this was a gear wheel, concentricity was important so a little time was spent adjusting the jaws until it was dead centre. The dial indicator with an internal adapter is ideal for this, but a "Verdict" type of indicator would have been just as good.

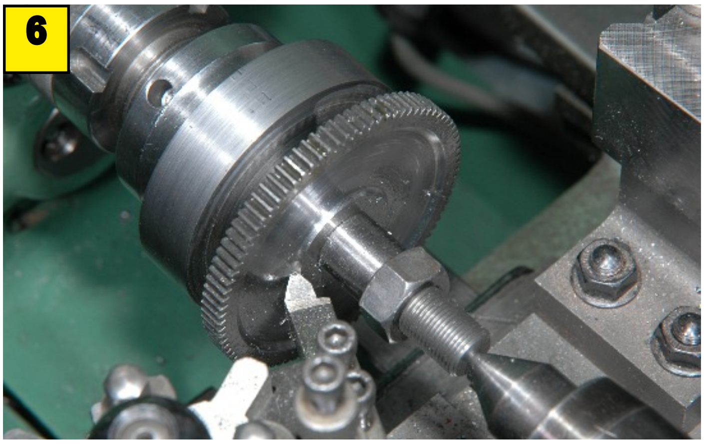
The central hole was bored to a few thou under ½" and finished off with a ½" reamer. The first face was recessed by 1.5 mm using a round nosed tool as shown in **Photo.5**. The original wheel was 6 mm thick and I wished to thin it to 3 mm, so



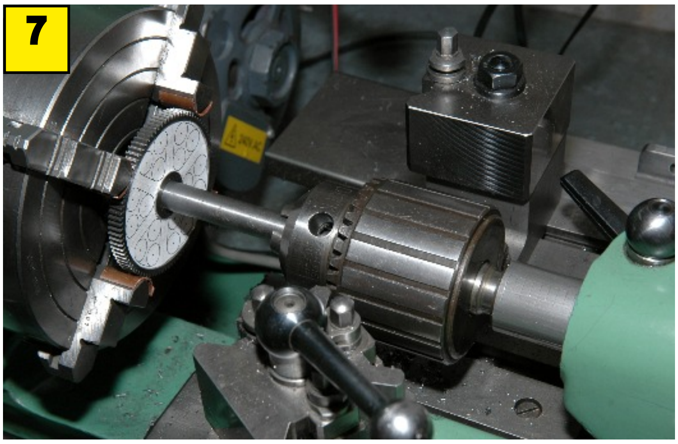
Checking Concentricity



Recessing the First Face



Recessing the Second Side



Re-mounting in the Four Jaw Chuck

the first task was to touch the face with the tool and reset the dials / DRO to zero. It was then easy to see when I had reached the required depth of 1.5 mm. It is not easy to judge this in any other way.

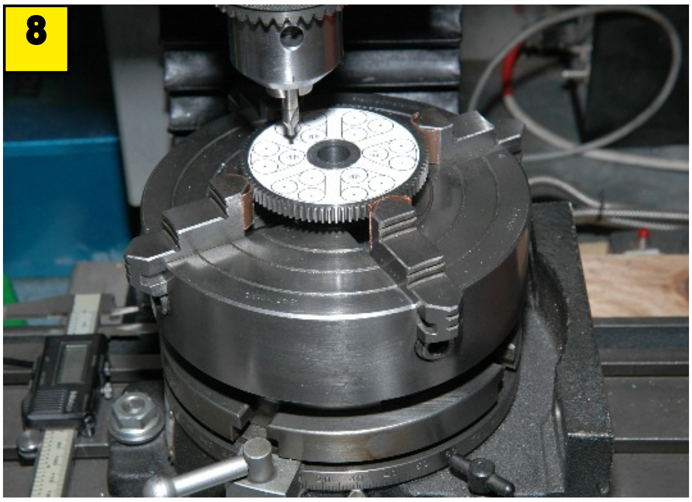
In order to ensure concentricity when recessing the second side, the wheel was mounted onto a mandrel taken from my box labelled "sundry mandrels" and the mandrel was mounted in a collet chuck. The second side was recessed in the same manner as the previous face, just mounted differently. It was now necessary to mount the wheel in the four jaw chuck once again for milling out the cut-outs on the vertical milling machine. It was important that the wheel was not mounted into the jaws of the chuck so that the back of the wheel was in contact with the chuck jaws as this would have meant that it was likely that the drills and milling cutter would damage the chuck jaws (and the cutter) when breaking through. The wheel had to be mounted on the outer ends of the jaws, but parallel to the face of the chuck. In order to do this, I mounted a length of ½" silver steel in the tailstock chuck to pass through the reamed centre hole and centralise the wheel whilst gently tightening the chuck jaws **Photo.7**. Absolute accuracy "to one thou", is not as essential in this instance. You will observe in **Photo.7** that I had cut out a printed drilling template, and stuck it into the recess, but it would have been better to have waited until the chuck was on the rotary table so that one spoke could have been aligned with 0 Degrees to make calculations easier. I did in fact move this after mounting on the milling machine.

Creating the Spokes

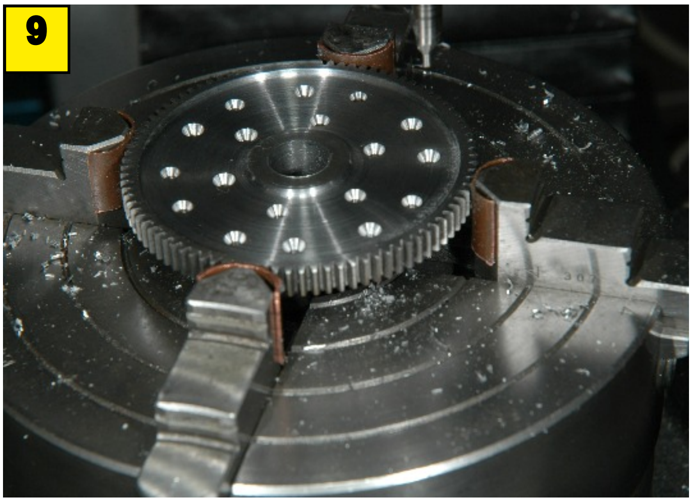
At this point, how you create the cut-out sections depends to a great extent on the equipment that you have available, and indeed the level of skill that you have with hand tools. If you have set out the spacing of the holes in a CAD or hand drawing, then it is perfectly possible to stick the drawing to the wheel as I have done and then use the template to spot drill the holes, opening them gradually to full size (10 mm in this case). It is then only a matter of sawing between the holes using either a piercing saw or a motorised scroll saw, and finishing off with a file. I am better with machine tools than I am with hand tools, so I went down the machine route as described below. In addition the thickness of the spokes being 3 mm thick, it is rather a tall order for a piercing saw.

Machining the Cut-Outs

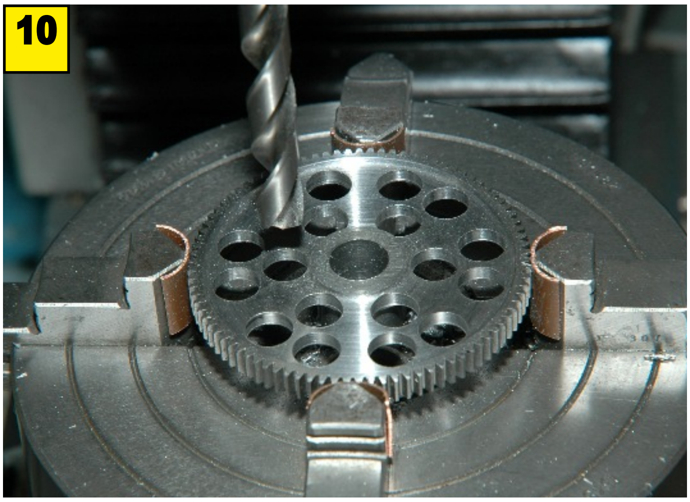
As already stated I intended to make my cut-outs / spokes by mathematics and mechanical means, so once the wheel had been centralised in the four jaw chuck, it was time to take the chuck com-



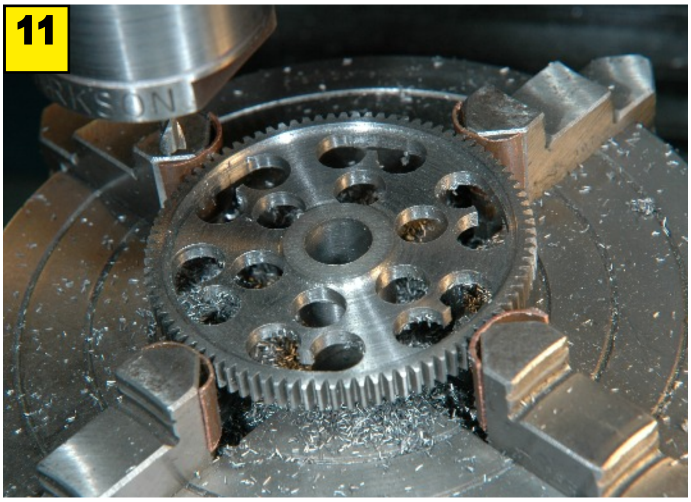
Spot Drilling with a Centre Drill



Template Removed Showing the Spot Drilling



Holes Enlarged to 10 mm Diameter



Milling The Curved Sides

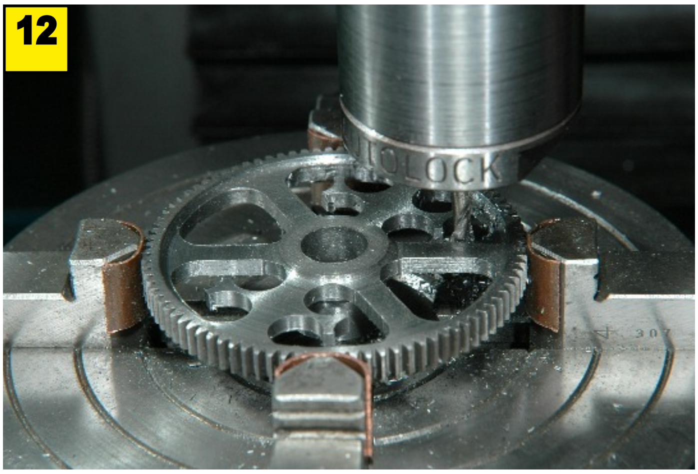
plete with blank wheel and mount it on the rotary table on the milling machine. I often find that a rotary table or a dividing head are interchangeable on the milling machine, but this is one occasion where a rotary table is the thing to use if you have one.

Firstly, the rotary table with chuck needs to be centred under the spindle of the milling machine. This was done by fitting a live lathe centre in the spindle and moving the table back and forth until the lathe centre fits evenly into the centre bore of the wheel. It could easily have been carried out using a centre finder with a pointer used in the fashion of a "sticky pin". Once the centre position had been found the dials and DRO were zeroed. The rotary table was set to zero degrees and the paper template that had been produced previously was stuck to the wheel with the centre line of one of the spokes in line with the "Y" axis, as shown in **Photo.8**.

The inner holes were now spot drilled with a centre drill by moving the table in the Y direction by 15.5 mm (the inner holes are on a circle of 31 mm diameter as shown in Fig. 1) and the table is rotated to positions 30^o, 90^o, 150^o, 210^o, 270^o, and 330^o respectively for spotting the holes. Readers may wonder why I used the template at all in view of the fact that I was drilling the holes mathematically. The fact is that it is very easy to make a mistake and to ruin the whole job by placing a hole in the wrong position. It is very comforting to see the drill go down exactly on a centre spot shown on the template and to know that all is in order.

It will be seen from **Fig. 1** that the outer holes for the first cut-out are at angles 17^o and 43^o (17 + 26) from the centre of the spoke. The holes are on a pitch circle of 52 mm diameter so the table was moved in the Y direction 26 mm (52 / 2) from centre zero. Holes were then spotted out at 17, 43, 77, 103, degrees etc. round the circle. At the end of this, the paper template may be removed and the wheel should look as shown in **Photo. 9**. Having now created all the spot drilled holes, each hole was repositioned under the chuck and the hole drilled through at 5 mm, 7 mm, and finally 10 mm until the wheel looked as shown in **Photo.10**.

To create the outer, curved, section of the cut-outs, using a slot drill, it is necessary to move the table so that the cutter just touches the edge of the outer holes when lowered



Milling The Spoke Sides.

The Finished Wheel

into the hole at 17° and 42° etc. Actually this will be with the cutter centre 31 mm minus half the slot drill diameter from the centre of the wheel. The table is then locked and the cut is made by rotating the rotary table anticlockwise to ensure that the cutter is never climb milling. I used a 3/16" (4.7 mm) slot drill for this using a cut depth of 1 mm. As the spokes are 3 mm thick, this meant 3 passes to cut each slot. **Photo.11** shows all curved slots having been cut.

To cut the spoke sides, the opposite procedure is carried out, locking the rotary table and using the X (or Y) travel of the table to make the cut. The rotary table is set to align the spoke with the milling table i.e. 0°, 60 °, 120 °, and the milling table zeroed on the dials / DRO so that the cutter is on the centre line of the spoke. The table is then moved – in Y direction in **Photo. 12** – by half the width of the spoke plus half the width of the cutter and the table is locked. You should find that the cutter will just drop into all the holes adjacent to that side of the spoke. If you are working with an even number of spokes, then two cuts may be made at the same setting using travel in the X direction. In **Photo. 12** the table is moving from left to right to eliminate climb milling. Rather than rotating the rotary table six times, I cut both sides of the same spoke at the same rotary setting, moving the cutter to the other side of the spoke. One side of the spoke is cut from right to left and the opposing side is cut from left to right, so as not to climb mill. Three passes of 1 mm depth were used for each cut.

Once all the cut-outs had been removed, it only required a few minutes with some emery and a deburring tool to leave the item as shown in **Photo. 2**. You will see that my application required a keyway, which was created using a slotting tool. This was an interesting exercise in both marking out and in machining. It would be most useful for creating a flywheel for a model of your own design. Once painted, my gearwheel is shown in **Photo. 13.**

Ref.1 - DrawPlus X5
www.Serif.com