Designing and making arc sided segment rings

Introduction

Jack Cox's book "Beyond basic turning" initiated my interest in circular arc segment design. I tried his methods and quickly found that they didn't fit my style of working or the materials I use.
In particular :-

1/ I like to see a design on paper before I make it.

2/ I feel that the most pleasing designs have a large displacement angle and his method does not handle this well.

3/ I use offcuts from furniture making and the corners of bowl blanks thrown out by turners.

I see I have introduced a concept that you won't be familiar with - "angular displacement" and as it is an important design parameter in my method I'll start with an explanation of it.
Consider the straight sided segment at the top of figure 1. (I've started with straight sided segments as I feel you will be familiar with them) Projecting the four corners of the segment to the ring centre generates only two lines, that is the inner and outer surfaces of the segment entirely cover one another. However in the lower segment the outer surface is displaced around the ring circumference. Now drawing lines from the segment corners produces two pairs of lines each pair having an angular difference which is proportional to the displacement. So this angle can be used as a measure of the displacement between the inner and outer surfaces of the segment. In figure 2 I have applied the same idea to arc sided segments.
Points to keep in mind:-

1/ If all the segments in the ring are identical the angles on either side of a segment will be the same. For non identical segments each one will have it's own displacement angle.

2/ The limit of angular displacement for a straight sided segment is 90 degrees. That is when the segment side is tangential to the inner surface at the inner corner of the segment. The limit for arc sided segments is also when the segment side is tangential to the inner surface at the inner corner of the segment and is 180 degrees.

Design Method.

You will need a compass, ruler, possibly a protractor and paper large enough to accommodate your design at full size. Or if you prefer a graphics package such as Sketchup.

You need to specify for your design the number of segments, the rings inner and outer radii and the displacement angle

For my illustration design I'll use :-

Number of segments	n	6
Inner ring radius	r_i	25 mm
outer ring radius	r_o	50 mm
Displacement angle	d	130 degrees

Start by drawing the inner and outer ring circles (full size) then split the inner ring circumference into n (6) equal parts. See figure 3. Using the line from point A to the ring centre as a reference draw a line at the required displacement angle d (130) from the ring centre to the outer ring circumference (point B).

Draw a line to connect the points A,B. Divide this line into 2 equal parts and construct a line at right angles to the line AB. Use your compass for this as it will generate both the division and the right angle line (normal) in one operation. See figure 3 again.

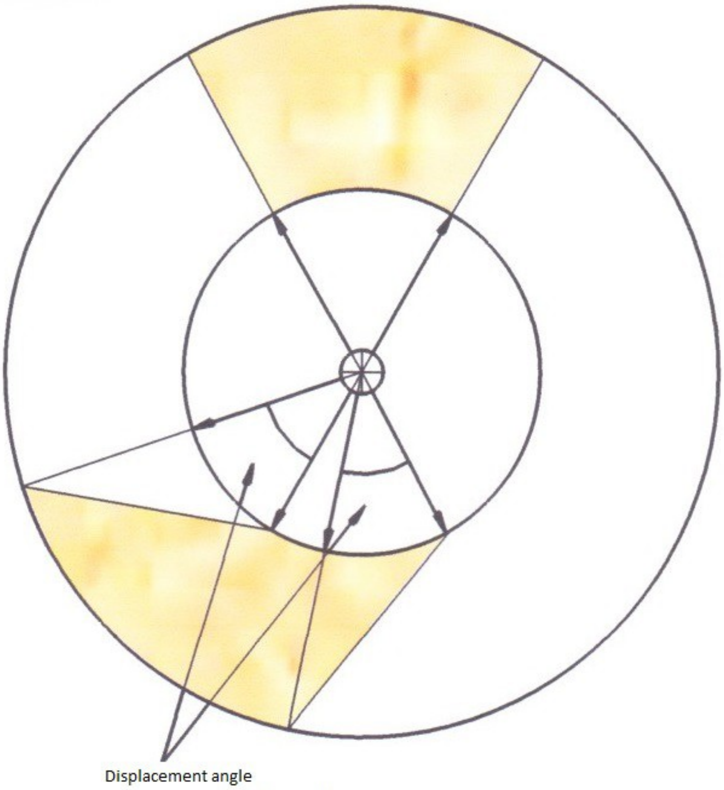


Figure 1

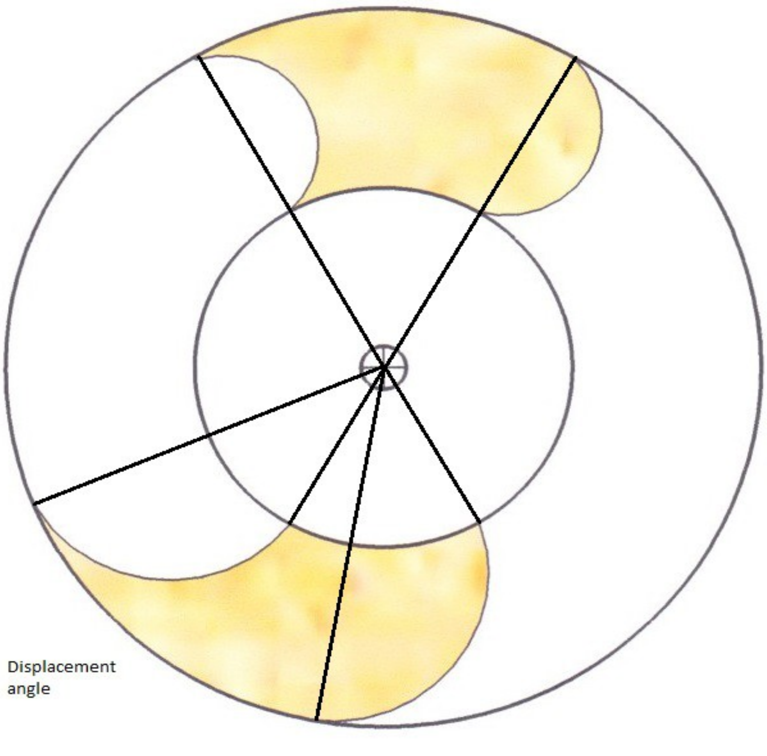


Fig ure 2

You now need to choose a radius r_s for the segment sides. The centre for this radius will lie on the normal line you have just constructed. The minimum radius must be greater than half the distance from A to B or large enough that the resultant arc cuts the outer ring only at B. The maximum radius must be small enough that the resultant arc cuts the inner ring only at A. See fig. 4. Note. Choosing either of these two extremes will lead to difficulties in making the segments because of the long points at one or both ends of each segment. I have chosen r_s as 38mm. The solid arc in figure 5.

Draw a circle whose centre is the ring centre and passes through the arc centre (C) you have just determined and divide this circle into n (6) parts starting at point C.

Using the compass with radius r_s and the points you have just drawn. Draw the sides of all the segments.

Finally, to see the effect of your design colour the segments according to the timbers you intend to use. See figure 6

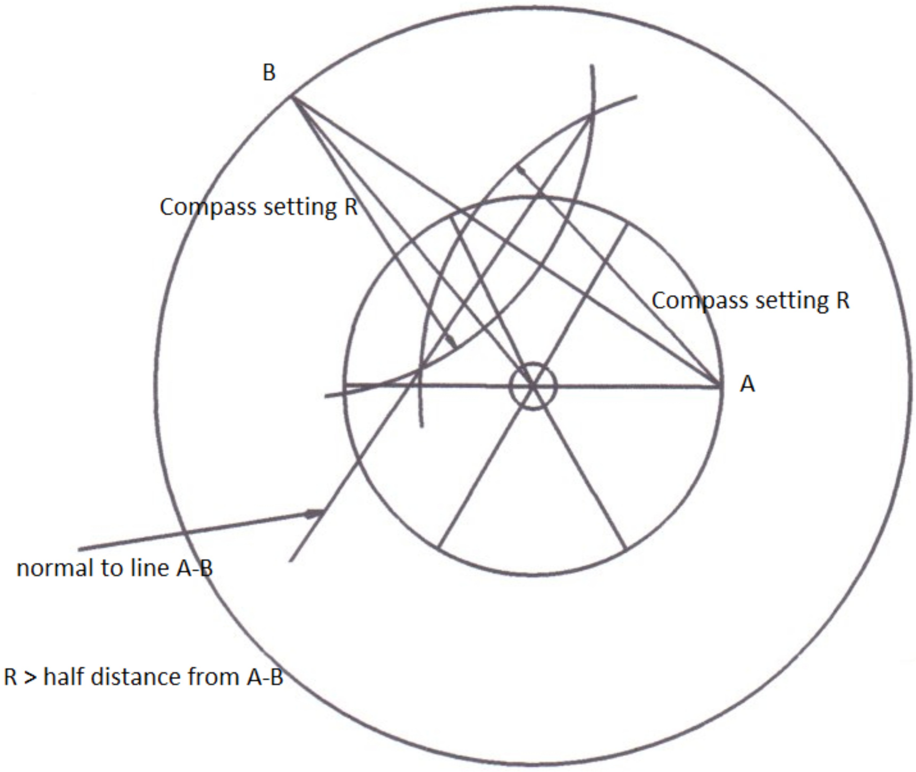


Figure 3

Simple wasn't it!!! No maths and just a bit of technical drawing, you don't even need that if you use sketchup. However nothing much new so far. Bear with me.

I'll now add an extension to the design that will make it much easier to make the segments and to assemble them into a ring. Draw circles 3mm larger/smaller in radius than the outer/inner surface of the ring (F and G in figure 7). Extend the segment arc sides for one of the segments to meet these new circles. Somewhere along these new circles between the arc sides mark the points D and E. See figure 7. This extra material will not be part of the finished ring and holes (2mm in diameter) can be drilled into the segment at D and E for location pins. Leaving 3mm outside/inside the point D/E draw a line to the new end points of the segment. Mark the positions of the location pin holes on circles G and F for all the other segments. We now have figure 7 as a pattern for the segments and for the jig to construct them.

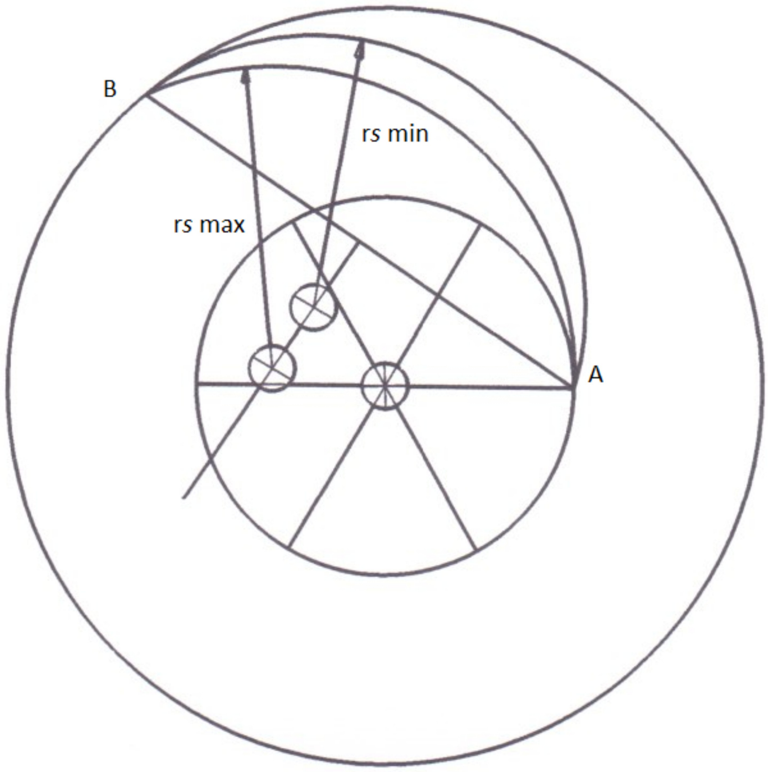


Figure 4

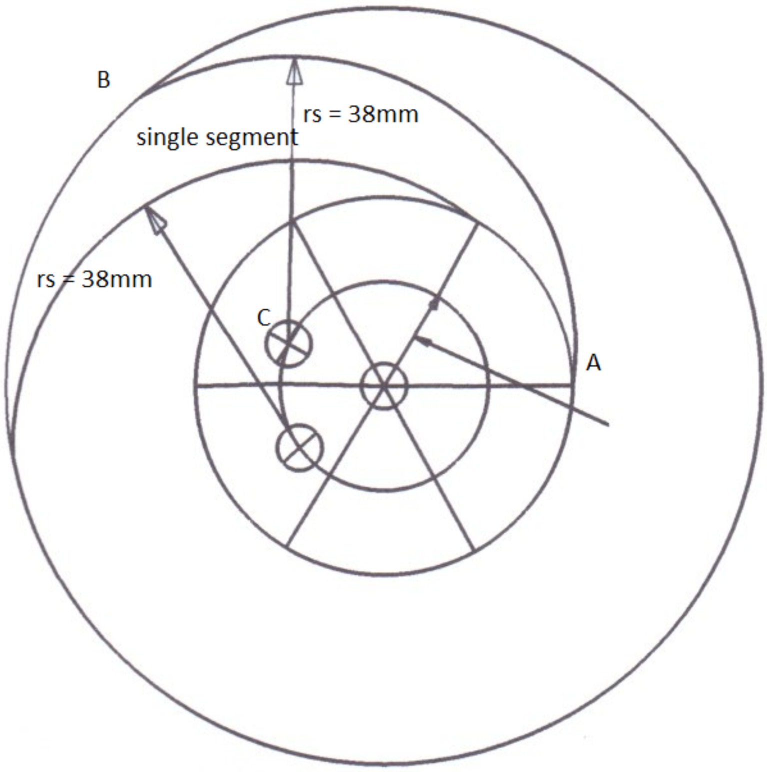


Figure 5

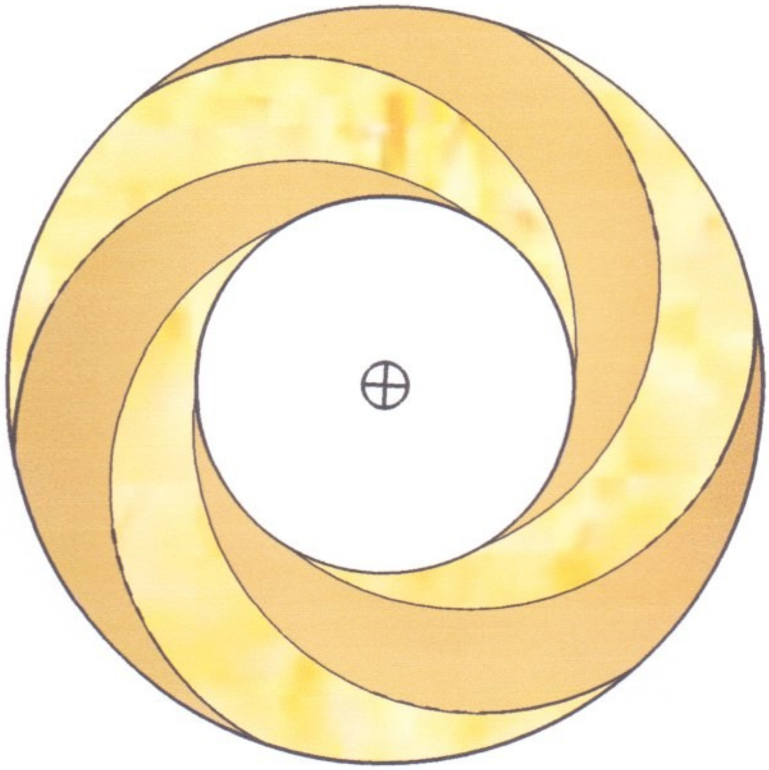


Figure 6 The finished design

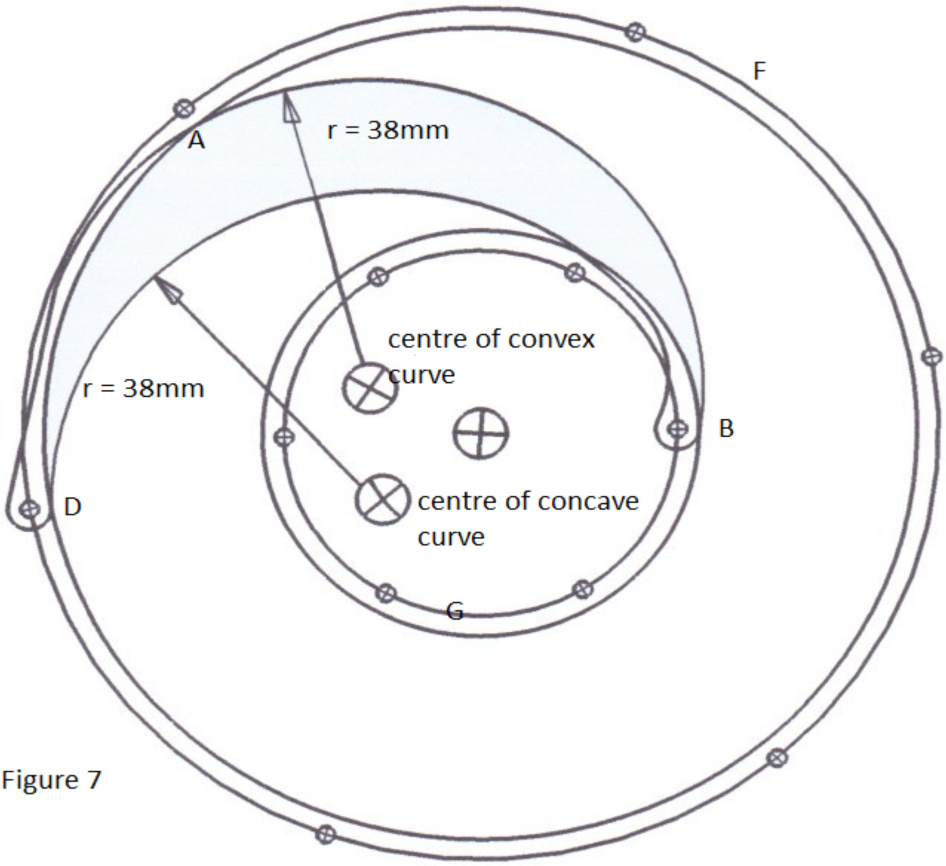


Figure 7

Overview of the making and assembly processes.

A pattern will be made from the segment design and used to layout the segments on the timber you'll use. The pattern is easy to make as it does not have to be precise. The segments as laid out can be cut on a band saw or scroll saw by eye about 1mm outside the defining lines of the segments

The arc sides of the segments will then be cut to their final position using a drill press, drum sander and a relatively simple jig. Finally an assembly board with pins in the places where the location holes need to be is used to assemble the ring.

Drill Press Sanding Jig.

The jig consists of a precision sliding platform with a screw feed and a micro-adjustable stop. The platform provides a line of holes which will be pivots for a project dependant pivoting platform. Figure 8 shows the sliding platform, the screw feed and stop and is I hope self explanatory.

The important aspects are:-

The slide should not be able to rise, twist or tilt. It should be reasonably wide (> 100mm.) to be this stable.

The tongues which are glued into the slide need to be a good fit in the slots in the retaining sides. One of these retaining sides is adjustable.

The top surfaces of the slide and the retaining sides must be flush to give a flat base for the pivoting platform.

The screw feed should operate smoothly and in both directions. Backlash is not important as the feed is always in one direction during cutting.

As the slide comes up against the stop you should be able to feel this as extra pressure on the screw feed so providing a precise indication of when to stop cutting.

The maximum required feed movement should be a little more then twice the distance between adjacent pivoting holes.

The holes are in an aluminium or steel bar to reduce wear and prevent the pivot becoming sloppy. I use 6mm. holes as I have precision 6mm steel rod from an old printer. The holes are 15mm apart

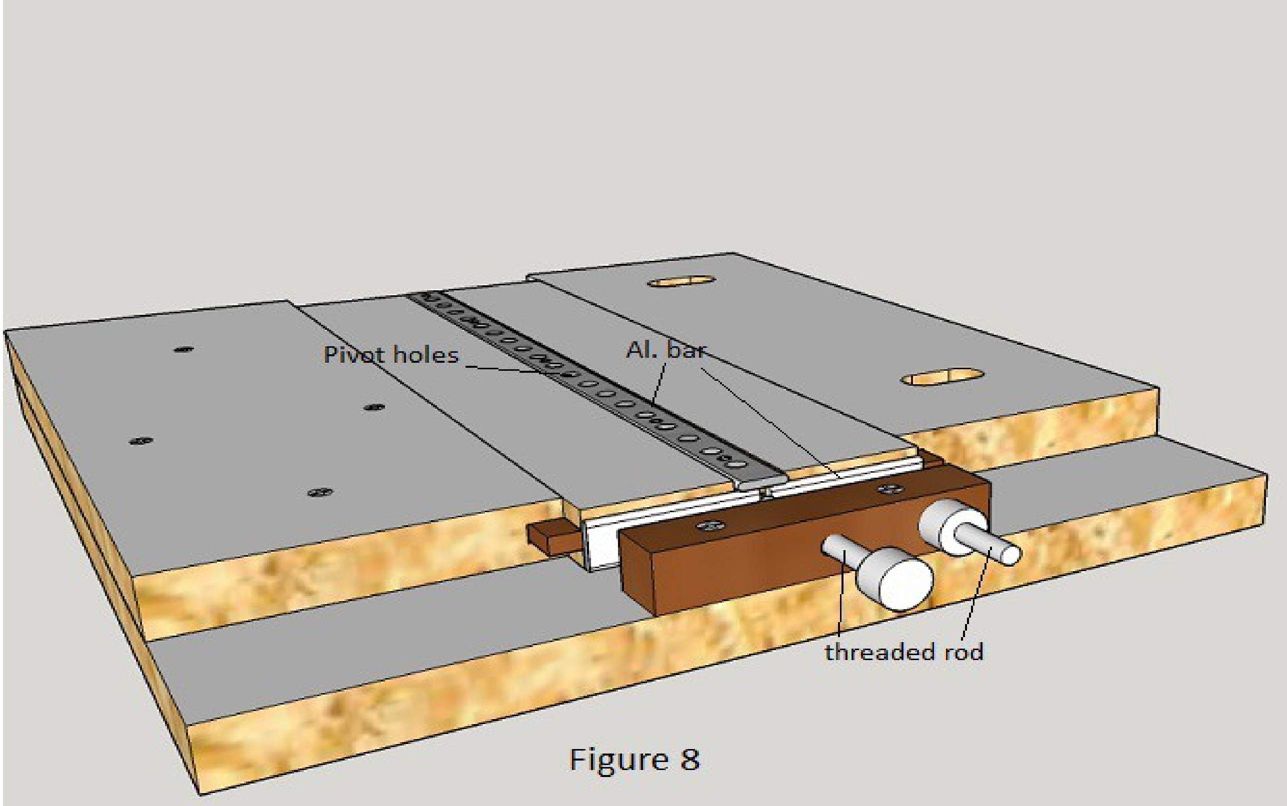
The slide, sides and base are 19mm melamine covered MDF or particle board (consistent, flat and stable). 16mm would be adequate.

The screw feed is 6mm metric (1/4” at 25 tpi would be OK) and has a region close to the inboard end which has been reduced (with a narrow file) to about 3mm in diameter and fits nicely in the slot in the bar on the front of the slide.

The stop, also threaded rod is screwed into and fixed to the slide. The adjustment is by a threaded knob on the outside.

Typical sizes for the base is 300mm by 350mm and the slide and it's retainers are 100mm wide and 300mm long.

The jig mounts on the drill press platform so that the line of holes are directly under the centre of the drill press quill.



Precision sliding platform

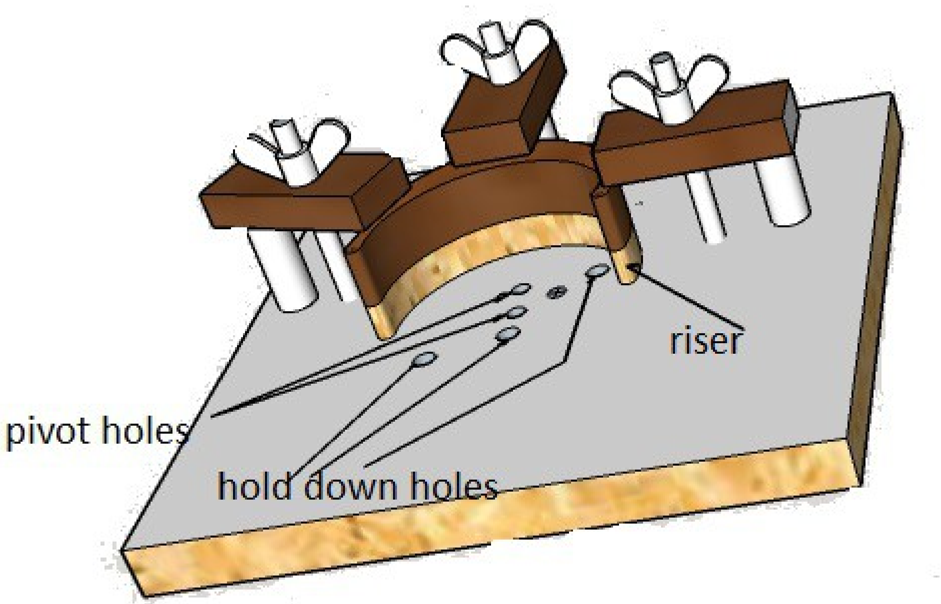


Figure 9

Typical work piece holder and pivot platform

Project dependant work piece holder and pivot platform

Looking at figure 5 you can see that the shape of the segment is fully defined by the three centres and the radii associated with them. So if these centres are drilled in the pivoting platform and the segment work piece correctly positioned (hence the alignment pins) the segment can be easily sanded to its final form. Figure 9 shows a typical work piece pivot platform.
Note that a concave curve will have its pivot point on the far side of the sanding drum and a riser is needed to ensure the entire surface of the segment is cut by the drum. The same holder and pivot platform is used to sand both the concave and convex segment sides. Finally there is a need for hold downs to keep the segment flat on the riser and the two ends stable(these can often be quite thin). Photo 1 shows a pivot platform set up for a convex cut.

To illustrate constructing a project dependant pivot platform and its use I'll go through the steps needed to make one for the 6 segment ring described above.

Making segments for the ring.

Start by making 3 copies of the design as shown in figure 7. If you are using pencil and compass to draw the design then make three photo copies of it. The 3 copies may not be exactly 1:1 copies but they will all be the same and this is important.

Segment pattern

From one of the copies cut out the segment shape including the alignment holes and the areas around them. Paste this to a small piece of 3mm MDF. Carefully mark and drill the 2 alignment holes to give a good fit to the pins you are going to use (I use pieces of 3/32 in. brazing rod). Cut the MDF closely to the outline of the segment. This pattern is not going to be used to generate jointing surfaces so does not need to be super accurate. These holes need some form of protection as the pattern will be used numerous times for this project. Drill 4 holes the same size as your alignment pins in a piece of 20 or 22 gauge mild steel and cut it into 4 strips, each strip including a hole, narrow enough to fit on the MDF pattern and about 25mm long. Glue the 4 strips to the MDF top and bottom with 5 min. epoxy. Use alignment pins to ensure correct alignment of the strips over the holes in the MDF.

Segment support riser

Clamp your pattern to MDF (or particle board) 6mm – 12mm thick. And drill the alignment holes right through the MDF. Do this drilling slowly to reduce drill wander. Mark around the pattern and cut out the riser just inside the marked line. The riser should be a fraction smaller than the final segment so the sanding drum does not touch it.

Pivot platform

Paste another design copy onto MDF (or particle board) 13mm – 19mm thick and about 200mm square. Carefully centre punch and drill the centres for concave and convex side arcs of the segment. The hole should be a good fit to the bar you are going to use for the pivots. Attach the riser directly over the segment outline with the alignment holes in the riser correctly aligned. Nails or double sided tape is good enough. Drill the alignment holes into the pivoting platform (but not right through as you will need the pins to bottom in these holes). The hold downs are short wooden bars supported at one end with a block with a coach bolt through the pivoting platform and the bar and locked down firmly with a wing nut. (see photo 1). The position of holes for the coach bolts in the pivoting platform are not critical but must not interfere with the pivot holes. Three hold downs are needed for concave cuts and three for convex cuts.

Set up disc.

Make a disc in 12mm – 19mm particle board (MDF does not sand well) with the same radius as the side arcs of the segments (in this case 38mm.) and having a centre hole to fit your pivot pins. This will be used to set up the sliding platform.

Segment first cuts

On the under side of the wood you are going to use for the segments use the segment pattern to layout, mark and drill the alignment holes. Ensure that your segment pattern is the correct way up. Mark the segments 1 or 2mm oversize to allow for sanding. Drill the holes for the alignment pins about 6 mm deep.

Drilling small diameter holes into wood is prone to drill wander, this if why I drill from underneath and only 6mm deep.

Cut and drill a segment from waste wood as a test piece.

Assembly platform.

Take the third copy of the design and paste it onto plywood. Hammer nails into the centre of each alignment mark (12 in all). These nails should stand about 5 mm proud of the board (a little less than depth of the holes in the segments). The thickness of the nails should be a little less than the diameter of the alignment holes to give some “wiggle” room during assembly and have their heads cut off.

Sanding drum

The shaft should be at least 10mm. in diameter and the drum body be solid. I use particle board discs for the body. Once assembled and turned into a cylinder, mount it into the drill press chuck. Mark the top of the drum and the drill press chuck so that the drum can be replaced in the same position. Mount a block of wood on the drill press platform to act as a tool rest whilst you scrape the drum surface to a true cylinder. Remove the drum and glue cloth backed abrasive (60 or 80 grit) on to it. Once glued bind tightly with cord and leave until the glue is cured.

Note. Cover the abrasive surface with masking tape before gluing.

Some contact adhesives “let go” at surprisingly low temperatures and I have taken to using epoxy.

Set up procedures for concave curves.

Mount the sliding platform and drum onto the drill press, lower and lock the drill press quill. Use an engineers square to check that the drum surface is at right angles to the sliding table surface. Adjust the drill press platform and/or shim the sliding platform until it is square. Now check this by placing a piece of MDF (or particle board) on the sliding platform almost against the drum surface. Take a piece of wood (ply is ok) some 50mm long, 25mm wide and 3mm thick which has one of the long edges straight. Place the piece on edge on the platform and sand its end. Do this inline with the platform feed. Repeat with another piece. Place them end to end with their long straight edges on a flat surface and check that no light shows between their ends. This check takes into account any slack in the quill.

Don't skip these steps as it is very important that the segment surfaces finish exactly at right angles to their bottom surfaces.

Using a pivot pin place the set up disc on the sliding platform so that its outside edge is close to being inline with the drum surface. Note that the pivot for a concave curve must be on the opposite side of the drum centre from the feed screw. Now adjust the feed screw until the alignment is correct. Adjust the stop at his position. When you feed the sliding platform up to the stop the pivoting platform will produce a concave curve of the correct radius. Mark the hole the pivot was mounted in.

Mount the test segment on the pivoting platform using the alignment pins and tighten the lock downs. Mount the pivot platform on the sliding platform using the pivot pin in the marked hole on the slide and the hole which is the centre of the concave curve on the pivot platform. Back off the feed until the drum can clear the segment and lower the drum until it almost touches the pivot platform. Lock the quill with the drum in this position. Advance the feed until the drum just touches the segment. Revolve the pivot platform clockwise until the segment is completely clear of the drum surface. This is the cut start position and is the only safe position to advance the feed. Feed anti-clockwise until the drum cutting edge has cleared the inside end of the concave side of the segment. The alignment pin and its surrounding wood will stop the cut going past the end of the segment and you will have to do a reverse pass to get to the starting position again. Keep control of the pivot platform as the drum can catch and throw it around. Advance the feed by only about 0.25mm (10thou) to reduce stress on the drum, jig and drill press.

As the slide approaches the stop lift the drum out of the way and check the fit of the set up disc against the concave curve just cut. (you will need to cut away a section of the set up disc to allow for the alignment pin and its surrounding wood). If the fit is correct before reaching the stop re-adjust the stop. If you reach the stop before the fit is correct back off the stop a small amount, advance the feed and re-sand. Keep going until you are satisfied with the fit. This adjustment of the stop is done only on the test segment – do not adjust it again.

Now cut the concave curve on all your segments.

Set up procedures for convex curves.

Mount the set up disc on the slide platform using a pivot hole between the drum centre and the feed screw. Lower the drum and advance the feed until the disc edge touches the drum. Set the stop at this position. Remove the disc and mark the pivot hole you used. Set up the pivot platform hold downs for the convex curve and mount the test segment. Use the marked pivot hole and the convex curve centre hole to mount the pivot platform. Lower the drum as before backing off the feed screw as necessary The cut will start with the pivot platform revolved ant-clockwise until the segment completely clears the drum. Once again this is the only position to safely advance the feed. The cut must take place against the direction of movement of the drum surface. As the slide approaches the stop check the fit of the convex curve against the concave curve of one of the segments. Adjust the stop as before as necessary. Proceed to cut all the segments.

Assembly

The problem with assembling a ring of arc sided segments is that there are a multitude of positions for which the ring will close. All but one of these will lead to closed but distorted rings. Finding even one of these positions is difficult let alone finding the one you want. Placing each segment on its respective pins on the assembly plate gives a unique and correct position for the segments. Caveat. Only if you correctly drilled the hole centres on the pivot plate and cut the curves to the right radius. If you haven't then you can still get a closed ring but it will take some fiddling to achieve and the final ring may be larger or smaller than desired and possibly not perfectly round.

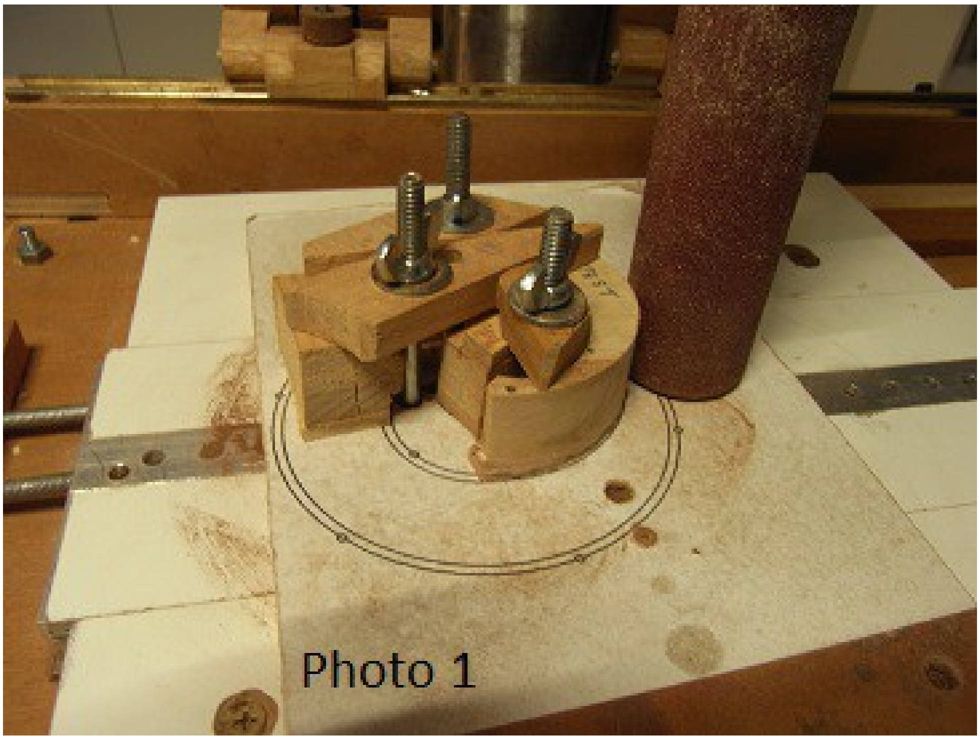
Assemble the segments onto the assembly plate and slip one or more rubber bands over the outside of the ring. Vibrate the ring by tapping with a hide faced hammer the segments should move slightly to take up some optimum position. Lift the ring off the pins and inspect the joints against a bright light. If there are unacceptable gaps try tapping again now it is off the pins. Number each segment and the direction of the numbering. Make a pencil mark across each joint at right angles to the joint. These indicate the exact relationship of each segment to its neighbours, necessary if a touch up fitting is required. If there are still unacceptable gaps mark their position dismantle the ring and **lightly** sand on the drum sander by hand.

Finally glue the ring using a non-grabbing glue for example, epoxy. Use a band clamp to provide pressure. Inspect the joints particularly near the inner edge of the ring as a band clamp will put very little pressure here. If there are gaps small clamps can be applied across the inner and outer ring surfaces. Photos 1 to 3 show various stages of these processes.

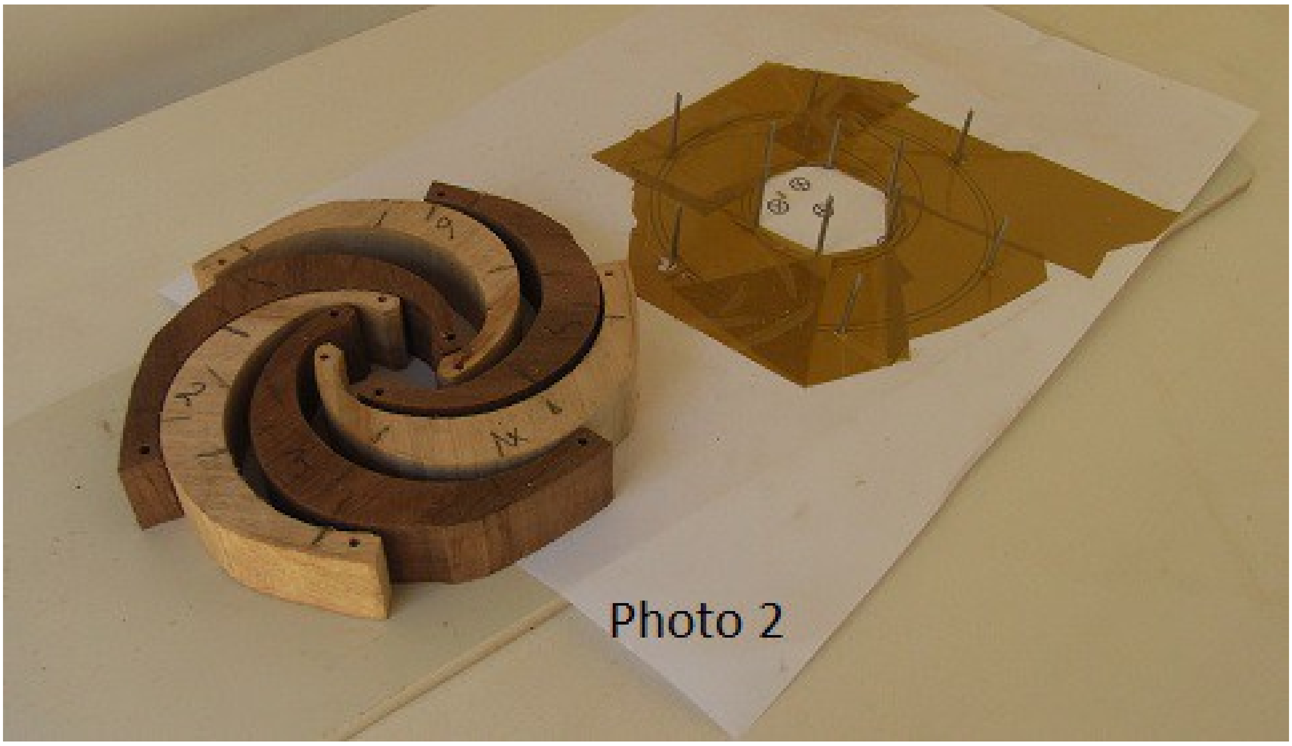
I made two such rings, cut one of them into 2 rings and stacked them. Made a base, a feature ring and a finial to make the lidded bowl (or box) shown in photo 4.

Finally I apologise for any lack of clarity in the descriptions. It has been a lot harder to write this article than it is to carry out the work. Should you have any questions please contact me via e-mail and I'll try to answer them.

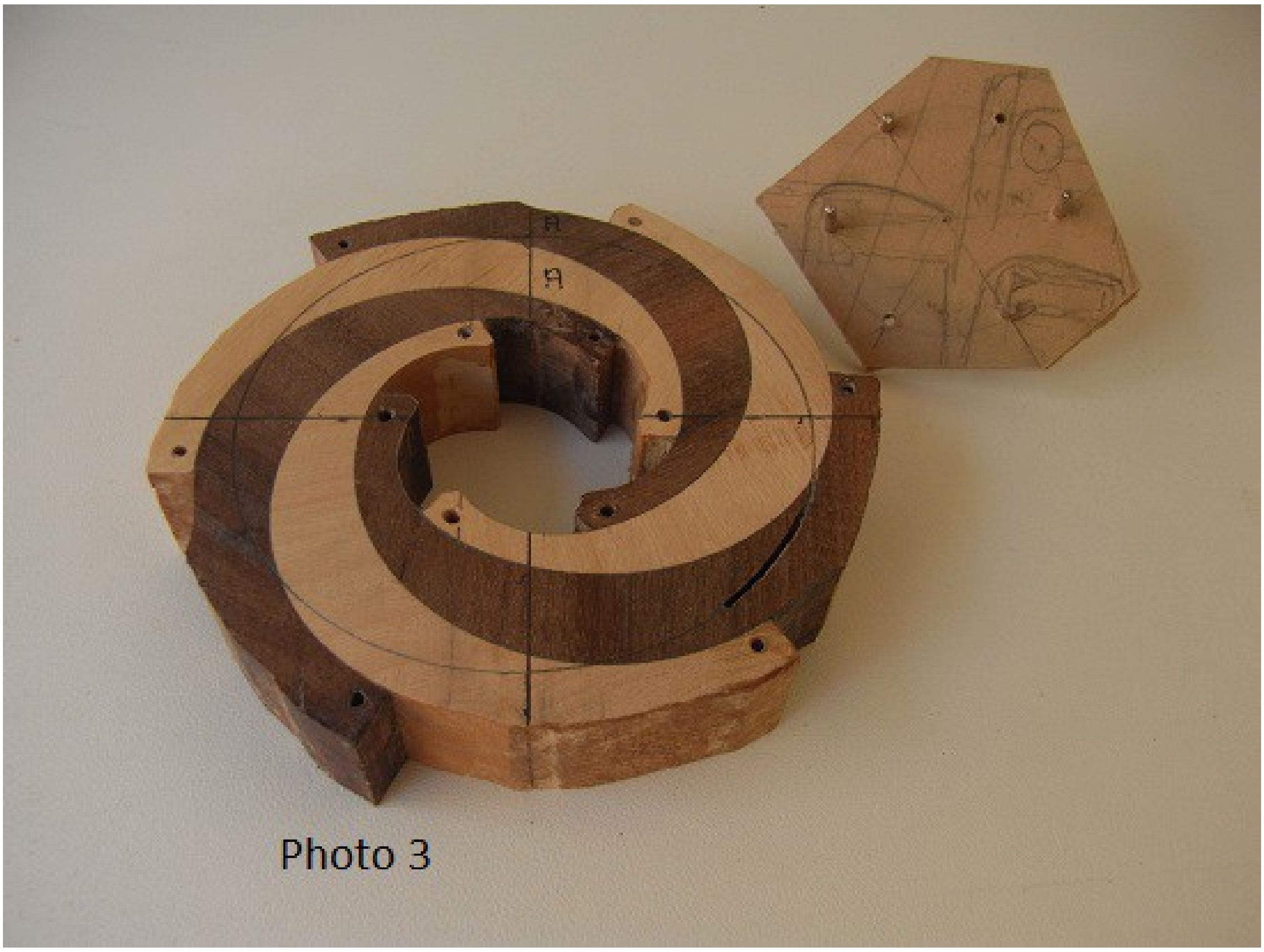
Bob Chaplin



A pivot platform set up for cutting the convex side of the segment



Segments cut, checked for fit marked and numbered ready now to be assembled on the assembly board.



The second ring glued and cleaned ready to be cut into two rings.
Notice the pre cut for the scroll saw blade. This was cut
on the scroll saw before glueing and obviates the need to drill
an angled hole.

A lidded box made from arc sided segments.