

## **CNC BASED CLOCK WHEEL CUTTING**

### **Introduction**

My inquisitive nature has driven a challenge to see how much of a traditional mechanical clock can now be made using modern CNC techniques. A major part of any clock is the wheels. (What would be known to a mechanical engineer as a gear is known as a wheel to a clockmaker). If clock wheels could be created in CNC this would greatly simplify and speed up the manufacturing process. This article records my investigation and experiments so far.

### **Traditional Method**

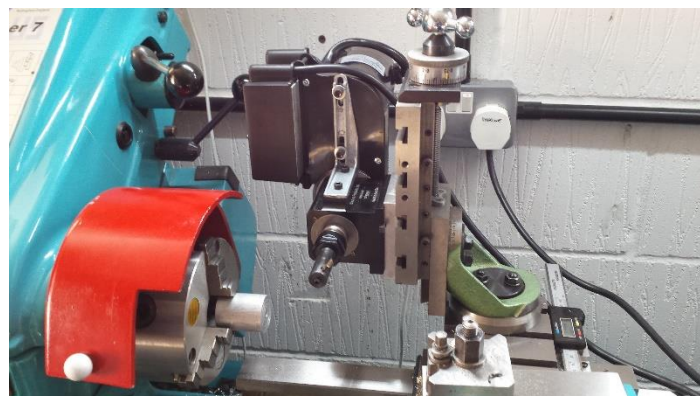
The traditional method of cutting clock wheels is to use a lathe, an indexing method and some form of cutter driven from an external source to the lathe. The wheel blank is usually a brass disc of the correct circumference to exactly match the properties and number of teeth required to be cut. The wheel blank is mounted in the lathe chuck using some form of mandrel of which a superglue arbor is the more modern method.

The indexing device is mounted such that it can turn and hold the spindle of the lathe in discrete steps. After an indexing step is made, the cutting source, usually mounted on the carriage of the lathe is passed through the brass blank and then reversed back through the blank before the chuck is incremented once again.



The wheel circumference is such that it will exactly fit the required number of teeth to the profile chosen. The profile is defined by the geometry of the cutting tool an example of which as shown to the left. The majority of wheels cut for use in a clock will have a cycloidal profile. There will be other special profiles for the escape wheel and these will require a purpose made cutting tool such as a fly cutter.

The cutting tool and its power source will be mounted on a vertical slide mounted in turn on the cross slide. Depending on the relative orientation of the various components associated with the cutting tool, the cross slide allows the cutting tool centre to be aligned accurately perpendicular and tangential to the wheel blank diameter line. The carriage allows the cutting tool to pass back and forth through the blank. The vertical slide allows the depth of cut to be defined. This setup can be swapped round if this presents a more satisfactory way of working. The picture below shows the set up on the lathe with a superglue adapter in the chuck ready for the blank wheel disc to be mounted and with a fly cutter in the cutting chuck. The cutter drive is a Sherline lathe headstock motor assembly. The cutting action in the image below will take place at 12 o'clock on the blank.



Regardless of the physical arrangement the method for setting up is the same. The peripheral edge of the blank disc is coated in a marking fluid. This could simply be a Sharpie pen. The cutting tool centre is aligned to be exactly on a horizontal or vertical diameter line and the adjustment axis used to achieve this is locked. The cutting tool is backed off and a single pass made forward and back through the blank. The wheel is then rotated one increment and a new cutting pass made.

Between the two passes there will be a visual residue of the marking pen. The depth of cut is now gradually increased until this residual marking between the two teeth is at the point of disappearing. At this stage the adjustment method used to set the depth of cut is also locked. All is now ready to cut the remainder of the teeth.

The blank is incremented and the carriage with the cutter assembly is passed back and forth to allow the cutter to cut each tooth. This is a full depth cut in one pass and its return so care is needed to not have a high feed rate and potential cause the blank to be dislodged from the mounting arbor. Fingers are usually crossed when the last tooth cut is made in the hope that the geometry and the stepping are accurate and there will be a full tooth for the final cut.

Once the teeth are cut, the wheel may or may not need 'crossing out'. This is the creation and cutting of the 'spokes' in the wheel. There will also be some form of central boss to mount and grip the wheel to its arbor (axle). Automating this process is not covered in this document.

### **Indexing**

The traditional method of indexing the lathe chuck was to use indexing plates. These consist of a circular disc with a matrix of a differing numbers of holes in circular patterns. The disc is mounted on the lathe and a mechanical device is used to lock the spindle to the appropriate circular hole pattern that suits the wheel being cut. Clearly the hole pattern must exactly match the number of teeth being cut and the pattern must be accurately spaced on the plate if the matching tooth is to be correctly spaced and cut. The operator must keep a set of indexing plates to suit all possible tooth demands.

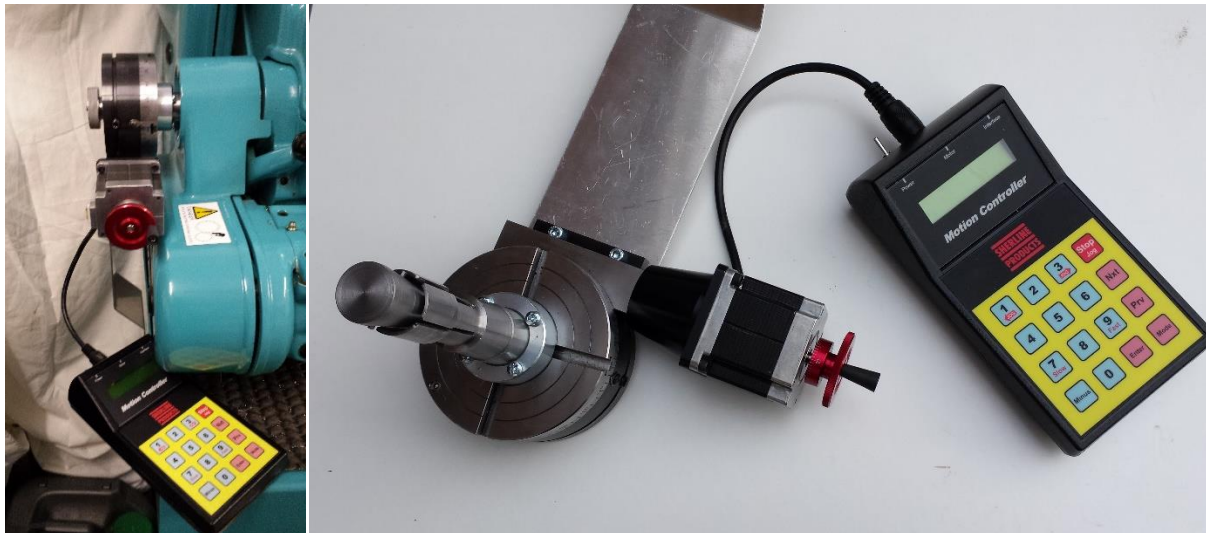


The advent of electromechanical techniques has seen a more flexible and indeed probably more accurate method for this process. There are now a number of microprocessor controlled indexing devices available on the market. These are based around a rotary table which has a stepper motor drive. The rotary table will have a worm drive reduction mechanism and the stepper motor will usually have 200 or more steps per rotation.

One such device is the Sherline CNC rotary table and this is the device I use. It has a 4" diameter rotary table driven by a 72:1 worm drive. The worm drive is driven by a stepper motor which takes 400 steps to make one revolution. This combination means that it takes 28,800 steps of the stepper motor to drive the rotary table round a single turn. This equates to 80 steps per degree or 0.0125 degrees per step.

The electronic controller for the table was designed for Sherline by Bryan Mumford and the controller allows the user to select any incremental movement of the rotary table from 1 to 999 and a similar ability to select increments in degrees. The controller calculates for a given increment request which is the best division ratio to use and this will be within +/-0.5 of one step. This equates to an accuracy at the edge of the table of 0.00022" or 0.0055mm. It is a lovely device to use.

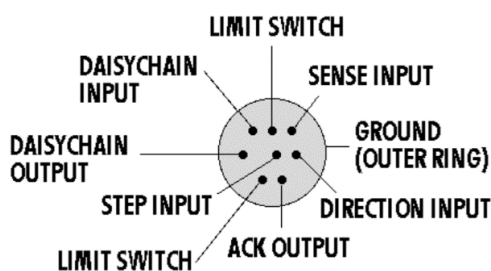
By making an expanding gripping sleeve to fit inside the bore of a lathe, the Sherline indexer can be mounted coaxially with the spindle and used to directly drive the chuck. It replaces a cupboard full of indexing plates. The indexer is shown below mounted on the end of a lathe spindle.



**CNC Operation**

Having used the Sherline indexer for some time and subsequently having purchased a Tormach PCNC440 CNC milling machine I wondered if there was a mechanism to integrate the mill and the indexer together to allow the automated cutting of clock wheels on the mill.

Discussing the idea with Bryan Mumford, he suggested I looked more closely at the handbook for the indexer as his design had allowed for a number of external interactive connections. These connections are available via an 8 pin MiniDIN connector and are shown below. The **Sense Input** when shorted to chassis would increment the table one step of the programmed division ratio. The **ACK** output can be used as a feedback handshake to indicate that an increment has completed.



Bryan suggested that a simple solution to achieve the incrementing on a CNC machine was to have a micro switch mounted on the mill table that had a known XYZ location. The spindle could be moved to this location between increment cuts to 'dunk' this switch which would in turn increment the indexer. Simple but effective.

**Tormach External Control**



My ideas took a big step forward when I discovered the Tormach USB Expansion Board.

This is a USB card having four dry contact single pole changeover relay outputs and four electronic sensing inputs. This means this card can switch on or off four external devices and the sensing inputs can act as acknowledgment flags to give feedback for an action having taken place.

The status of the inputs and outputs is defined and set by special G Code commands that are understood by PathPilot. The card clearly offered a way forward to increment the indexer and give me the potential to cut wheels on the Tormach. The card could control many activities around the mill.

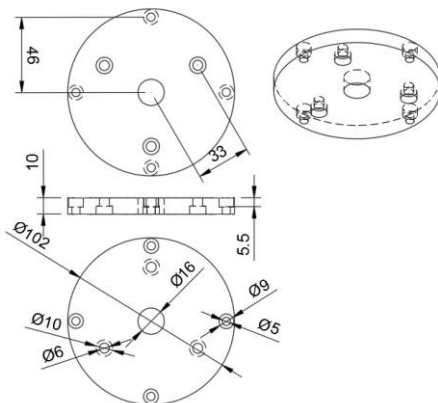
**Practical Implementation**

**1 Mounting the Sherline Indexer on the Mill**

It would be important to ensure the rotary table was firmly mounted on my tooling plate on the Tormach. My tooling plate has a matrix of M8 holes on a 25mm grid with incremental tooling pin holes within the Tormach operational footprint. I made a three part bracket with a sprinkling of holes to suit both vertical and horizontal mounting of the Sherline device. It was a bit over engineered but made use of available stock. I also added a small tray to support the Sherline control box which hangs off the front of the tooling plate.

**2 Chuck Mounting**

I use a variety of superglue arbors for holding the wheel blanks. For holding flexibility I chose to fit a small 80mm diameter chuck onto the Sherline table. In order to mount the chuck I had to make a backing plate. The chuck had three 120 degree spaced mounting holes and the Sherline table has four T slots. Holes for these are in the backing plate and these have counterbores to match. The chuck had a 16mm bore and the backing plate had a similar sized central hole.



In order to mount the chuck central and concentric to the table I made a centralising rod which is shown above. This was made from 11mm silver steel rod. This matched the centre hole in the Sherline table. The rod needs to be long enough to protrude beyond the chuck by 25mm or more. It has a short 3/8"-16 UNC thread on one end that picks up on the Sherline table central hole thread. A 16mm collar was silver soldered in place on the rod and then turned square in the lathe. The threaded section pulls this collar against the face of the Sherline table.

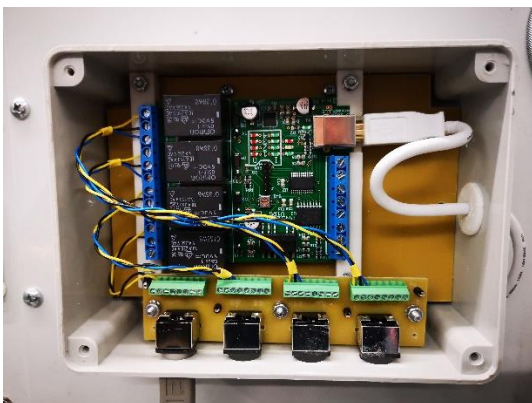
Once the centralising rod is in place and protruding from the table, the chuck and backing plate combination is slid onto the rod and chuck lightly tightened. The chuck and backing plate are then rotated round to correspond to the four T slots in the Sherline table face. The T slot screws are fitted and pick up on floating nuts in the slots. These pull the chuck assembly into position and the chuck jaws tightened before a final tighten on the T slots.

This method accurately and repeatedly positions the chuck in place centrally on the table. I cut a M6 thread in the free end of the rod to fit a M6 cap head screw. This was glued in place with Loctite and acts as the freeing mechanism to remove the rod once the chuck was positioned and fastened in place.

### 3 Tormach USB Interface

As delivered the Tormach card has a DIN rail mounting enclosure. I opted to ignore this and mount the card instead in an ABS enclosure. I mounted four MiniDIN sockets for the interface connections on a small breakout PCB. Using 8 pin sockets allowed compatibility with the socket on the Sherline controller which meant I could use a standard off the shelf cable. The 8 pin version also allows both the input and output ports, power supply etc to be accessed via each of the four connectors.

I milled a small aperture in the box lid so I could see the status LEDs on the printed circuit board and made a matching Perspex window for this.



The finished boxed assembly is mounted on the ATC blanking panel on the Tormach.

### 4 Cutter Arbor

I had bought the Tormach TTS slitting saw arbor which I had never got round to using. I made an adapter for this to allow cycloidal cutters to be mounted as a TTS device. For reference the Fusion 360 model is shown below but I made this totally on my manual lathe using a piece of hexagonal section mild steel.



It is important that the adapter runs true so the manufacturing process is important. The adapter has a M6 threaded hole in its end (RH end as shown above) and this is compatible with the TTS adapter. This end of the adapter is completed first and the opposite end (LHS) is roughly cut to shape on the lathe and then cut off to length. The adapter is mounted in the arbor and the TTS shank is mounted in the lathe with the free end of the adapter mounted in a revolving centre. The remaining cutter mounting sections are then cut to size. It is important to make sure the clearance on the cutter mounting hole is a tight fit. The cutter is held in place with a M6 nut. This completes the cutter holder adapter concept.

## 5 USB Expansion Card Programming

PathPilot recognises the four M Codes used by the expansion card. These are straightforward to use.

Outputs : -

M64 Px (where x = 0,1,2,3) causes the appropriate relay to activate and deliver a closure.

M65 Px (where x = 0,1,2,3) is the corresponding code to de-activate the relay chosen.

Inputs : -

M66 Px Ly Qz

where x = 0,1,2,3 to select which input

where y= 0 for no waiting, return immediately

where y= 1 wait for input to rise

where y= 2 wait for input to fall

where y= 3 wait for input to go high

where y= 4 wait for input to be low

where z = number of seconds to wait before flagging an error

So M66 P0 L3 Q100 means “check input #1 to see if it has gone high level and wait for 100 seconds for this to happen”.

## A Simple Program

The automation of the wheel cutting can only take place after the basic setup for depth of cut has been manually done as explained earlier. Having set the depth of cut (Y0) it would be possible to now have a variable depth of cut defined within the GCode to reference to this. This would ease the load on the cutter and the brass blank. Judgment would be needed as to whether this was merited.

Assuming a fixed depth of cut the process would be :-

- 1 Boot the mill, reset and zero XYZ
- 2 Manually perform the centring of the mid line of the cutter to the blank horizontal diameter line and set Z to zero. (Alternately you could use the process detailed below to semi-automate this).
- 3 Manually run the depth of cut checks as described above and when satisfactory zero Y.
- 4 Switch on the Sherline Indexer control box and select the number of indexing steps needed.
- 5 The mill is now ready to make the back and forth cuts and increment the indexer.
- 6 Here is a simple program to do this with explanatory notes :-

(Trial Wheel Cutting Automation)  
(Version 2 1/4/2019)

### Program Steps

(Setup)

G21  
G90  
G94  
G92.1  
G91.1  
G54  
G98  
G49  
G40  
G17  
G80

### Instructions

These are my standard Setup steps on the Tormach  
Programming in mm  
Absolute programming XYZ (type B and C systems)  
Units per minute feed mode. Units in inches or mm.  
Cancel offset and zero parameters  
Incremental programming UK (type B and C systems)  
Work coordinate systems: 1st Workpiece  
Return to Initial Z plane after canned cycle  
Tool length compensation cancel  
Tool cutter compensation off  
X-Y plane selection  
Cancel canned cycle

(Cut)

(Use Modulus Cutter as Appropriate)

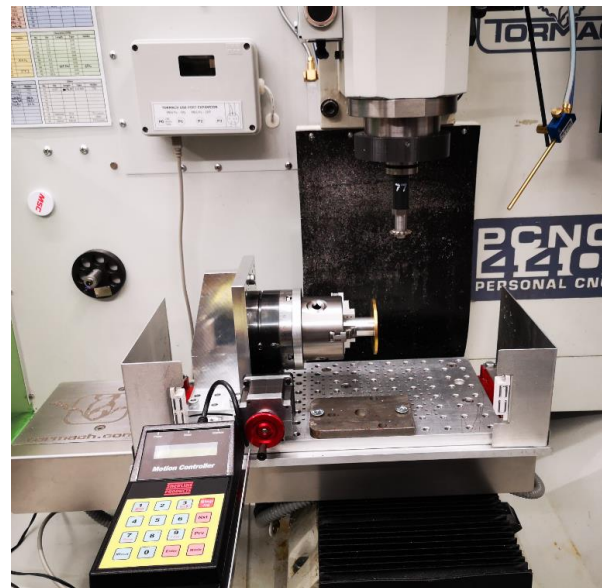
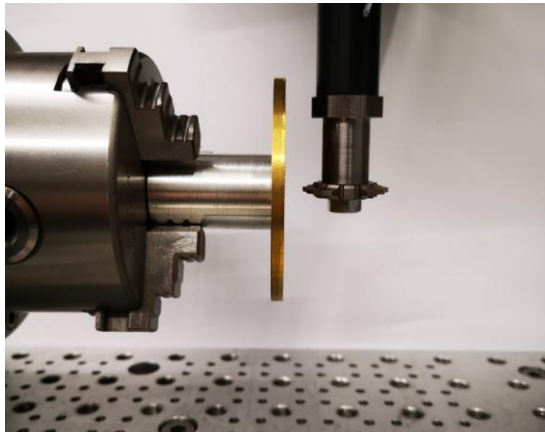
F500  
S5000  
M3  
G0 X0 Y0 Z10  
G1 X20 Y0  
M98 P1001 L5  
Z10  
M5  
G30  
M30

Feed Rate = 500  
Spindle RPM = 5000  
Spindle ON (CW rotation)  
Rapid linear motion to endpoint XYZ = 0.000, 0.000, 10.000  
Linear motion to endpoint XYZ = 20.000, 0.000, 10.000  
subroutine call to O1001 (P-word sets target). Repeat 5 times  
Linear motion to endpoint XYZ = 20.000, 0.000, 10.000  
Spindle Stop  
G28/30 home endpoint: 0, 0, 1  
End of program with rewind

O1001  
G1 Z0  
M64 p0  
G4 P2  
G1 X-5  
G1 X20  
M65 p0  
G4 P2  
M99

Subprogram Label (O number): 1001  
Linear motion to endpoint XYZ = 20.000, 0.000, 0.000  
Close relay P0 on Tormach USB Expansion Board  
Dwell: Stop for a specified time of (P)milli seconds or (X) seconds  
Linear motion to endpoint XYZ = -5.000, 0.000, 0.000  
Linear motion to endpoint XYZ = 20.000, 0.000, 0.000  
Open relay P0 on Tormach USB Expansion Board  
Dwell: Stop for a specified time of (P)milli seconds or (X) seconds  
Subprogram Cancel

This runs correctly but it will need editing on the back and forth movement needed to match the diameter of the cutter in use. ***The good part about using a sub routine is that for a change in the number of teeth being cut, only the L5 factor needs changing to match.***



### Automating the Centring of the Cutter

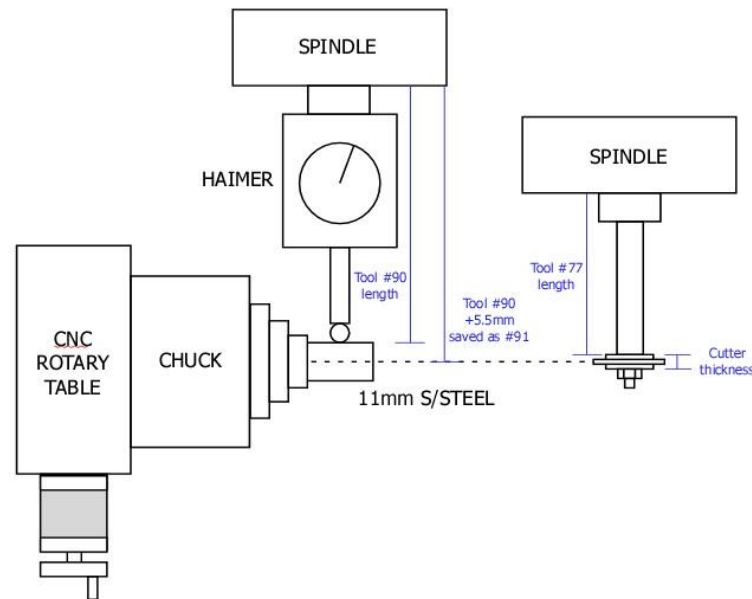
In step 2 above it is important to set the cutter centre line to be in line with the horizontal diameter line on the wheel blank. I have already described how an adapter was made to match the TTS Slitting Saw Arbor.

This centring can be semi-automated as follows :-

- 1 Mount the 11mm centralising bar already described into the chuck and engage with the rotary table central hole and tighten in place. Fully close the chuck jaws to grip this.
- 2 Select the tool number associated with your Haimer and pick up on the top surface of the 11mm bar. Rock the Y axis back and forth to ensure the Haimer is at the highest point. Zero the Z axis.
- 3 Go to the Tool Table in PathPilot and create a new tool entry with a tool length of the Haimer + 5.5mm (the radius of the bar). I entered this under Tool #91.
- 4 Select Tool #91 and using the Haimer pick up once again on the top surface of the 11mm bar. Rock the Y axis back and forth to ensure the Haimer is at the highest point. This is a check only and should read a Z value of +5.5mm.
- 5 Take the TTS Slitting Saw Arbor with the adapter in place and measure the tool height as per a normal tool measurement to the face of the adapter which the cutting tool is held against. Enter this as a new tool in the PathPilot Tool Library. I randomly used #77 and my Haimer is in #90 because my touch off probe is in #99.
- 6 There is now a fly in the ointment. I expected all the cycloidal cutters to be the same thickness. On this basis I could perform the same routine as above and create a new version of Tool #77 that had half of the cutter thickness added to it. This would have ensured that the cutter sat centrally about the centre line of the chuck centre. Sadly this is not the case so the automation stops at this point with the need to add half the thickness of the cutter being used to the #77 length. It could be automated by creating virtual versions for each cutter thickness but there were a lot of variations and it would have been a recipe for a clanger if selecting the wrong tool number.

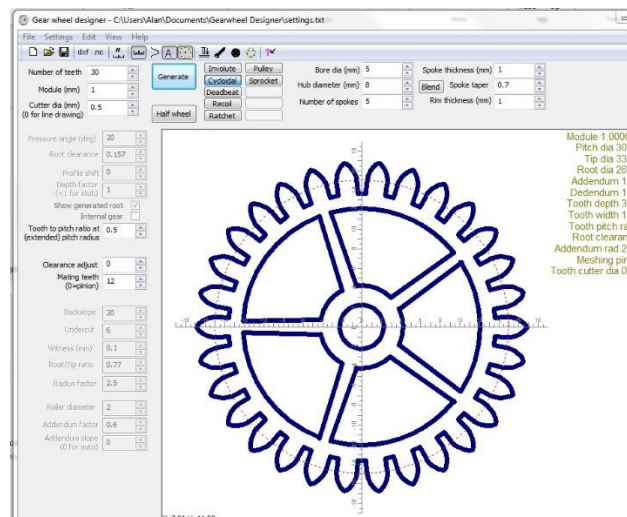


- The above hiccup aside this process only needs to be done once and it then allows a quick centralising of the cutter on the chuck centre and therefore the wheel blank centre. The image below shows this setup.



### Gear Wheel Cutting Software

In detailing this procedure I need to mention a fully integrated software package that allows a completed wheel to be fully machined by a CNC mill. I have used this program extensively and find it excellent in the quality of wheel produced. It allows the programming of all manner of cutting actions that might be envisaged including mounting holes for the central boss, crossing out the wheel etc. It also has options for the inclusion of mill start up routines, tool table etc



I have found it particularly good for wheels being cut on very thin sheet where small diameter carbide bits are needed with only short lengths of cutting edge. It might not be so attractive on very thick materials such as used in turret clocks. As a tool it is another weapon in the armoury of the clockmaker and does not detract from the process as detailed above but more a compliment to it.