Intro to CNC- Using the SainSmart 4040-PRO Rotary axis

By Graham Bland. You can find me on the Facebook group SainSmart Genmitsu CNC Users Group All comments, suggestions and corrections are welcome.

This is my first attempt at using a rotary 4th axis so please bear with me and if you know better please correct me.

This is a 'getting started' guide, it goes through how to make two sample projects, one engraved around the axis, the other requiring full 4th axis machining. Even if you don't make these projects the processes and workflow should apply, in the basics, to any other rotary project.

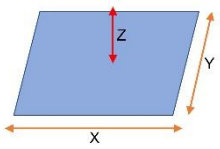
There is some duplication here from my review, such as reversing the chuck jaws… If you have read the review then I apologise, just skip the relevant sections, To make it easier to skip, if needed, the sections from the review are in grey text.

Please read the Grbl settings though, my thoughts have changed since the published review as I have used the rotary axis more!

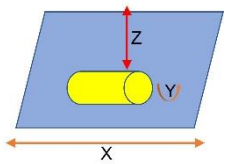
What is a 4th rotary axis?

Firstly the 4040-PRO is currently unique in the SainSmart range in that it has support for the 4th axis on the control board. Often a rotary axis is plugged in to the Y axis stepper cable once the bit has been centred above the rotary axis, the movement of the bit in the Y axis is 'simulated' by the rotation of the stock.

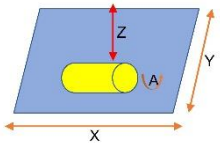
'Normal' 3D routing involves the end of the bit being able to be positioned in the X, Y and Z axes. In other words it can move freely in three dimensions. If you want to produce a cylinder then you will have to mill the top half, turn the stock over, re-align it and then cut the bottom half. Tricky and tedious to get right.



Often rotary attachments plug the Y axis into the rotary which effectively wraps the Y axis movement around the surface of a cylinder. The actual Y axis movment is disabled and the position of the bit is fixed over the top of the cylinder. This is the way that a rotary roller normally works.



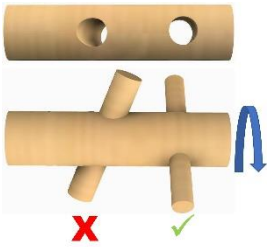
A full rotary axis adds a 4th axis, the Y axis is not disabled and can be moved as well, for example machining the top and bottom of a surface is possible, not just wrapping the machining around a cylinder. It can be turned to create angled pockets or expose another surface to be fully machined.



This on the 4040 PRO is a full 4th Axis! In the GCode it is refferred to as the A axis, rotation around the X axis.

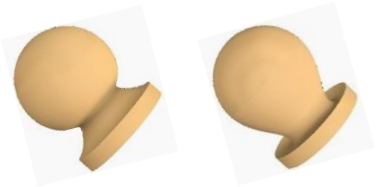
Limitations of a 4th Axis

The bit will always be vertical with regards to the rotary axis, Taking the example in the picture you cannot cut the left-hand hole, this would require a 5th axis to rotate around the Y axis as well! The bit cannot align with or reach through the hole. There is a possibility of machining the part with the rods, but you will not get any bit to produce crisp corners.



The hole on the right is aligned with the rotation of the A axis can be cut easily, it doesn't even have to be at the centre of the stock.

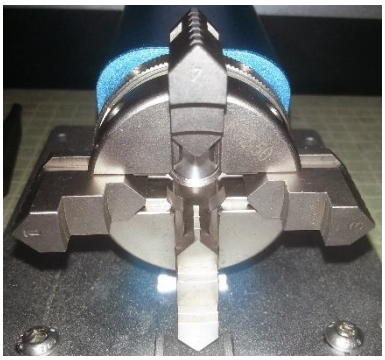
Perhaps a better example is these two knobs. The left hand one can be cut, no parts will be underhung *(an underhang is a place that the bit cannot reach using a straight bit as it is under another feature)*.



The one on the right however has a recessed base, the bit, moving vertically will not reach into the recess. This is a limitation of using any 4th rotary axis.

BUT the non-underhung knob can be machined in a single operation without machining half, turning the stock over and cutting the other half which means working out how to align and secure it.

Chuck



Already mounted onto the motor this is a K02-50, a 2-50mm diameter 4 jaw geared chuck.

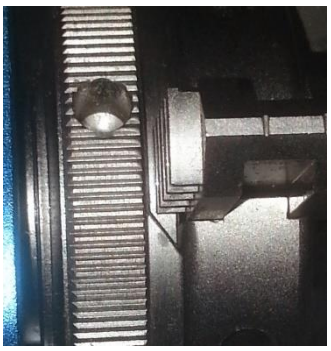
At first glance this will only take stock from 2mm (0.08“) to 24mm (0.94“) diameter. But the jaws are easily reversed as in the right picture, giving a maximum diameter of 55mm (2.17“)

I am using my measured values which are slightly higher than SainSmart says. To be safe use their values, the differences are small and I don't support the warranty!

The knurled collar at the rear is used to open and close the jaws, once the jaws are snug on the stock by hand, then use the chuck keys, one in the collar and one in the chuck body to tighten or release the stock.

The centreline of the rotational axis is 40mm (1.57“) above the top of the baseplate, (50mm (1.97“) above the router bed). This would allow stock up to 80mm (3.15“) diameter to be used with an adapter or some machining at the end of the stock to form a cylinder which would fit in the chuck.

Maximum opening



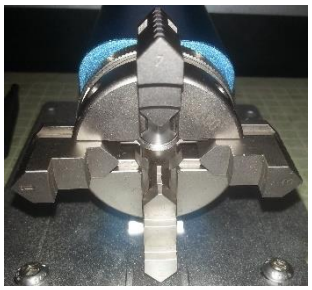
The chuck jaws are opened and tightened by the teeth at the base of the jaws fitting into spiral grooves on the chuck plate, there are 5 teeth on each jaw.

At all times all teeth must have at least 2 teeth in those spirals to mount the stock securely, if not the jaws may not hold the stock square and can ‘wobble’ even after they are tightened, and are more likely to work loose during machining.

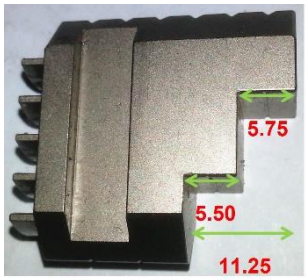
The picture shows the chuck jaw ready for removal with 5 ‘teeth’ showing.

With the chuck fully open the edges of the chuck jaws will collide with the top of the axis baseplate, do not force them past, if you need to rotate the chuck when fully open tighten the jaws a little, then rotate the chuck and open them again. They will NOT collide at the maximum usable diameter!

Reverse mounting the jaws

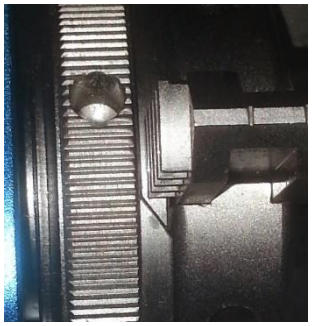


Using reverse mounting (*A simple process, it’s called reverse mounting as the jaws are reversed in the chuck mountings.*) of the jaws increases the maximum stock diameter which can be clamped. See Maximum Stock Sizes below.



The price paid is that while normal mounting allows a 14mm (0.55”) clamping length on the stock, when reversed the outer jaw has a 5.75mm (0.23“) clamping length while the inner jaw is 5.5mm (0.22“) but will take 11.25mm (0.44”) of the stock before it clears the jaws.

How to reverse the Jaws



Use the knurled knob to fully open the jaws and move the slot (diagonal line in the picture) just past a jaw with all 5 teeth on the bottom of the jaw showing, the jaw will now slide out of the side of the chuck. Rotate the knurled knob anti-clockwise by 90° so the next jaw can be removed. Remove each jaw in turn. The chuck may be a little stiff, especially when new so you may have to use the chuck keys but do not force the chuck. *Also beware of the outside of the jaws catching on the top of the baseplate, when fully open they will!*

Once all the jaws are removed*, you do have to remove all 4 before re-inserting them,* reverse each one so the stepped side is toward the centre of the chuck and re-insert each one in turn rotating the chuck clockwise by 90 each time.

IMPORTANT NOTE: The jaws are numbered on the top, 1,2,3 and 4 they are all different in the position of the teeth on the base of the jaw which engage with the threads on the chuck plate. They MUST be re-inserted in the correct order.

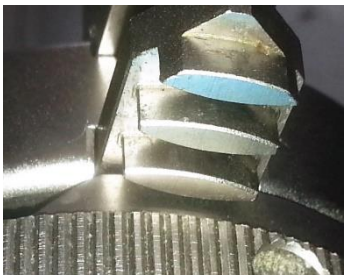
Normal mounting, with the long jaw to the inside, when fitted the numbers increase in the Clockwise direction with 1 and 2 bracketing the K02-50 engraving on the chuck plate.

For reverse mounting with the long edge of the jaw on the outside the order is also reversed, when fitted the numbers Decrease in the Clockwise direction with 4 and 3 bracketing the K02-50 engraving on the chuck plate.

There may be other orders possible but this order works!

A certain amount of wiggling and rotary adjustment may be needed to remove and reseat each jaw.

Once all the jaws have been reversed and re-fitted rotate the knurled clamping knob by a minimum of 2 full turns clockwise to make sure the jaws are securely seated. Each jaw must have at least 2 of the teeth on the base are within the 'thread' of the chuck, a maximum of three teeth outside.



To check the alignment and the correct order of the jaws fully close the chuck, the centres of each jaw should come together evenly in the fully closed position.

Maximum Stock Sizes

I measured the jaw openings for each configuration.

Measurements are in mm and (inches)				With Tailstock		Without Tailstock	
Jaw Mounting	**Min Diameter**	**Max Diameter**	**Jaw Length**	**Min Length**	**Max Length**	**Min Length**	**Max Length**
Normal	2 (0.08")	24 (0.94")	14 (0.55")	0	110 (4.3")	0	210+ (8.3")
Reverse (Inner)	18 (0.71")	39 (1.54")	11.3 (0.44")	0	110 (4.3")	0	210+ (8.3")
Reverse (Outer)	34 (1.34")	55 (2.17")	5.8 (0.23")	0	110 (4.3")	0	210+ (8.3")

NOTES:

- Min and Max Lengths are from the end of the Jaws, add the Jaw length, the length of stock which will be inside the jaws, to determine the actual stock length.
- The maximum unsupported length is determined by the actual cutting area of your router and the size of the bit being used.
- Some of these values are slightly larger than SainSmart quotes but only by a few mm. SainSmarts values are safer, mine are at the absolute maximum I consider possible.
- The absolute maximum diameter of stock which can be used is 80mm (") this would require some sort of adapter or cutting a round boss at the end of the stock which would fit in the jaws.

The jaws could also be used to clamp the inside of a hollow object, such as a tube, as long as the hollow is straight but I have not tried this yet

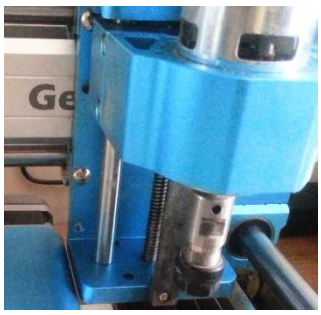
Mounting and Alignment of the Rotary axis

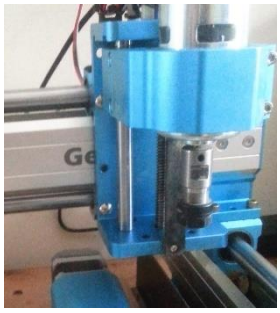
The centreline of the 4th axis along the X axis needs to be parallel to the height of the Z axis as it moves along the X axis, so if you have not fitted and surfaced a spoilboard this is a good time to start. I am assuming here that the top of the bed/spoilboard is level with the movement of the Z axis. If you don't have a surfaced bed/spoilboard you can add shims underneath the mounting holes and check the bedplate alignment with the router Z axis to make sure it is level.

Setting the Motor mounting height

Before fitting move the motor Z frame to its highest setting, this gives an extra 20mm of clearance below the spindle and means the frame will clear the top of the 4th axis.

At the low setting (left pic) the Z frame base won't clear the top of the rotary axis, regardless of what motor you have, and a collision may occur.

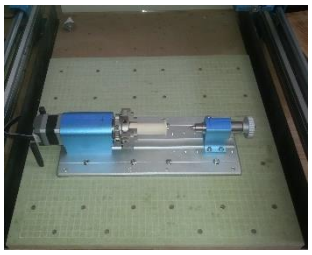




Where to put it

The mounting slots are designed to fit the 4040-PRO bed holes with the rotary axis in the middle of the bed along the X axis, stepper to the left, closest to the control box. Place it in position and loosely tighten all 8 mounting bolts. Where you mount it on the Y axis, front, rear or somewhere in the middle is entirely up to you.

I mounted it at the front middle of the cutting area.



I may change my mind on this in the future, mounting at the rear would make it harder to get to, but it would also mean I could use the front of the router to make small 3D carves without removing the axis first, it could also be mounted at the front for the same reason. Either way the motor mount will have to remain in the top position to avoid collisions.

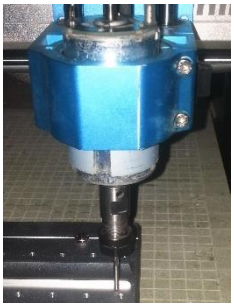
Aligning the rotary axis along the router X axis

I strongly suggest that before measuring things you check the alignment of the X axis carriage is correct, both Y gantry carriages are the same distance from the back frame.

The X axis alignment is fairly critical and needs to be done as accurately as possible so that the bit will follow the centre line of the rotary axis as it moves along the X axis.

To make life easier when aligning remove the tailstock and move the chuck jaws to the smallest position.

If you have a lever action dial gauge which can be placed in the motor mount that will be the most accurate method, but while I have a dial gauge it is not lever action so I am using a manual *(paper)* method, as I think most people will. This method is accurate, not quite as good as a dial gage but perfectly adequate.



The best place to measure the alignment is along the edge of the centre bar where the tailstock fits, this is the most accurately machined and as it is used to align the tailstock and motor housings along the rotary axis bedplate this position is ideal.

Place a bit long enough to reach the top of the rotary axis bed plate with the Z axis of the router jogged down. I used a standard 3.17mm flat end bit, **but mount it upside down so the round smooth end is at the bottom, otherwise the flutes on the bit will give you variable readings.** *For safety I also disconnected the spindle motor.*

Jog the bit over the rotary axis bedplate and then jog it down so it is nearly touching the top of the bedplate.

Oops! *I have already raised the Z plate so a 'standard' length bit won't reach the top of the bedplate, I was a few mm short! If this happens there are 3 possible solutions which can be used, together if needed:*

- *Slide the bit down in the collet a little*
- *Slide the motor down in its mounting a little.*
- *Use a longer bit, if you have one a 3.175mm (1/8") drill bit could be used in a standard collet.*

The lowest the bit has to travel when rotary machining is normally to the centreline of the axis, the highest will be a maximum of 40mm above that. So, after positioning the bed, the motor can be moved to its normal position withing the housing.

Now position the bit so it is just touching the edge of the bedplate centre bar at the front right-hand side.

I use the paper method for accuracy, place a thin piece of paper between the bit and the edge so that while there is a little friction between bit and bed the paper can be moved. This is more accurate than estimating contact by eye, it allows you to sense that the pressure needed to move the paper is the same at each position, if just using direct contact then it is more difficult to determine exactly the point where contact is made as the bit can be deflected slightly.

Adjust the position of the baseplate (and/or the Y axis position of the router) so that the end of the bit is just touching the edge of the centre bar Tighten one of the end bolts a little to keep the baseplate in place while allowing just a little rotational movement.

Once a position at an end has been set do not adjust the Y axis at all. Now jog along the X Axis to the left end of the centre bar and move the bed plate to align that end. Once you are happy carefully tighten all the baseplate bolts, then recheck the alignment at both ends.

To make life easier for when I remove and replace the rotary 4th axis, I have marked a line onto the spoilboard around the bed plate. This will make the process much easier when re-mounting it (until I re-surface or replace the spoilboard), the alignment will still need checking, but just checking!

Setup and Testing

Testing is good just to make sure it works; the DIP switches are set correctly and the router control board is configured correctly.

Offline Controller Note

I have an offline controller with the axis, its useful and convenient for me. This is currently running Version 2.6 of the firmware which also affects the 4040-PRO router control board.

The Offline Controller has in its settings a Mode, set to 3-Axis or 4-Axis. This affects the operation of the Grbl on the 4040-PRO router control board.

In 3-Axis mode:

- The $$ settings command WILL NOT return any settings specifically for the 4th axis.
    - These can still be changed by the $x=nnn commands, they are just not displayed.
- GCode commands to move the A axis are still accepted and acted on.
- Status reports from the router to another GCode sender WILL NOT include position information for the 4th axis.

At the moment I believe there is no way of setting the axis mode on the 4040-PRO controller board without using the Offline Controller. IMHO this is a major error and I have let SainSmart know.

I believe the default for the board is to operate in 4 axis mode, but I did not record my setting before the last time I updated the firmware so I am not sure.

Updating the firmware

The Offline controller allows updating the firmware on the controller and the Grbl version at the same time which is very useful, but an update could change Grbl settings in the future!

To update the firmware, you need a micro-SD card of 16Gb or less formatted as FAT32.

The card supplied with the offline controller can be used but you may need to reformat it to FAT32 first. *The one supplied with mine was formatted to FAT, not FAT32, but reformatted without a problem.*

1. If you want to save any files from the SD card copy them to a safe place first!
2. Updating the firmware **can** alter the Grbl settings on your 4040-PRO, so connect a GCode sender to the router, send it a $$ command to display all the settings and copy them to a text file and save it in a safe place.
3. Take a note of any Settings on the offline controller, especially the Z-Probe details, these could also be changed by the update.
4. On your PC either delete all the files on the SD card or if needed re-format it to FAT32.
5. The firmware is supplied as a .zip file, within the .zip directory structure find the directory which contains firmware.bin, there will be lots of other .bin files in the same directory.
6. Extract or copy all the files in that directory to the root directory of the SD card.
7. Power off the router, disconnect any USB cable and place the SD card in the Offline controller.
8. Connect the Offline controller to the router.
9. Power on the router.
10. The update process will start automatically and progress will be displayed on the offline controller.

11. Do not power off the router until the process is complete! If power is lost before completion for any reason just restart the process.
12. When complete remove the SD card from the offline controller and delete all the firmware files from it, they are no longer needed.
13. If you have the rotary axis connected then check that in the settings on the offline controller the Mode is set to 4-Axis.
14. Also check that the Z-Probe settings are also correct for your router.
15. Power off the router and connect a GCode Sender program to the router board via the USB cable then power the router back on.
16. Note the startup version displayed by Grbl will have changed, the $$ settings will also be displayed.
17. Compare any changed settings with the ones saved earlier. **It is possible that settings have changed for a reason so change any values back carefully.**

Basic Testing

Connect the rotary axis motor to the control board and Candle *(UGS is better if you have it installed, or another GCode sender)* to the router via a USB cable. *The offline controller cannot easily be used for this as it does not display the current coordinates in the Jog menu (V2.6) and will not display or change the Grbl settings. Any Offline controller should be disconnected, or at the least not be used, when a USB cable is connected.*

Checking Grbl Settings

Controlling the 4th axis adds some extra parameters to the GCode used for a full 4th axis operation. All this is based on the Grbl version used on my 4040 motherboard *(V2.6)*.

I have been informed by SainSmart that a new update to the firmware is being developed but as yet there is no release date set as yet. This will primarily affect the offline controller but could also make changes to Grbl on the 4040-PRO Control board.

The 4th axis is controlled by the A axis in the GCode, just as G1 X2 will move the X axis by 2mm G1 A2 will turn the rotary axis by 2°. *The position of the rotary axis is set in degrees, not mm as the descriptions suggest, mm makes no sense on a rotary axis.*

Before using the rotary axis make sure the settings are correct in the 4040-PRO board.

Even though it does not support a 4th Axis Candle can be used for this. *If you already have another GCode Sender installed such as UGS then that can also be used, the process will be the same but the details will be different.*

NOTE: There are some differences here from the published review!!!!!

Display the Grbl settings by sending a $$ command to the router, this will display the current values of all the settings. To change a setting send $nnn=value command to the router where nnn is the setting number.

$1 (Step Idle Delay, ms)

This is the time delay in ms after which a stepper motor will be unlocked and so be free to be manually turned. Setting this to 255 disables this delay so the stepper motors will always be held in position. I have seen the rotary axis being turned slightly by the indexed rotary cutting process. Since leaving the steppers permanently locked this has not re-occurred. I suggest setting $1=255.

The settings relevant to the rotary 4th axis are:

$103 (A axis pulse:step/deg)

The value **MUST** be 177.777

$113 (A axis Max rate:deg/min)

The default value is 1000.

This results in a very slow rotational speed, nowhere near the maximum of 300 °/sec. After testing the maximum rate is easily achievable, this works out to a maximum rate of 18,000 °/min. I have changed mine to 18,000 and I suggest you do the same.

$123 (A axis acceleration:deg/s^2)

The default, value is 20.

After some testing this is very slow, especially with the higher Max Rate of 18,000. You can see the axis accelerating to get up to speed. I have changed this to 200 °/sec^2 which is still quite conservative. Much faster values are possible but there is a drop off in any benefit to be gained at higher rates, hence the conservative 200 °/sec^2.

$133 (A axis max travel:deg)

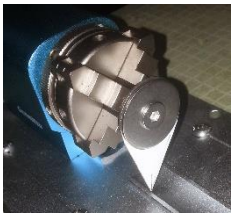
The axis will continuously rotate but the position is recorded, if you rotate by 100 revolutions in one direction (36,000°) there is still a zero position held.

The default setting is 9999, my suggested value is 360000 which is 1,000 revolutions.

There is really no practical limit, it will just keep on rotating. Grbl does have a limit on the size of the numbers it can handle though, this is well within that. This value is not significant unless soft limits are turned on!

Testing Rotation and direction

Clockwise and anti-clockwise are defined when looking into the face of the chuck!



While I am just testing, not calibrating, I built my *(non-patented)* rotation marker from a piece of cardboard between two washers and a nut and bolt from my spares box. But this should allow me to set a fairly accurate rotational position, using an edge on the centre block is ideal!

If you are just checking yours noting the position of the chuck jaws is quite sufficient.

Direction tests

Note the position of the rotary axis then send G92 A0 to the router to set the zero position of the rotary axis.

Send G91 G0 A90 to the router, the rotary axis should turn 90 degrees clockwise. *The G91 says movement values are relative to the current position, G90 would use absolute values from the origin.*

Send G0 A-90 to the router, the rotary axis should turn 90 degrees anti-clockwise rotation returning to the start position. No problems were encountered.

Accuracy


I set the starting position then sent a G0 A36000 command, this will rotate the axis by 100 full turns, the end position should be the same as the start position. *(This takes a while!)*

At the end I couldn't tell the difference between the positions (the end of the pointer relative to the bedplate) not bad after 36,000°. *Any visual difference is more to do with my lack of photography skills than the position.* Definitely mine passed!

You can do a test with fewer revolutions *(G0 A720 will just make 2 revolutions which is much quicker)* which will show any obvious errors. You don't even have to make the pointer, just look at the alignment of the chuck jaws relative to the Baseplate at the start and end positions.

If the end point is not as expected then check the DIP switch settings on the stepper motor and the Grbl $103 setting.

Initial setup, Making things easier!

Setting some of the zero points for a rotary axis is a little trickier than a standard XYZ setup, I am looking for ways to make this easier for me by recording them.

NOTE: HOME POSITION, I have my home position set to the Top, Rear, Right ($23=0) and my homing pull off set to 1mm ($27=1). If your 4040 has different settings then these measurements will be wrong! Some of them need to be verified by you anyway and set for your mounting position.
If the home position of the router is changed (23), the homing pull off distance is changed ($27), the steps/mm for the XYZ axis ($100-102) is changed or the rotary axis is moved or removed and replaced then some of these measurements will have to be redone as all of them use machine coordinates!
The Z Offset to Centreline values from the top of the Motor housing and tailstock though will remain unchanged as it is just the difference between two coordinates on the rotary axis itself.

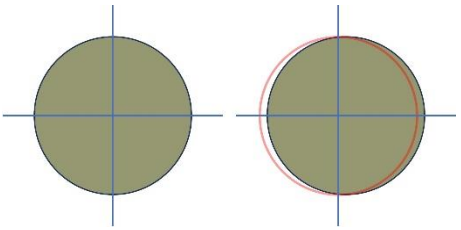
If the axis is removed and replaced using the same mounting holes then the only measurement which should need updating is the Y coordinate of the rotational centreline.

Y and Z Zero

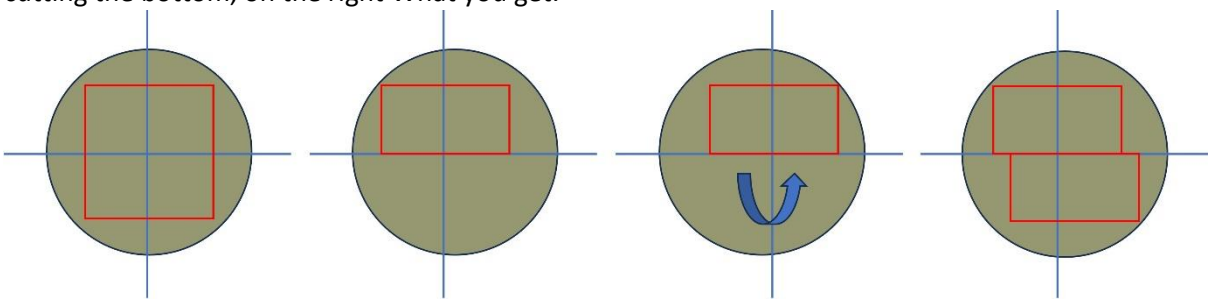
There are three main requirements for accurate rotary machining, carving or engraving:

1. The centreline of rotation must be aligned along the X axis
2. The position of the Y zero point must normally be along the centreline of rotation.
3. The position of the Z zero point must normally be along the centreline of rotation.

If one of the Y or Z axes are misaligned and you are using a wrapped operation (XZA) then you will see something like this. The red line shows the actual rotation of the surface of the cylinder. The bit will rise above the surface at one side and cut too deep at the other.



If you are using an indexed operation (XYZ and A) and the Y zero coordinate is wrong then the results will be something like this. From left to right – What is wanted, cutting the top, rotating by 180° and cutting the bottom, on the right What you get.



I am just showing a 2-sided operation, cut the top, then rotate by 180°….

if both the Y and Z axes are misaligned or if the rotary axis itself is misaligned with the X axis it gets much more complex!

Setting these zero points accurately is just as essential as for example cutting a groove round the edge of a chopping board, misalign the board along the X axis and the groove will be skewed, set the Y axis zero wrong and the groove will not be in the centre of the board….

It's just that with a rotary axis as the centreline of rotation is an invisible line setting the zero points is much trickier, especially as all the dowels I have are not perfectly round, close but not exact.

Setting Y and Z Zero by measurements on the rotary axis

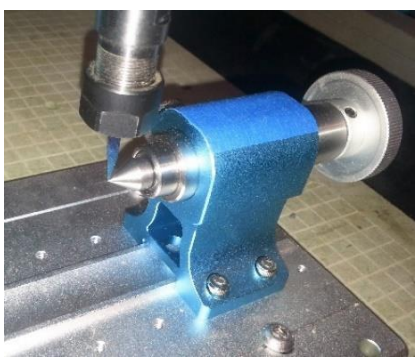
The rotary axis is effectively a single part. Once it is aligned and mounted on the bed then the Y and Z zero positions on the rotary centreline will not change!!

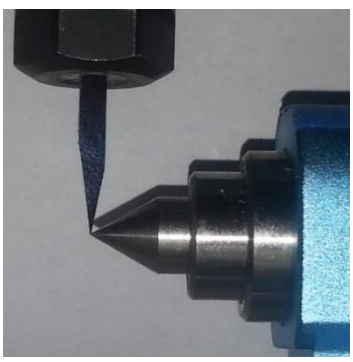
Also the position of the Z and Y axes zero points relative to the construction of the rotary axis will not change, even if has been removed and then re-mounted.

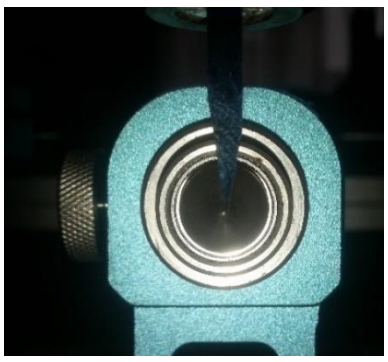
I measured as accurately as I can to points on the construction of the rotary axis and the distances from those points to the centreline of rotation noting the Machine coordinates for each position.

While the measurements are tedious to make it does make it easier to set it up for a second time though. Read this section through first before starting, there are not that many measurements that You should need to make yourself, actually just one!

The Tailstock has a pointy end, I visually aligned the tip of a bit (*I used a new 20° V bit so that the end point was narrower and sharper)* with the point of the tailstock along the X, Y and Z axes by homing and then jogging (all you need to do is measure and record the Y axis coordinate). And noted the machine coordinates. *Beware of parallax when sighting!* Get the tip of the bit as close to the tailstock point as possible to reduce these errors.







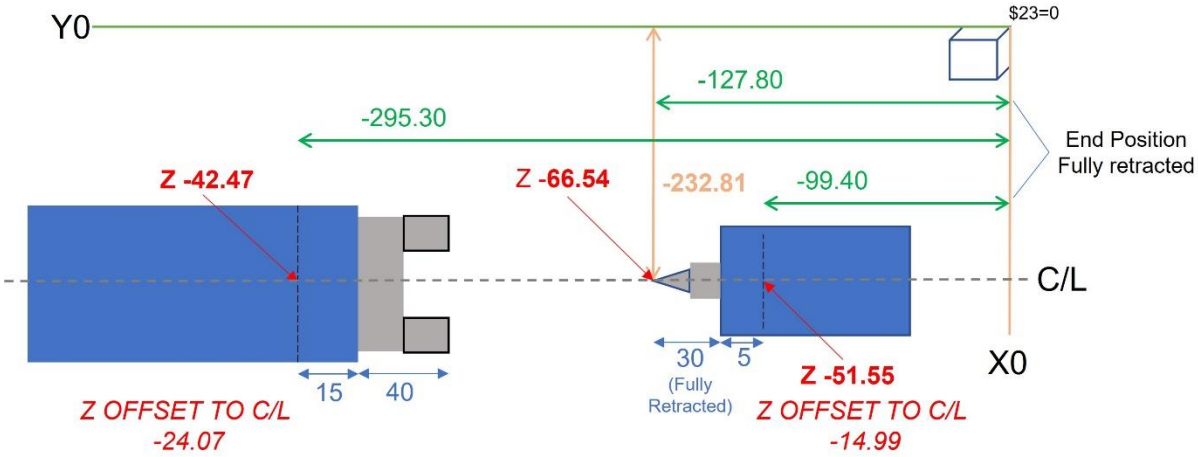
The images show the alignment of the tip of the bit to the tailstock point.

I then took more measurements and recorded the machine coordinates in Candle using a bit in the same way, for some non-critical ones I just used a ruler.

There is an alternative method of measuring the Y axis Zero, both the motor housing and the tailstock slide along the machined block on the bedplate, this is 20 mm wide. Mount a bit, upside down so that it is round, and measure the Y machine coordinate of the rear edge then the Y zero coordinate will be Position at the back – Bit Diameter/2 – 10. I actually did both and the results only differed by 0.02mm.

The Z position of the top of the tailstock housing and the top of the motor housing were determined using the paper method but using a feeler gauge for better accuracy.

These are my results:



NOTE: All Z measurements will depend on the length of the bit and where it is mounted in the chuck. This is not a problem as all I need accurately is the <u>difference</u> between the axis centre and the top of the housings.

Why the detail?

There are only two critical values I needed to measure.

- The position of the centreline of rotation on the Y axis.
- The Z offset from the top of the motor housing to the centreline.

The rest are not critical but they will be useful as I plan to set up some macros to, for example, position the bit for probing the height at the top of the motor housing. *I have recorded some X coordinates because I was there anyway and it makes this guide look 'more mathematical'.*

For everything else approximate measurements are good enough. *The X values only apply if you have mounted it on a 4040 using the Bedplate mounting slots on a standard 4040-PRO*.

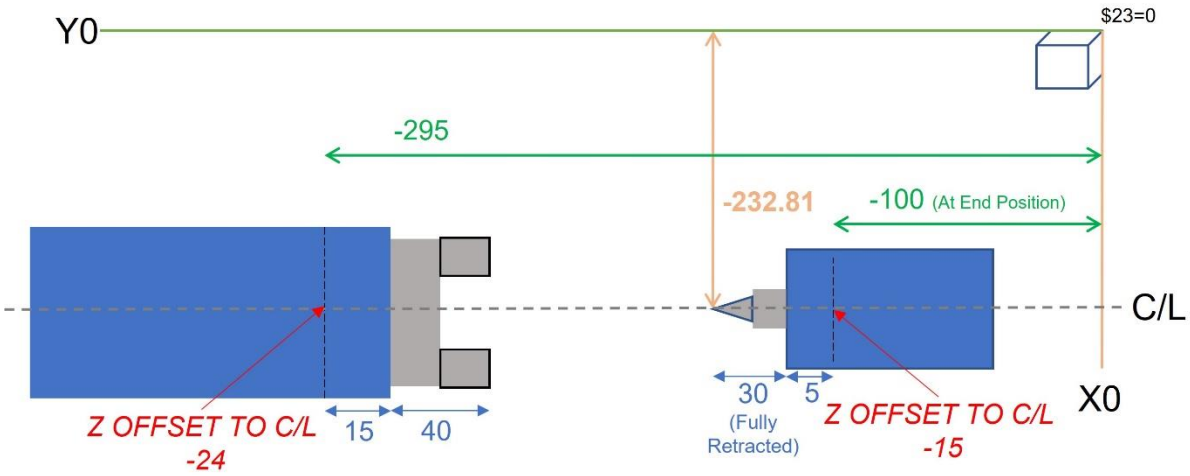
Simplifying things

NOTE: In my experience designers prefer to use round numbers in their designs! If something measures at 24.07mm or 14.99mm it is a fair bet that the value used in the design was 24mm or 15mm. I am rounding my measurements and assuming they were out by a few 1/100ths of a mm and that the manufacturing tolerances are tight, which is not a bad guess.

I am happy to accept 24mm as offset from the top of the motor housing to the centreline *(it's 3/1000 of an inch out!)*. From the top of the tailstock, I am happy using 15mm.

The X coordinates are not critical so they can be rounded without a problem.

The simplified results.



From here on I am going to use these simplified values.

NOTE: This does give me a theoretical maximum stock length without the tailstock of ~250mm Measured from the chuck jaws to the edge of my cutting area, not the 210mm SainSmart quotes.

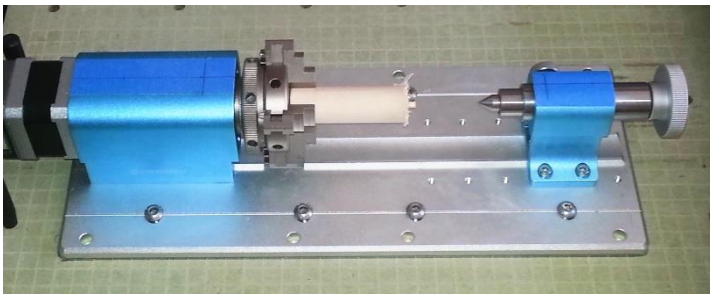
I am measuring the distance from the top of the motor housing to the centreline for the very simple reason that I can sit my Z probe base on top of the motor housing and set the centreline Z zero from there! See the Macros below.

Marking the centreline

It's not necessary but it may be useful in the future, I am going to mark the centreline along the top of the tailstock and motor housings. As everything is still shiny, I have used a piece of blue tape on the top to allow a pencil line, when I am sure my measurements are correct, I may use a V bit to make a very fine engraving.

Jog the bit along the X and Z axes only, make a mark where the tip touches the motor housing at the left and right sides and draw a line between the points. Repeat for the Tailstock housing.

The advantage will be that when mounting stock I can see the centreline by sighting down from a straight edge, not totally accurate but better than nothing!



I have drawn a line around the bedplate on the spoilboard to make re-mounting it in the future a little easier.

Macros

I am going to create some macros. *I am using the Macro term very loosely! They are small GCode files which can be run from the offline controller or your Gcode Sender, or the contents can be incorporated into a macro or feature of your Gcode sender depending on what you use.*

NOTE: Most of these must only be run when the current home position is accurate. ***The home position will be inaccurate if a homing cycle has not been completed, after a reset or if any limit alarm has been raised.***

If using the offline Controller

As the offline controller does not support macros, I have copied the GCode files to the SD card. To execute just run the relevant file, there is no need to do any setup, apart from homing. Just go to Prepare, Start Project, load the file and run. *Part of the reason for setting these up is that the offline controller does not currently show work or machine coordinates while jogging making it very difficult and tedious to go to a pre-defined position.*

Either use the supplied files, suitably edited for your values, or open a text editor and copy the commands into it, substitute any relevant values, then save the files to the offline controller SD card. *I have provided suggested names only because I will reference them in this document. Call them anything you want; I have started all the names with RM- for Rotary Macro or M- for generic macros just to make them easier to find.*

If using another GCode sender

Please see the instructions for the relevant GCode sender to see if it supports macros and how to set them up, if it does not support macros then just create the files on your PC and run them as if they were a job.

NOTES:

- ***There are probably more macros than I need here but I have tried to cover all possibilities.***
- ***Y Zero***
  - ***Most operations on the Rotary axis set the Y zero coordinate along the centreline of rotation. I can't see the case for not setting this or changing it and it doesn't harm to set it repeatedly.***
  - ***The G10 L2 command is used because the G92 command cannot be used with Machine coordinates. However once set this is persistent, it will remain set after a power off or reset so must be manually cleared, for example when removing the rotary 4th axis and reverting to 3 axis use.***
- ***Tool offset and Z Zero***
  - ***If the position of the Z-Zero point is along the centreline of rotation this is tricky to set accurately, especially if changing the bit between passes.***
  - ***I find the easiest way is to set the Z-Zero position somewhere else, the top of the motor housing is perfect, and then apply a tool offset to set the Z zero at the top of the housing.***
  - ***The tool offset then moves the effective position of the bit at Z zero to the centreline.***
  - ***BUT if you are not setting Z-Zero at the centreline, maybe on the top of the stock then the tool offset needs to be zero.***
  - ***The tool offset is cleared by a reset, but not by a homing cycle.***
  - ***I have added a piece of tape to the top of my housing, it's ~0.1mm thick, this needs to be factored into the height of my Z probe base.***
- ***WCS Origin***
  - ***It is assumed the default G54 origin is being used and is not set explicitly.***
- ***Substitutions***

    - ***Before using any of these macros change the -232.81 value in the code for your measured distance on the Y axis to the centreline of rotation.***
    - ***If you are using your own measurements or values change any green values to your measured values.***
- ***Files***
    - ***I have created files for all the suggested macros using the suggested filenames. I have tried to keep the filenames to 18 characters, excluding the extension as this is the limit the Offline Controller will display on the Start Menu.***

Using any of the RM- macros requires a valid machine position, in other words a Homing cycle must have been run!

Macro – Setup for Laser

Suggested filename: M-SetupLaser.nc

Purpose:

Setup the 4040-PRO for using a Laser, the Grbl Laser mode setting needs changing and I also set the maximum and minimum spindle speeds I normally use with a Laser. Substitute your preferences as required.

- Set Laser Mode ON and max and min spindle speeds for Laser Power.

GCode:

```
$32=1                ; Set Laser mode ON
$30=1000             ; Set maximum spindle speed for Laser Power
$31=0                ; Set Minimum spindle speed for Laser Power
```

Macro – Setup for Spindle

Suggested filename: M-SetupSpindle.nc

Purpose:

Setup the 4040 for using a Spindle Motor, the Grbl Laser mode setting needs changing and set the maximum and minimum spindle speeds. Substitute your preferences as required.

- Set Laser Mode OFF and max and min spindle speeds for the normal spindle motor.

GCode:

```
$32=0                ; Set Laser mode OFF
$30=9000             ; Set maximum spindle speed
$31=1500             ; Set Minimum spindle speed
```

Rotary Macro – Clear All

Suggested filename: RM-Clear All.nc

Purpose:

The method used to set the Y axis centreline on the 4th axis is persistent, once set it will remain set even after a reset or power off. When removing the Rotary Axis this sets the Y zero point back to the machine zero and clears any Tool offset without moving any of the axes. If you remove the rotary axis I suggest you run this.

- Set the Y-Zero position WCS offset back to zero.
- Clear any tool offset.

GCode:

```
G10 L2 Y0                ; clear any Y zero WCS offset using M/C Coordinates
G43.1 Z0                 ; cancel any tool length offset.
M30                      ; End Program
```

Rotary Macro - Set Y Zero and Clear Tool offset

Suggested filename: RM-Set Y0_Clr TO.nc

Purpose:

To setup using the Rotary Axis For when you want to manually set the Z position, set the Y zero point and clear any Tool offset without moving any of the axes. n.

- Set the Y-Zero position to the rotational centreline.
- Clear any tool offset for any Z-Probing method.

GCode:

```
G21                      ; Units mm
G10 L2 Y-232.81          ; Set Y zero on centreline using M/C Coord
G43.1 Z0                 ; cancel any tool length offset.
M30                      ; End Program
```

Rotary Macro - Set Y Zero and Set Tool offset

Suggested filename: RM-Set Y0_Set TO.nc

Purpose:

To set the Y zero point and Z axis offset from the motor housing to the centreline without moving any of the axes. For when you want to manually set the Z position at the top of the motor housing AND the Z-Zero position is on the centreline of rotation.

- Set the Y-Zero position to the rotational centreline.
- Set the tool offset from the motor housing to the centreline.

GCode:

```
G21                      ; Units mm
G10 L2 Y-232.81          ; Set Y zero on centreline using M/C Coord
G43.1 Z-24               ; Set Z offset from Motor Housing top to Centreline
M30                      ; End Program
```

Rotary Macro – Setup for ZProbe on Housing

Suggested filename: RM-Set H ZProbe.nc

Purpose:

To set the Y zero point and position the bit to the probing position above the motor housing with the relevant tool offset set. Follow with the '*RM-H ZProbe.nc*' macro or set Z zero at the top of the motor housing manually.

- Raise the Z axis to a safe height to prevent any collisions.
- Set the Y-Zero position to the rotational centreline.
- Move the X then Y axes to the defined position above motor housing for probing.
- Set the tool offset so that the Z zero will be at the rotational centreline allowing manual setting of Z Zero.

GCode:

```
G21                      ; Units mm
G53 G0 Z-3               ; Raise to a safe height
```

```
G10 L2 Y-232.81          ; Set Y zero on centreline using M/C Coord
G53 G0 X-295             ; Go to probe start X Machine coordinate
G90 G0 Y0                ; go to the Y0 position
G43.1 Z-24               ; Set offset from MHousing top to Centreline
M30                      ; End Program
```

After running:
Place the Z-Probe base, attach the probe clip and start a Z-Probe cycle (or use another method) to set the Z-Zero position at the top of the motor housing. The tool offset will convert the Z zero position at the top of the Motor housing to the rotational centreline.
If you are not using the *RM-H ZProbe.nc* macro to set Z Zero jog the bit past the chuck jaws to avoid a bit breaking collision with the jaws after setting Z Zero.

Rotary Macro Z Probe on housing

Suggested filename: RM-H ZProbe.nc

Purpose:
Perform a probe cycle, with the bit pre-positioned over the motor housing, using the Z-Probe base *(the position can be set by running the RM-Set H Zprobe.nc macro)*. The resulting Z-Zero position is set to the centreline of rotation. This does not use any tool offsets which will be cleared.
NOTE: The positioning of the bit and the probing are in two macros to allow the probe base to be positioned and the clip attached to the bit.

- Clear any tool offset.
- Set the Y-Zero position to the rotational centreline.
- Run a Z-Probe cycle using the probe base at the top of the motor housing.
- The probe base height is set to be the distance from the top of the Z-Probe base to the rotational centreline.
- Raise to a safe height to allow the probe base to be removed and provide clear movement to the stock.
- Move the bit back over the stock to clear the chuck jaws.

Extra Substitution:
The height of the probe base needs setting to the total distance from the top of the probe base to the Z Centreline of rotation. in this case change the 35.98 value in the code for the measured thickness of your Z-Probe base PLUS the Z Offset value *(with no – sign)* to the centreline. *My Probe base measures at 11.88mm Plus a 0.1mm piece of tape (11.88+24+0.1 = 35.98)*.

GCode:

```
G21                      ; Units mm
G43.1 Z0                 ; Clear any tool offsets
G10 L2 Y-232.81          ; Set Y zero on centreline using M/C Coord
G91                      ; Use relative positions
G38.2 Z-35 F150          ; Probe down
G0 Z3                    ; Back off
G38.2 Z-4 F20            ; Probe down slowly
G92 Z35.98               ; Set Z Zero from the top of the probe base to the rotation axis
G53 G0 Z-3               ; Raise off the probe to safe height
G53 G0 X-235             ; Move bit over the stock clearing the chuck jaws
M30                      ; End Program
```

Rotary Macro – Lathe

Suggested filename: RM-Lathe.nc

Purpose:
To rotate the axis at maximum speed in an anti-clockwise direction. This allows you to use sandpaper or other tools to finish a round surface including using a cut off saw while allowing the rotary axis to do the hard work! *This really only makes sense if the maximum rotational speed and acceleration values have been updated in Grbl.*

- Set rotation in a counter clockwise direction for 1 minute as fast as it will go (50 RPM).

GCode:

```
G92 A0                  ; Set any A axis position to Zero
G0 A-18000 F18000       ; Rotate for 50 revolutions, (1 minute)
G92 A0                  ; Set the end A axis position to Zero
M30                     ; End Program
```

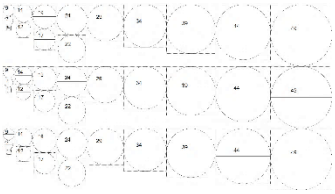
NOTE:
*To increase the duration of the rotation, change the A-18000 value to a higher or lower number. Rotation is at 50 RPM so 2 minutes would be 50*360*2 = 36000. You could even create multiple macros like RM-Lathe_1.nc and RM-Lathe_2.nc*

Setting up a job

Marking the centre point on a cylinder

There are mathematical methods which can be used to find the exact centre of a circle but they involve multiple lines and right angles which are tricky to use on small circles due to the size of the rulers, squares and the thickness of the lines involved. I find these to be impractical and inaccurate when used on small circles.

For small cylindrical stock I use printed guide on the end of the stock. *The human eye is good at centring two objects of a reasonably similar size around the edges, not quite so good at guessing the centre of a circle. Well, at least my eyes aren't!*



Print the 'Centre Finders for 4th Axis.pdf' on an A4 sheet of thin card or paper (no scaling). Cut out the square closest to but smaller than the actual diameter and poke a small hole at the centre mark, just enough to make a pencil mark through.

Align the edges of the circle so that it is in the centre of the stock *(A dab from a glue stick can make this easier)*. Now the centre point is at the centre of the diagonals. Mark it with a sharp pencil. *Or just leave it in place if glued on.*

For larger stock I normally use this square to mark lines across the centre, draw multiple lines and where they cross is the centre. *I got this from SainSmart but unfortunately it is now discontinued.*

Mounting the stock

Cylindrical Stock

I am assuming that the cylinder being mounting is straight and uniform, if it resembles a banana then I wouldn't use it.

- Set the chuck jaws according to the diameter (see Reverse mounting).
    - 2-22mm use the normal mounting position, 14mm of the stock will be in the chuck jaws.
    - 18-39mm use reverse mounting of the jaws and the inner step closest to the chuck plate, 11.3mm of the stock will be within the Jaws.
    - 34-55mm use reverse mounting of the jaws and the outer step away from the chuck plate, 5.8mm of the stock will be within the Jaws.
    - 55-80mm diameter you will have to use an adapter plate OR cut a round boss at the centre of one end so that it will fit into the chuck.
- At the other end (assuming the tailstock is being used) mark the centre of the stock. *Hard stock will need a small hole drilled.*
- Place the end of the stock in the jaws and hand tighten.
- If being used, position the tailstock and extend the point, aligned with the centre mark at the marked centre point, to either fit into the hole or make a small indentation. *Even if you are not using the tailstock, as in the drawer knob project, I still find it worthwhile, if possible, to mount the stock as if it were ging to be used, and only remove it after the chuck jaws have been fully tightened. This improves the alignment of the stock along the rotary axis.*
- Tighten the chuck jaws to firmly clamp the stock.
- Check the alignment visually by turning the rotary axis.

Other shapes

I have not tried any yet but I am thinking either make and use an adapter plate or cut a round boss at the end of the jaws. It is a 4-jaw chuck so you could secure square stock directly into the chuck, but I think alignment and stability may be difficult to get right.

Setting zero positions on the axes.

All the zero positions are dependent on your CAM software settings, but for a 4th rotary axis;

- Y Zero is normally at the centre line of the axis rotation.
- Z Zero is normally at the centre line of the axis rotation.
- A Zero, if you are using a cylinder, is normally irrelevant but it is worthwhile zeroing it to the current position to prevent unnecessary rotations. For other shaped stock, or if needed, align the stock and zero the A axis.

The X Zero position will depend entirely on what position the CAD software used and where you want it on the stock.

I normally set the Z-Zero position in the job to be at the centre of the rotational axis and use the *RM-Set H ZProbe.nc* macro followed by the *RM-H ZProbe.nc* macro to set the Z Zero position to the centreline of the rotary axis. These also set the Y zero position to the centreline.

That just leaves setting the A zero position and the X axis zero position manually, jog to and then set the X Zero and A Zero points depending on the zero positions of your job.

Using Multiple Bits, Roughing and finishing passes.

Assuming the Z zero is set on the centreline, just run the *RM-Set H ZProbe.nc* macro followed by the *RM-H ZProbe.nc* macro to set the Z Zero position leaving the X, Y and A Zero coordinates unchanged. If not just repeat the process you used to set the initial bit Z Zero position.

Software

Back in the dim distant past a programmer would take the blueprint for the part and then write the GCode to machine it, my first exposure to GCode was in 1975! Nowadays we use CAD/CAM software to perform the same task far more accurately and much faster!

Just a comment but the use of a full 4th axis on a 'hobby' router is still at the early days but there is reasonably priced and free software available for 'hobby' purposes. As the 4th axis becomes more popular in the hobby market I expect all CAD/CAM vendors to improve their support for a rotary axis.

CAM Software

Computer Aided Manufacturing, this takes a design produced by a CAD program (Computer Aided Design), takes the design and the details, such as stock size, required to turn the model into the instructions required to machine it.

I am just looking at the CAM options here.

Fusion 360

The 'Personal – Hobby' licence does not have any features available for a rotary 4th axis. Even with a paid for licence the full 4th axis CAM options require an extra payment to activate, the price they are charging is far too steep for me to consider, well over £1,000 a year plus the standard licence cost. Even Wrap text on a cylinder requires a paid subscription so sorry, I am not going to be using it for rotary axis machining. I will still however continue to use it to design, but will export the projects into other CAM software.

Carveco

Supports wrap around machining on a rotary axis, but I want full 4 axis machining!

DeskProto

This is the best rotary axis CAM software I have found.

A fully featured CAM program. there are no design/CAD features but will import a model (AI, DXF, EPS and STL) or bitmap (BMP, GIF, JPEG, PNG and TIFF) and generate the toolpaths, both 2D, 3D and 4th axis *(even for 5th axis)*, needed. It runs on Windows, MacOS and Linux.

It offers full 4th and 5th axis support, not just wrapping a design around a cylinder. *But like any other software it has some limitations and although easy you still have to learn how to use it.*

My initial opinion is that it is very simple to use, it has excellent wizards which lead you through the steps from importing a design to generating the toolpath and the help is the best I have ever seen!

DeskProto offers a number of licences, all of which are perpetual, and includes both educational and hobby (non-commercial) licences. My Hobby licence with full 4th *and 5th* axis support is ~£220. It allows a small number of sales (<€3,000 per year) within the hobby licence.

The basic version is free with a perpetual licence with some more advanced features restricted. It runs on Windows, MacOS and Linux. *In the free version the multi axis version is also available in a trial mode, this is fully featured BUT a watermark will appear in all your simulations, parts and toolpaths. To remove the watermark, you are going to have to buy the licence. Please see their website* https://www.deskproto.com *for full details.*

I am using the DeskProto 7.1 Multi Axis Edition Hobby Licence for all the projects using the Rotary 4th axis, it is the best one I have found which I could afford! *(DeskProto did kindly donate a licence to me so I can remove the watermarks!)*

Lasers

Lightburn does support a rotary axis for Lasers, this is wrapping the engraving around a cylinder. Again I have not had the time to try this out yet myself but Crystal Rabbon has produced a video https://www.youtube.com/watch?v=jYM4syVLJDI which goes through the setup of the Rotary axis in Lightburn. Thank you, Crystal, for permission to use this here.

Others

I have looked for other options, but all are beyond my price range or do not respond to customer enquiries so I have ignored them.

There are many others out there, please let me know if there is one you can recommend.

GCode Senders

This is the software that will take the instruction file for the router and send it, these will also offer options to set up the router, setting zero coordinates etc and may provide other features such as a visualisation of the machining toolpath…

SainSmart Offline Controller for the 4040-PRO

Not only an offline controller but one that supports 4th axis rotary operations such as zeroing the A axis and setting coordinates for the X, Y, Z and A axes. I have produced a separate review of this. It does have some limitations however as all Offline controllers I have seen do in that it does not display or allow you to change the Grbl Settings and as yet I think the firmware is immature.

SainSmart says that that the Offline Controller is the only sender to support the rotary axis, not quite true, but so far it is the only way I have found to enable the Grbl 4th axis reporting on the 4040-PRO controller board. But having said that this is what I have used for running the sample projects.

Candle

3D only, still useful though as a simple mechanism to view and modify the machine parameters, it will send 4 Axis GCode files via the console pane but the visualisation, jogging etc do not support the 4th axis and there is no way to control or set up the 4th axis, apart from sending manual commands.

UGS

Supports a 4th axis fully. *As long as the router board is in 4-Axis Mode!*

Others

There are many out there but UGS and Candle are the ones I normally use, some of the other options support a 4th axis, some do not.

Setting up DeskProto

This is what I decided to use, with a perpetual licence I can afford!

First download the Multi Axis edition suitable for your computer, *or the free version which has a Multi Axis trial included*, from the DeskProto Website and install the software. In the initial setup select the Machine ‘SainSmart Genmitsu 4040-PRO (mm)’ *or the inch version* and units you want to use. *All my sample projects are in mm!*

NOTE: For A axis rotation DeskProto follows a standard "Positive rotation is defined as a counterclockwise rotation looking from X positive towards X negative" (EIA Standard RS-274-D). When looking at the chuck jaws from the tailstock end G0 A90 should rotate the axis by 90° in a counterclockwise direction. The standard rotation of the SainSmart Rotary 4th axis is the opposite of this! The latest versions of the DeskProto SainSmart postprocessor files already have this change.

Setup Files

DeskProto has recently added the machine and postprocessor definitions for the SainSmart 4040 PRO with the rotary 4th axis. If you can't see these in the Library of Machines then update to the latest maintenance release.

For the Machine select 'SainSmart Genmitsu 4040-PRO(mm)' this references the 'SainSmart (GRBL) – mm' post processor. *Inch variants are also available.*

For the bits I am using I have provided the configuration files which can just be copied into the DeskProto Drivers directory These are located in the 'DeskProto Drivers' directory of the .zip file.

To find your DeskProto Drivers directory go to Options / Library of Cutters and select Open location. This will open a file explorer window in the Drivers directory. *The same directory is used for all definition files for machines, post processors and bits.*

Type	Filename	Description
Cutter	SS_70SB17.ctr*	SainSmart 70SB17 3.175mm Ball nose, 2 Flute.
Cutter	SS_70SF17.ctr*	SainSmart 70SF17 3.175mm Flat end, 2 Flute.
Cutter	SS_TR10A.ctr	SainSmart TR10A 3.175mm Triangular 30°V bit, 3 Flute.

*** The stickout and cutting lengths have been modified in these definitions for use with a 45mm diameter dowel.**

NOTE: After copying the files DeskProto must be restarted for them to become visible.

Other bits can be substituted if needed, but the basic types and dimensions should remain the same to use the supplied Gcode.

General Notes

Material Size.

Quite rightly DeskProto will not allow an operation to exceed the material size, this could be because of a number of things, changing a tab, bit and many others. If the material size or area has been manually set then an error will be generated. However, if in the part the material is set to 'Use whole geometry' and the operation areas are set to 'use material block' then the material block size will be adjusted instead. You can switch the settings back to custom at will and just adjust the necessary parameters, in this case the diameter of the block, but not the length.

Vertical Surfaces

(If your model does not have vertical surfaces, it will not be affected)

DeskProto uses a Z net method of calculating toolpaths, this method does not allow the same XY position to have differing Z heights. The side effect is that vertical surfaces are not machined vertically.

This can be corrected though. Double click on an operation or right click and select Operation Parameters. In the Roughing Tab check 'Protect Vertical Surfaces' or for a finishing operation in the

Advanced Tab select ‘Assume Vertical surface……..’ and set the ratio. *Do not select both! See the help for an explanation of the differences and ratio.*

Chains and .nc files

Operations can be added to a chain, multiple chains can be used, each chain will produce a single .nc file by default. *If different bits even within a chain the .nc file will also be split into multiple parts one for each bit to allow manual tool changes to be made.*

Help

In the Wizard hovering the mouse button over the ? icons shows a quite comprehensive help for that setting, clicking Help shows a more comprehensive help in a new window.

Sample Projects

The router I am using is a standard 4040 with the supplied 775 motor as it came out of the box. ***The only modifications are a 6mm spoilboard, surfaced, engraved and trammed, and dust baffles.*** **If you have upgraded the spindle motor on yours then the layer heights and feed rates can be adjusted accordingly.**

NOTE: The projects went through a few attempts to get them right. I did not necessarily take detailed photos each time so some of the photos may be of early iterations, there should only be minor differences!

All these projects were designed and machined using mm as the measurements and mm/min for feed rates.

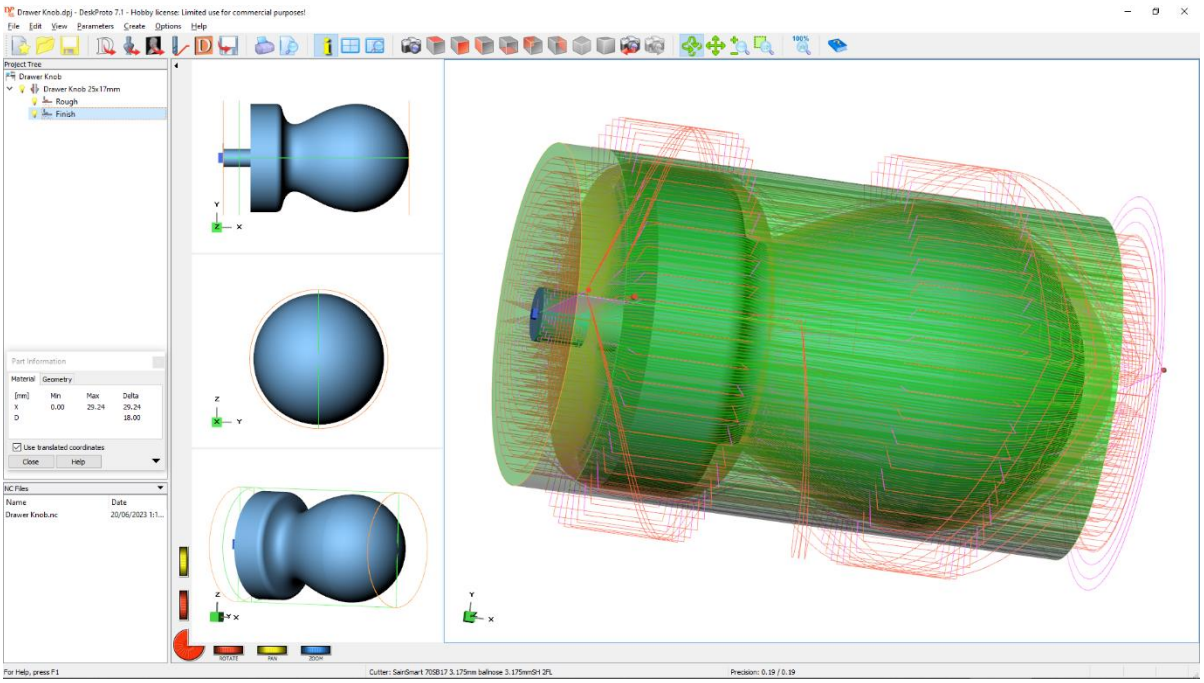
All the models were designed in Fusion 360 *(free hobby/personal version)*, exported as .stl files which were imported into DeskProto. The built in Wizard interface was used to set up the projects with a few tweaks in the parameters using the standard interface.

While this is not intended as a DeskProto manual that is what I used to create these projects and as the way I work is to make notes as I succeed (or fail) so there are a lot of DeskProto project notes included here.

Drawer knob

A very simple uniform curved shape, a small drawer knob. This is machined using a wrapped 4th axis or in DeskProto using the rotation axis (XZA paths). *In a wrapped operation rotation of the A axis is substituted for movement on the Y axis which remains unchanged.*

This uses the same 3.175mm ball nose bit for both roughing and finishing making it a simple project.



Project files

Type	Filename	Description
Model	Drawer Knob.stl	Model for a small drawer knob (17mm Diameter, 25mm long).
Project	Drawer Knob.dpj	DeskProto Project file.
Gcode.nc	Drawer Knob.nc	Grbl Gcode file for roughing from an 18mm diameter dowel.

Material and Scaling

The model has a maximum diameter of 17mm and the length is 25mm to be machined from an 18mm wooden dowel. The actual length needed including the support tab is 29.24mm.

The model can be scaled if needed in DeskProto, but the internal radius has been designed for a 3.175mm bit, too much smaller or the bits used will not fit into the internal radius at the base. If using a different dowel adjust the material diameter in the DeskProto project Part Parameters / Material and re-save the GCode files to prevent very deep first cuts.

Bits used

The same SainSmart 70SB17 2 Flute 3.175mm Ball nose bit is used for both roughing and finishing operations for simplicity.

Support and Tabs

DeskProto will automatically generate tabs, for this I am just using a left tab, this means that the part edge will be close to the right-hand side of the stock. The Tailstock must not be used to avoid trying to machine it! This allows the rounded end of the knob to be fully machined which will require minimal, if any, hand finishing.

Project Setup

This is an outline of the steps I used in DeskProto to set up this project and some hints for novice users, like me!

- Start the Wizard and select the SainSmart 4040 PRO… as the machine and Advanced Geometry: Rotary Machining for the type of milling.
- Select the Geometry file, 'Drawer Knob.stl', it will show in the main window.
- Adjust any scaling.
- Orient the model along the rotary axis. *Not needed for this as the model has already been oriented correctly.*
- DO NOT change the dimensions of the material block, select Don't add support Tabs then click Next. *DeskProto uses the bit diameter to automatically calculate the size of the material block and support tabs, but the bits are selected in the next screens.*
- Select the bit or 'Cutter' to be used for the roughing operation, then hit Next.
- Select the bit or 'Cutter' to be used for the finishing operation, then hit Back twice to return to the Material and Support screen.
- Now set the support tabs you require; they will be automatically sized now the correct bit has been defined. I am just using one on the left so Custom and check left tab.
- Now the Dimensions of the material block can be set, the X dimension has been set to include any tabs, so select use Cylindrical Stock, then custom and set the material diameter, in this case 18mm.
- Hit Next to go to Roughing, set the parameters as required. Distance between toolpaths is the stepover (Distance between toolpaths) and stepdown (Layer height).
- Hit next and set the values you want for finishing.
- No point in writing toolpaths at this point, there are some tweaks still to be made, look at the simulation after finishing the Wizard and you will see the problems, the right-hand side is not machined as I would want, the left-hand side of the base is not vertical.
- Finish the Wizard. I think it is worthwhile saving the project as a base version.
- Right click on the Roughing operation and select Operation Parameters. In the Roughing Tab check 'Protect Vertical Surfaces'.
- *Not necessary but I have limited the area to be machined on the finishing pass, I do not need a smooth finish on the support tab, just the knob base. This may save a minute on the machining time?*

Work Origins

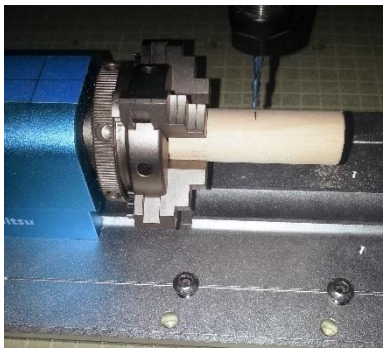
- Y and Z axes Zero are along the rotary 4th axis centreline.
- X axis Zero is to the left of the project, place the centre of the bit 31mm from the right end of the stock.
- A axis Zero, I don't care, it is a round object being machined from a cylinder.

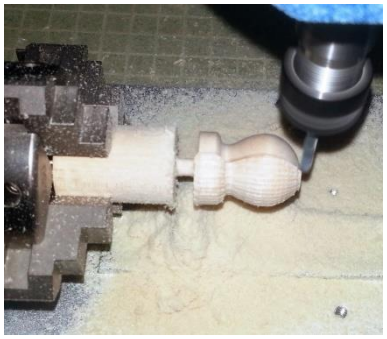
Workflow

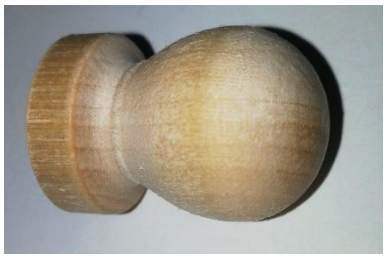
All of this was performed using the Offline Controller and uses some of the macro files described earlier.

1. Mount the bit, the stickout from the bottom of the collet must be at least 11mm for safety.
2. Mount the stock securely with the Jaws in the normal position and ensure it is aligned along the rotational axis. *Even though the Tailstock will not be used I find I get better alignment by hand clamping the stock in the jaws and aligning centre of the other end with the tailstock before tightening the jaws fully!*
3. Remove or adjust the tailstock so that it is well clear of the end of the stock to avoid trying to machine it.

4. Open your macro file ‘RM-Set H ZProbe.nc’ and run. *This will set the rotary axis Y origin and position the bit over the top of the motor housing ready for probing.*
5. Place the Z-Probe base on the top of the motor housing under the bit and attach the clip.
6. Open your macro file ‘RM-H ZProbe.nc’ and run. *This will perform a probing sequence, set the Z Zero point at the rotational axis centreline and move the bit past the jaws to somewhere above the stock.*
7. Jog along the X axis to position the bit centre at least 31mm from the right-hand end of the stock and set the X0 Zero position, *just to prevent any unnecessary rotation*.
8. Set the A0 Zero position.
9. Load the ‘Drawer Knob.nc’ file and run it.
10. When complete if you want use some fine sandpaper to finish the part, then use a small saw to cut the machined knob free from the tab holding it to the stock. *To make life easier I ran the ‘RM-Lathe.nc’ macro to let the router do most of the work!*
11. *If you have more than one drawer – repeat as needed.*







No sandpaper or files have been harmed in any of the pictures!

Summary

Total machining time was 1:05 DeskProto estimated 0:11 for roughing and 0:20 for finishing.

Could this time be improved, almost certainly. I am using quite small stepover values with a with a reasonably conservative feed rate and stepdown for roughing. But there is a trade-off between speed, stepover…. and surface quality!

The surface quality is excellent, the only finishing that will be needed is a very light sanding and sanding the base to remove any remnants of the support tab.

NOTE: Before cutting of the drawer knob from the stock I did check the alignment of the finished part with the stock. (Obviously errors could be caused by the stock not being straight and true in the jaws) but it's I think worth checking, My Y deviation from the edges of the stock to the edges of the finished part on the X axis was too small to see, my Z was, I estimated (It's very tricky to measure exactly, I would need an extra 2 hands!), ~0.1mm too low. I used a straight edge along the edges of the stock and sighted down to the edges of the finished Knob. If there are large errors these would be much easier to spot!

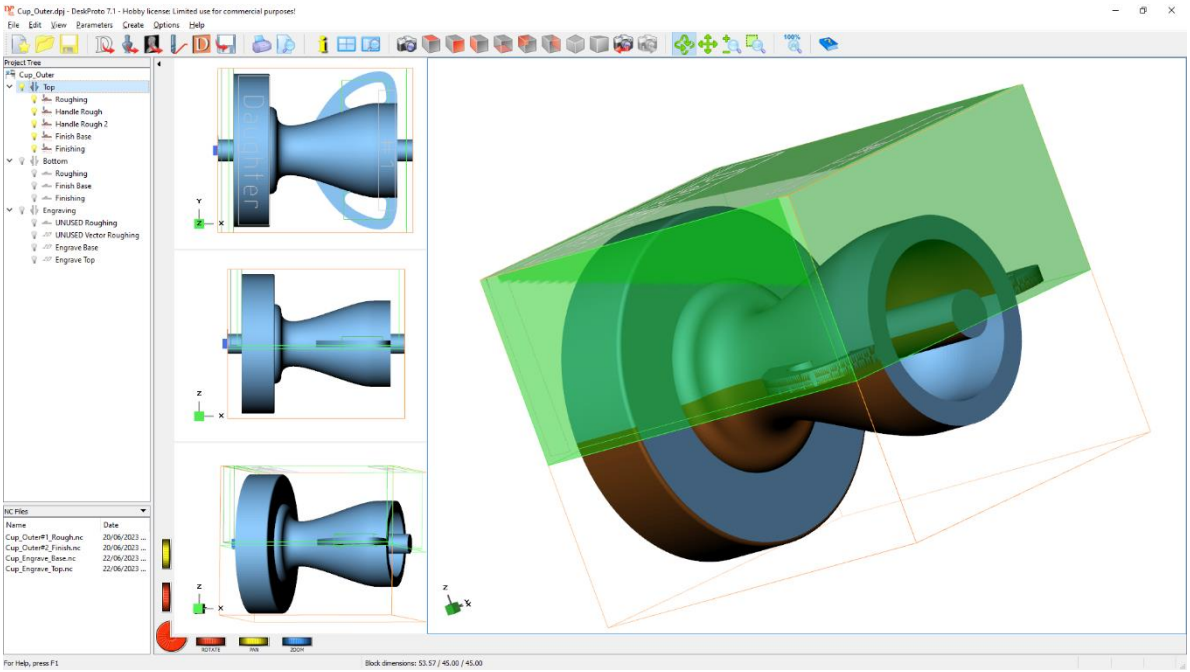
For the moment I am putting the Z difference down to stock alignment or perhaps a not quite round dowel, but I will keep an eye on it as I make and check more projects.

Trophy Cup

A not very simple shape, a trophy using full 4th axis machining. You cannot wrap this one around an axis unless you want very bad handles as the bit will just not cut them out correctly!

There are three steps to make this:

- Cutting out the Cup outer, both roughing and finishing using indexed rotary machining on 2 sides.
- Optional, engraving onto the base and/or at the cup top using XZA rotational machining.
- Optional, cutting out the centre pocket at the top, both roughing and finishing using a standard 3D carve.



Material and Scaling

The model has a maximum diameter of 42mm and the length is 48mm to be machined from an 45mm wooden dowel. The actual length machined, including tabs is 53.6mm. My speeds and feeds are set for a Beech dowel.

The model can be scaled if needed in DeskProto, but the internal radii on the cup and handles has been designed for a 3.175mm bit, too much smaller or the bits used will not fit into the internal radii used so will become the bit diameter. If that is the case then smaller diameter bits will be needed or the radii will be the bit diameter. If using a different diameter dowel adjust the X and Y material dimensions.

Any scaling must be applied equally across all the parts. And all .nc files re-generated.

Speeds and Feeds….

- The 775 motor has a max RPM of ~9,000 so that is used for all operations.
- For the feed rates, stepdown etc please see the operations in the DeskProto Project

Project files

Type	Filename	Description
Model	Cup_Full_V2.stl	Trophy cup on base. (42mm Diameter base, 48mm High).
Engraving	Base_Text.dxf	Optional, the text to engrave on the cup base saved as a .dxf file.
Engraving	Top_Text.dxf	Optional, the text to engrave around the cup top saved as a .dxf file.
Project	Cup_Outer.dpj	DeskProto Project file to cut the outside of the cup.
Gcode.nc	Cup_Outer#1_Rough.nc	Grbl Gcode file for roughing the outer surface with a 3.175mm flat end bit from a 45mm diameter dowel.
Gcode.nc	Cup_Outer#2_Finish.nc	Grbl Gcode file for finishing the outer surface with a 3.175mm ball nose bit.
Gcode.nc	Cup_Engrave_Base.nc	Grbl Gcode file for engraving text on the cup base with a 30° V bit.
Gcode.nc	Cup_ Engrave_Top.nc	Grbl Gcode file for engraving text on the cup top with a 30° V bit.

Bits used

- SainSmart 70SB17 2 Flute 3.175mm Flat end bit, roughing and finishing the bottom of the cup base.
- SainSmart 70SB17 2 Flute 3.175mm Ball nose bit, finishing operations.
- SainSmart TR10A Triangular 30° V bit, engraving.

Stickout

The length of the bit is important to make sure there is enough stickout to reach into the dowel. The maximum depth for the finishing Ball nose bit is ½ the material block plus the ball radius plus safety = 45/2 + 1.5 + 2 = 26mm.

For the flat end it's ½ the material block plus a cut through on the handles plus safety =45/2 +1.5 + 2 = 26mm.

I am using the commonly available bits which are ~38mm long. This does not leave a lot left to place into the collet, so only ~12mm of the bits will be in the collet rather than the full 18mm. This should not cause any problems, and did not. Mounting the bits must be done carefully to ensure that the bit is secure.

For the engraving bit make sure it sticks out far enough to avoid fouling the cup handles, this will depend on the width of your text.

Operation 1 - Cup Outer

Machines the solid cup body model from the dowel using a 2 faced indexed operation.

Support and Tabs

DeskProto will automatically generate tabs, for this I am using left and right tabs allowing the tailstock to be used for support, *without machining it! I think for a large dowel which needs reverse mounting of the chuck jaws using the tailstock is necessary.*

Project Setup

This is an outline of the steps I used in DeskProto to set up this project and some hints for novice users, like me!

This requires full 4th axis machining to ensure that the handles, especially the interior, are machined correctly. All the operations will be full XYZ movements of the bit, then the part will be rotated to present the next face and that will be machined using full XYZ movements…..

- Start the Wizard and select the SainSmart 4040 PRO… as the machine and Advanced Geometry: Two or more sides, automatic rotation.
- Select the Geometry file, 'Cup-Full.stl', it will show in the main window.
- Adjust any scaling if you need it.
- Orient the model, *Not needed for this project as the .stl file has already been oriented correctly.*
- Select Centre Geometry around rotation axis and 2 sides.
- DO NOT change the dimensions of the material block, select Don't add support Tabs then click Next. *DeskProto uses the bit diameter to automatically calculate the size of the material block and support tabs, but the bits are selected in the next screens.*
- Select the bit or 'Cutter' to be used for the roughing operation, then hit Next.
- Select the bit or 'Cutter' to be used for the finishing operation, then hit Back twice to return to the Material and Support screen.
- Set the support tabs you require; they will be automatically sized now the correct bit has been defined. I am using two, left and right.
- Now the Dimensions of the material block can be set, the X dimension has automatically been set to include any tabs. *DeskProto does not support cylindrical stock for this type of machining, so select Custom and set the Y and Z dimensions to 45mm.*
- Hit Next to go to Roughing, set the parameters as required.
- Hit next and set the values you want for finishing.
- No point in writing toolpaths at this point, there are some tweaks still to be made.
- Finish the Wizard. *I think it is worthwhile saving the project as a base version.*

- Double click on the Roughing operations to select Operation Parameters. In the Roughing Tab check 'Protect Vertical Surfaces' Repeat for the finishing operations but do not check 'Protect Vertical Surfaces' in the roughing tab but in the advanced tab select 'Assume Vertical Surface…..' *See help for an explanation of the ratio to use. I used 10. This is needed for both the top and bottom parts.*
- I added a separate finishing step for the base. As part of the normal finishing operation the plunge depth of the bit was too large causing it to bind and jump. The overall time was mostly unchanged as I also limited the area of the finishing steps to exclude finishing the base. *These operations use the same Flat end bit as the roughing operations so they are actually in the '….rough.nc' file as the operations are grouped by bit used.*
- I also added two roughing operations for the handle interiors on the top part. These are limited in area to the handle interiors and use a contour operation. Without these the finishing operations were having to cut away a little too much material for my liking.
- I adjusted the area in all operations to extend the bit down by up to 1.5mm to avoid leaving any uncut parts of the material.

Work Origins

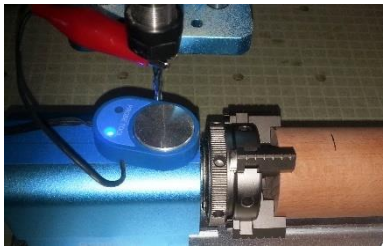
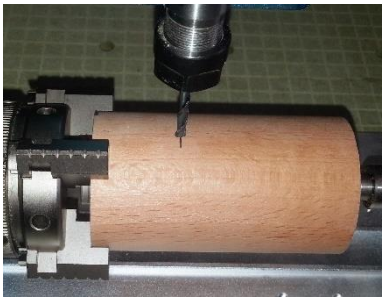
- Y and Z axes Zero are along the rotary 4th axis centreline.
- X axis Zero is to the left of the project, this will be 54mm from the right the end of the stock to the bit centre. *The part can be positioned anywhere along the stock but to save as much stock as possible I position the X origin in from the right-hand end of the stock.*
- A axis Zero, I don't care, apart from aligning the grain of the dowel, it is being machined from a cylinder.

Workflow

All of this was performed using the Offline Controller and uses some of the macro files described earlier.

NOTE: When mounting the stock consider which way the grain of the wood will show in the finished cup. I prefer the grain to be aligned with the handles or at 90° to them, I just think it looks better that way!

1. Mount the roughing bit, the stickout from the bottom of the collet must be at least 26mm.
2. Mark the centre point at the right-hand end of the dowel.
3. Mount the stock loosely with the Jaws in the reverse position.
4. Adjust the tailstock so that the tip is aligned at the marked centre of the dowel and compress the tip 1-2mm into the stock.
5. Tighten the Chuck Jaws securely and if needed adjust the tailstock to make sure it is still into the stock. Secure the tailstock with the clamping screw.
6. Open your macro file 'RM-Set H ZProbe.nc' and run. *This will set the rotary axis Y origin and position the bit over the top of the motor housing ready for probing.*
7. Place the Z-Probe base on the top of the motor housing under the bit and attach the clip.
8. Open your macro file 'RM-H ZProbe.nc' and run. *This will perform a probing sequence, set the Z Zero point at the rotational axis centreline and move the bit past the jaws to somewhere above the stock.*
9. Jog along the X axis to position the bit centre 54mm from the right-hand end of the stock and set the X0 Zero position.
10. Set the A0 Zero position.
11. Load the 'Cup_Outer#1_Rough.nc' file and run it.
12. Remove the roughing bit and mount the finishing bit, the stickout from the bottom of the collet must be at least 26mm for safety.
13. To set the new Z zero position re run steps 6-8.
14. Load the 'Cup_Outer#2_Finish.nc' file and run it.
15. If you are going to engrave the cup leave in position.
16. If not then cut off the bottom tab and remove it.

No sandpaper or files have been harmed in any of the pictures!

Summary

Total time was 3:04 for roughing (flat end bit) and 0:57 for finishing with the ball nose bit, total 4:01.

DeskProto estimates were 3:31 and 0:51 respectively.

The surface quality is generally excellent, the only finishing that will be needed is sanding off any stringing left by the finishing operation and some tidying of the edges of the base at the sides.

Operation 2 - Engraving

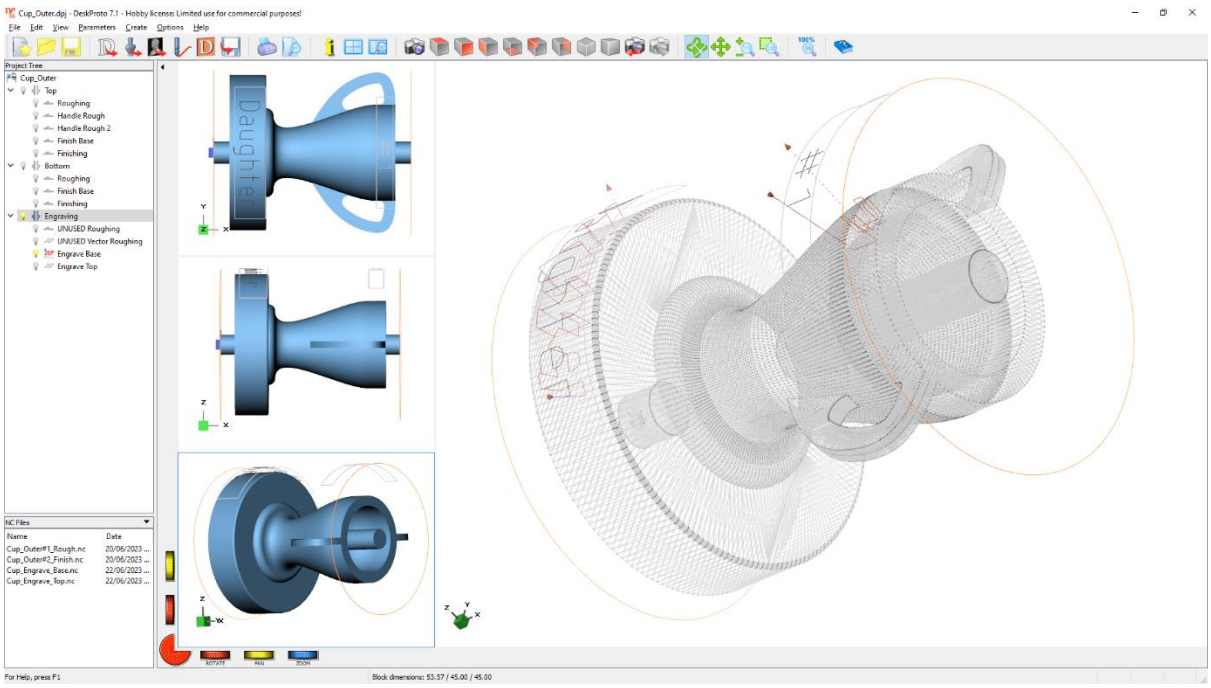
If you want to engrave the Cup the time to do it is before the top and bottom supports are removed, while it is still attached to the rotary axis in its original position and without any power off, reset or changing of the work origins. At this stage the front side of the cup is still aligned with the A Zero position and the X Zero position will be the same.

- For engraving the base is 42mm diameter and 10mm high, the circumference is 131.95mm.
- The top of the cup is 26mm diameter and is straight for the top 5mm. The practical circumference, allowing for the handles is going to be about 20mm at each side but this will depend on the length of the bit being used, make sure that nothing fouls the handles.

I am engraving along the top band of the cup '1st' and along the base 'Daughter' ***NOTE: I have two daughters; in case they ever read this or receive a cup the 1st is just the order of their birth.*** *HINT: Don't use the '#' symbol on the top engraving, it came out OK but a little indistinct!*

The text will be small so I am using a V bit, I want the text to be arranged round the cup so I have copied the bottom part, this copies all the geometry which is sitting in the chuck so things like X0 will stay the same but I then modified the part parameters to use rotation axis (XZA paths).

What this means is that as the text is projected onto the part the bit will always be vertical to the part, if not then the bit would be parallel to the top of the axis meaning that, especially at the sides, the text would not be clear. *This also allows wrapping the text around the full edge of the base, not just the top 180°.*



Project Additions for engraving

This adds onto the existing Cup_Outer project. *The Wizard interface should not be used, it's good for setting up projects but not modifying them.*

- Select the Top part, right click and copy. This will create a new part with all the same operations under it.
- Rename the new part to Engraving.
- In the Project Parameters select the Vector tab and add the two files Base_Text.dxf and Top_Text.dxf. *(See Changing the text to use your own text)*
- The orientation, scaling and positioning of these files on the model is performed by selecting the relevant vector file and selecting Transform, *transformations can also be set in the part parameters but those apply to all vector files*. This is easiest if you have a top view of the model displayed.
    - Use scale to size each text as you wish, use rotation to align the text with the cup base or top. Translation moves the text along the X and Y axes. The default base text has an X translation of -16.5mm. The top text has an X translation of 20.65mm. The Preview button will update the display with the current parameters.
- Double click the Engraving Part to show the Part Parameters, select Vector Settings and in Machine settings select Use rotation axis (XZA paths). Ignore the warnings.
- Rename the copied Roughing operation to UNUSED Roughing, this has to be present but will not be used.
- Right click the other Engraving operations in turn and remove them.
- Add three vector operations, rename them to 'UNUSED Vector Roughing', 'Engrave base' and 'Engrave Top' (*from top to bottom).*
- *To avoid repeated errors, select the UNUSED Vector Roughing operation and in the Profiling tab under Select curves check All.*
- Select the Engrave base operation and in the Profiling tab under Select curves check Custom and select 'Select'. Highlight all the curves in the base text you want to engrave, select a strategy of On Curve (for a stick font).

- In Z Settings adjust the Z Value for the depth of Carve and select Project vector curves on 3D part geometry.
- Repeat for the Engrave Top, selecting the curves to be engraved on the top rim of the cup.
    - As the text is projected onto the cup surface it will become compressed around the rotary axis of the cup. This can and should be corrected for the top text, see Changing the text for details.

NOTES:

- **In the engraving part there is an unused Roughing operation, DeskProto requires a geometry operation before vector engraving operations otherwise projection onto the model is not allowed. This does not need and should not have a toolpath generated for it.**
- **There is also an unused Vector roughing operation, this is needed to allow Layers to be turned off for the actual engraving operations.**
- **The Engrave base and Engrave top have the toolpaths generated and .nc files created separately, you may want to not engrave anything, or just one, or both.**
- **To see the toolpaths as they are below the surface of the model in the Items Visible dialogue change the geometry to Wireframe.**

Changing the text

Probably you don't want to make a cup with 1st Daughter on it. If you do then no changes are needed!

The text engraving is in separate vector operations in the Cup_Outer project and uses DeskProto to wrap the text around the base and/or top, this makes the text easier to change.

For a vector operation DeskProto will only import .ai, .dxf, .eps and .svg formats it will not import text directly. I am using Fusion360 to create the text in a sketch, then exporting the sketch as a .dxf file. *Other options are available to create the text but the text must be exploded into vectors before saving as a vector file.*

Create two text files in one of the above formats, one for the cup top and one for the base using the guidelines below. And import them into the DeskProto Cup_Outer project as vector files.

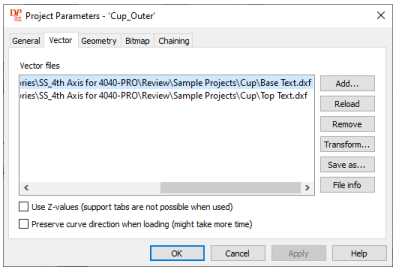
The size limits are shown above, but the resulting file can be scaled in DeskProto.

Fonts

I am using a stick font, one made of just single lines, an inbuilt font in Fusion360 (romans.shx). In DeskProto this can be engraved with a vector operation, profiling, On Curve, where the tip will follow the centre of the curve. At the depth set in the Z Settings, projected onto an inner surface.

There are many other options such as pocketing inside a font, but as these are small letters it would require a very small bit to get into the pockets of individual letters in the font. If you want to use pockets then use the values on the pocketing tab for the vector operations.

Replacing the files

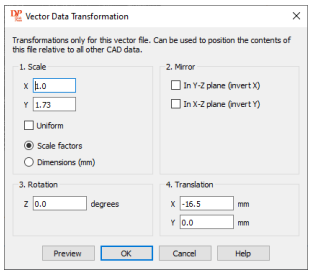


Open the Project Parameters and select Vector. A list of vector files is displayed, remove the current ones and add the new ones, or if re-using the same filenames close the project and re-open it to refresh the files. *You may get errors about missing vectors, ignore them and reselect the vectors for each operation later.*

Positioning and adjusting the text

Possibly the text may need to be rotated to align it with the cup surfaces, the X position may need to be adjusted to centre it along the cup surfaces.

Hint: Select the top view in the DeskProto before continuing, it makes it easier to see where the text is placed.



Select the vector file and click transform. This allows scaling of the text, rotating it and positioning it on the X and Y axes. For the top text the Translation X should be ~20.65mm, for the base text ~-16.5mm. Click preview to see the adjusted position and modify or scale as necessary.

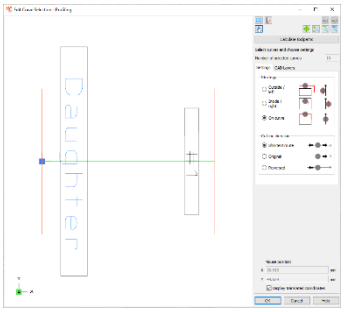
As the text is projected down and wrapped around the inner surface diameter the wrapping operation by its nature is going to compress the text around the rotary axis. Text on the base is only projected in by a couple of millimetres so that can safely be ignored, but the effects on the cup top, with a smaller diameter are more pronounced. Only the size on the rotational (or Y) axis is affected, the X dimensions are unchanged.

The ratio that the text will be compressed is, as a rough calculation, Inner radius / Outer radius, for the cup top 13/22.5 = 0.58 To compensate for this compression the text needs stretching on the Y axis by a factor of Outer radius / Inner radius, for the cup top 22.5/13 = 1.73

In the Scale options, uncheck uniform and set the Y scale factor to 1.73 this restores the character size and spacing around the cup top edge.

Selecting the vectors

As the original files have been replaced or changed the vectors selected for the engraving operations have been removed, the new ones need adding.



Select the Engraving operation and double click for the Vector Operation Parameters. Select Profiling *(or pocketing if that is your preference)* and in Select curves check Custom and click Select. A window will appear showing all the vector curves, select the appropriate vectors for the selected operation, Base or Top.

Depth of cut

Using a 30° V bit with a 1mm depth of cut the cut width will be 0.64mm. Other values can be used but I am using a depth of 1mm, *it's easily adjusted*. The engraving operations as set do not have layers, just cut in one pass, so be careful of too deep a cut!

Regenerating the .nc files

- Make sure the Engraving part is visible and only the Engrave Base or Engrave Top is visible.
- Calculate the toolpaths and verify visually that these are what you want.

- Select Create | Write NC-program File.
- Enter the filename to be used.
- When prompted ‘Do you want to calculate the visible operations only?’ Select Yes.
- If you have changed both engravings repeat for the other one.

Workflow

All of this was performed using the Offline Controller and uses some of the macro files described earlier. This assumes that the position of the cup has not been altered after the finishing operation to cut the outer.

1. Mount the Engraving bit. *Make sure the stickout from the bottom of the collet is enough to give sufficient clearance from the handles for engraving the top of the cup.*
2. Open your macro file ‘RM-Set H ZProbe.nc’ and run. *This will position the bit over the top of the motor housing ready for probing.*
3. Place the Z-Probe base on the top of the motor housing under the bit and attach the clip.
4. Open your macro file ‘RM-H ZProbe.nc’ and run. *This will perform a probing sequence, set the Z Zero point at the rotational axis centreline and move the bit past the jaws to somewhere above the stock.*
5. As the X zero position has already been set this does not need changing.
6. Load the ‘Cup_Engrave_Base.nc’ file and run it.
7. Load the ‘Cup_Engrave_Top.nc’ file and run it.

NOTE: I have added an extra operation at the start of the engraving operations to return the bit to the Y axis zero point before it starts just in case it has been jogged away from the Rotary axis Y centreline. In Advanced select Extra NC Commands – Settings and check Move Y-axis to 0.0

NOTE: The A axis MUST NOT be manually moved while sanding! If you are going to do this it helps to permanently lock the stepper motors by sending a $1=255 command before starting the engraving.

Can you spot the deliberate mistake? After changing the top text I left it a little too high on the cup! Corrected here, in the project and Gcode files.

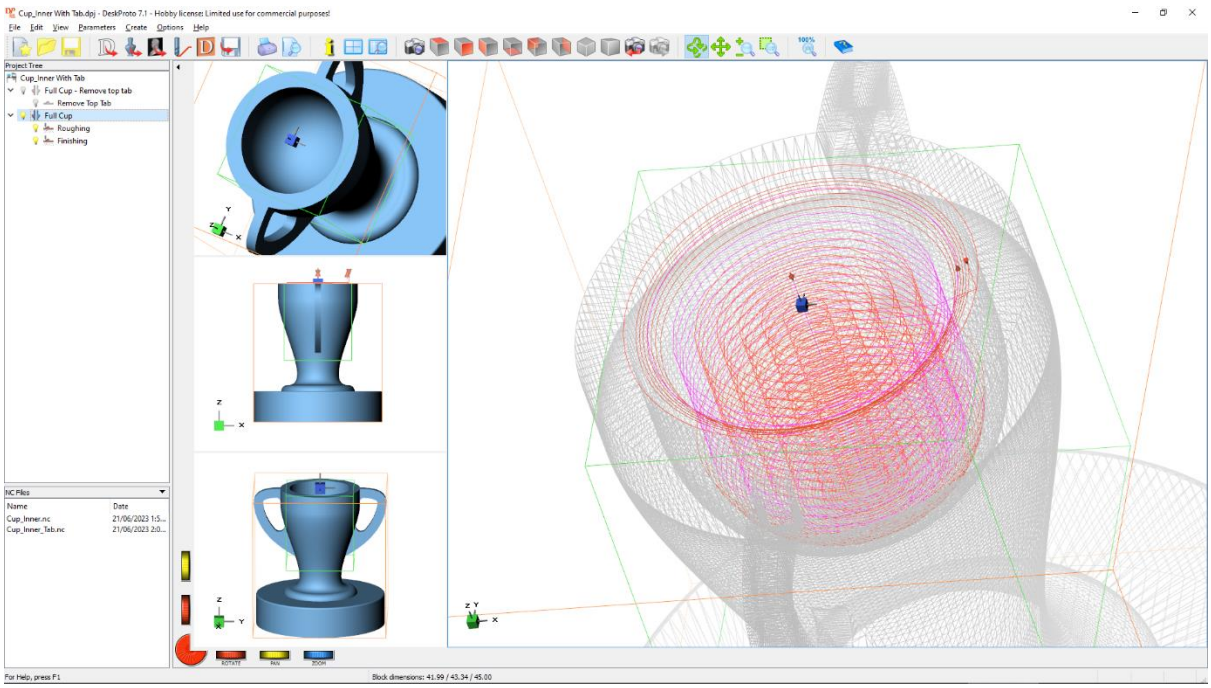
The Engraving operations take ~1 minute each.

To get the best results I engraved the text, performed some light sanding to remove any burrs, and then re-ran the engraving to clean up the interior of the engravings.

Operation 3 - Cutting out the interior

This is optional but I think it makes it look nicer. Although it could be added into the Cup_Outer project I have used a separate DeskProto project for the following reasons:

- It’s optional.
- It’s a 3D carve; no rotary axis is used.
- The alignment of the cup is vertical.
- The Wizard interface can be used to set it up.



There are two possible methods of cutting the interior provided: With the top tab remaining or with the top tab removed.

In both cases the bottom tab must be removed and the cup base sanded flat to allow it to stand vertically on the router bed without any ‘wobble’.

Top Tab remaining

NOTE: To use this method the cup must have been cut out of the right end of the stock leaving a top tab of no more than 6mm high.

The advantages of this method are:

- The router does all the work in removing the top tab.
- The centre point of the top of the cup is still marked accurately by the tailstock indentation.

If you are not going to cut out the interior leaving a solid cup do not use this method to remove the tab, it will remove the tab but can also leave an indentation or a raised part. A Saw and sandpaper will be better!

Top Tab removed

This method may be needed if the cup was cut out of the centre of a dowel leaving a piece at the end of the top tab.

- The top tab of the cup must be finished to be relatively flat to the top of the cup.
- The centre point of the top of the cup must be accurately marked to allow the inner to be machined accurately.

Project files

Type	**Filename**	**Description**
Model	Cup_Full_V2.stl	Trophy cup on base with inner cut out. (42mm Diameter base, 48mm High).
Project	Cup_Inner.dpj	DeskProto Project file for the inner cutout of the cup.

Type	Filename	Description
Gcode.nc	Cup_Inner_Tab.nc	Grbl Gcode file for removing the top tab, one operation with a 3.175mm ball nose bit
Gcode.nc	Cup_Inner.nc	Grbl Gcode file for cutting the inner of the cup. Roughing and finishing both use the same with a 3.175mm ball nose bit

Material and Scaling

If the cup has been scaled when cutting the outer profile, the same scaling must be applied to the Inner project.

Bits used

The SainSmart 70SF17 2 Flute 3.175mm Ball Nose is used for both roughing and finishing operations.

Support and Tabs

No tabs are needed, the cup is mounted vertically on the bed secured using clamps, tape or any other method.

Project Setup

This is an outline of the steps I used in DeskProto to set up this project and some hints for novice users, like me!

This uses basic 3D machining operations. Start the Wizard:

- Select the Machine and Basic Geometry machining (3D).
- Load the Cup-Full_V2.stl model and adjust the orientation, select the right side as the top surface (or rotate on the Y axis by -90°)
- Leave the material block size as the bounding box of the geometry, no Tabs and select for the Zero Point the XY centre and Z top.
- Select the bit to be used for roughing (3.175mm ball nose) and a stepover of 1.27 (d/3), select the layer height and a circular strategy, Layer height Custom, 0.75mm.
- For finishing use the same bit and operation, I am using a stepover of 0.19 (d/17) and a circular strategy.
- Uncheck Use contour only operation.
- Finish the Wizard.

I have made a number changes to the project which are not covered by the Wizard:

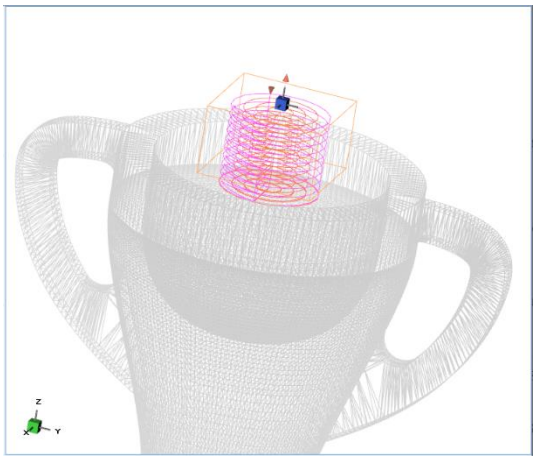
- This is currently going to try and cut out the whole cup, so double click the roughing operation to open the operation parameters.
    - In Strategy change the Detail settings, circular to Inside – out.
    - In Area select Custom rectangular and set the boundary coordinates to X -11 |11, Y -11 | 11, Z -17 | 0 (or use Set Graphically and drag the area around the centre cutout).
    - In Borders tab select Cutter stays within area to just machine the inside of the pocket.
    - In the Movement tab select the plunge federate you prefer.
    - In the Advanced Tab select Skip hor. Ambient to ignore the top surface of the cup and check Ignore enclosed ambient so the inner portion is machined.
- Now select the finishing operation parameters.
    - In Strategy select Circular and change the Detail settings, circular to Inside – out.
    - In Area select Use area of 1st Geometry operation.

    - In the Movement tab select the plunge federate you prefer.
    - In Borders tab select Cutter stays within area to just machine the inside of the pocket.
- Now right click the part and hit copy, this will be used for the removal of the top tab.
- Right click the new part and select move up, this will be machined first, if used.
- Rename it to Full cup – Remove Top Tab.
- Select the Finishing operation in the new part and remove it.
- Rename the remaining operation to Remove Top Tab.
- Double click the Full cup – Remove Top Tab part to open the Part Parameters.
    - The top of the material block needs moving up to encompass the top tab which is not shown on the model and the size machined needs reducing to the tab size. In the Material tab select Custom and set the boundary coordinates to X -5 |5, Y -5 | 5, Z 0 | 6. This will give an error but just ignore it.
    - *NOTE: after hitting OK the Z Coordinates will change to -6 | 0 as they are adjusted for the new top of the material block.*
- Double click the Remove Top Tab operation to open the Operation Parameters.
    - In General I am using a Distance between toolpaths of 1.27 (d/3) and a Stepsize along toolpath of 0.76 (d/5) to make the cut rounder.
    - In Strategy change the Detail Settings Circular to Outside – in.
    - In Roughing change the skin thickness to 0.
    - In Area select Use material block (Part).
    - In Advanced select Machine All.

Removing the top tab

Work Origins

XYZ Zero is at the centre of the top of the tab. The centre is already marked by the tailstock indentation. As I still have the V bit fitted from engraving operations, I am leaving this in place to allow setting the XY origin more accurately by using the point of the bit.



NOTE: The actual height of the tab will not be well defined, the end has not been machined, just cut off by hand. The operation will normally extend down into the top of the cup, this is a not a problem as the interior is going to be machined away.

Workflow

1. Remove the tab from the bottom of the cup and finish the base of the cup so it is flat and level.
2. Using Clamps, or blue tape and superglue, mount the base of the cup to the bed/spoilboard. If using clamps make sure the base of the cup will not be damaged. The alignment of the handles does not matter as the centre pocket is round.
3. Mount the bit, 3.175mm Ball nose.
4. Clear any tool offsets and rotary axis centreline positions by running the macro ‘RM-Clear All.nc’.
5. Set the XYZ zero points as in Work Origins above.
6. Load the ‘Cup_Inner_Tab.nc’ file and run it.

NOTE: I mounted the cup towards the rear of the bed, this way I did not have to disturb the mounting of the rotary axis.

When this is finished it is a good time to review the centre position based on the alignment of the outer edge of the depression with the edges of the cup and tweak it, if necessary, before cutting the interior.



Total machining time is under 2 minutes.

Cutting the interior pocket

Work Origins

If you have just removed the tab by the router then the XY origins are unchanged, if not mark the centre point of the top of the cup as accurately as possible. And set the XY zero points to this position.

The Z zero position needs setting to the top of the cup (Excluding any tab remnants or depression). Use the flat surface at the top of the cup. This may not be possible to set using the Z-Probe

Workflow

All of this was performed using the Offline Controller and uses some of the macro files described earlier.

Any operations in Green do not need repeating if you have just used the tab machining method.

1. Remove the tab from the bottom of the cup and finish the base of the cup so it is flat and level.
2. Remove the tab from the top of the cup and finish it enough so that if using a Z-Probe base the base will not 'wobble' during probing.
3. Mark the centre point of the cup top, ***make the XY zero as accurate as possible to keep the inner pocket centred around the outer edge of the cup.***
4. Mount the bit, 3.175mm Ball nose.
5. Using Clamps, or blue tape and superglue, mount the base of the cup to the bed or spoilboard. If using clamps make sure the base of the cup will not be damaged. The alignment of the handles does not matter as the centre pocket is round.
6. Clear any tool offsets and rotary axis centreline positions by running the macro 'RM-Clear All.nc'.
7. Set the XY zero points to the centre of the top of the cup using your normal method for 3D milling.

8. Set the Z zero point to the flat top of the cup.
9. Load the ‘Cup_Inner.nc’ file and run it.
10. While it is running keep the interior pocket free from debris to get a clean cut!!!!

No sandpaper or files have been harmed in any of the pictures!

Summary

Total machining time 0:10

The Finished Cup!

Actually, even though it is the finished item it is still unfinished!

I am very pleased with the result. Maybe there are some improvements possible, there always are, nothing is ever perfect but after a little sanding in some places I will be happy to present it to my 1st Daughter.

Total Machining Summary

This took:

- 3:04 to rough out the cup outer.
- 0:57 to finish the cup outer.
- 0:02 to engrave the top and bottom text.
- 0:02 to remove the top tab.
- 0:10 to cut out the inner pocket.

Giving a grand total of machining time as 4:15

TROUBLESHOOTING

Just some possible solutions to problems 'a friend of mine' encountered using the rotary axis!

Steps in an indexed operation.

As in the Cup project the top side is cut, then the stock is rotated by 180° and the bottom is cut. If the centreline of the rotary axis is not aligned with the Y or Z zero positions set then after rotation the part will have been offset by this misalignment, this can occur on both the Y axis and the Z axis.

If the step is on the Y axis first check the alignment of the gantry carriages on the Y axis, they can get out of synch which will mess up the Y home position. Then check that you haven't changed any GRBL parameters such as home position, pull off etc. which can also change the home position.

Then recheck the alignment of the rotary axis completely has the base moved? Re-measure the alignment on the X axis and then re-measure the Y coordinate of the rotary centreline. Update any changed coordinates, especially the Y Zero coordinate and the Y Zero coordinate in any macros that you are using to set positions.

Z axis steps can also be caused by the same misalignment and/or the rotary centreline being at a slope to the movement of the Z bit position as it moves along the X axis so check that the bed was level before the rotary axis was mounted. Also, double check the Z Probe base height is measured and set correctly.

Rotary (XZA) operation not centred in the Dowel

This will be either a mounting problem or an alignment one.

Next time Double check the alignment of the stock in the jaws, and if using the tailstock, the centre position used on the stock and the alignment of that centre with the point of the tailstock. After mounting sight along the edge while rotating the chuck to see if there is any deviation.

If that doesn't fix things then recheck the alignment of the rotary axis completely, described in Steps in an indexed operation. above.

Rotary axis shifts in an indexed operation

This is likely to be seen only in an indexed operation, in a Rotary (XZA) operation the bit will be above the centreline so exert minimal rotational force.

When using an XYZ operation force is applied to the rotary axis, especially at the edges of the cuts. The larger the stock the larger these forces can be and this can cause the rotary axis to rotate slightly.

There is a Grbl setting which keeps all the stepper motors locked at all times (Set $1=255) rather than being released when not moving. This will greatly increase the resistance of the rotary axis to being turned. If this is not a cure consider reducing the feed rates, depth of cut…. especially any plunge rate.

I hope that even if you don't make these projects the descriptions and methodology of how they were created and made will be useful and aid you in creating your own.

Enjoy!