A HALL EFFECT BASED TOOL HEIGHT SETTER FOR CNC OPERATIONS

Introduction

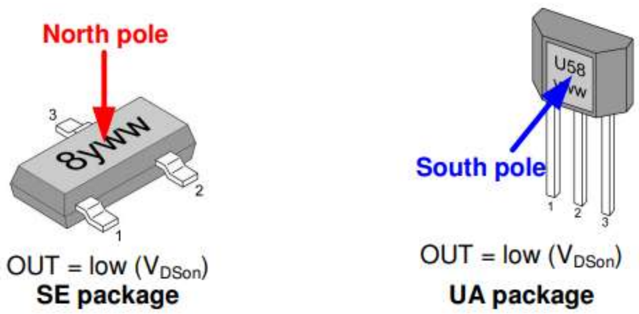
For some time I had been unhappy with my method of measuring tool height. I have the Tormach granite block and the associated digital height caliper with electronic download software and I also have a Chinese tool height setter. I never seemed to get repeatable results from these. The reading on the caliper display never seemed to agree with the electronic download to PathPilot and the Chinese tool height setter would give a different reading.

I had been doing some work on a different project using Hall Effects and I was impressed by the repeatability of their trip point. This got me thinking that maybe I could make a tool height setter using one of these devices.

Hall Effect Devices

A Hall Effect device is an electronic chip that responds to a magnetic field. These can be digital or analogue. Depending on the type used, the body of the device will sense magnetism on each side and this might be North or South Pole activated. These are known as Uni-Polar devices.

I had been using the US5881 device made by Melexis which is marketed as 'low sensitivity'. The conventional package (TO92) 'with legs' is South Pole sensitive and the SMD version (TSOT package) is North Pole sensitive. Here is a diagram from the Melexis data sheet.



The Magnet being used to trip the sensor needs orientation to suit the device chosen. To use the device you simply need a pull up resistor (47k) from the output to the supply plus a decoupling capacitor across the supply and ground. The output sits at the supply potential until tripped by a magnetic field whereupon the output goes to ground. Because the device is high impedance there needs to be a driver/buffer transistor connected to the output to allow high current devices such LEDs or relays to be turned on.

Proof of Concept

Before embarking on metal destruction I did some trials on my Tormach PCNC440.

I mounted a small magnet on the end of a short length of Acetal rod and put the rod in a collet in the mill spindle. I mounted a Hall Effect device and LED driver transistor on a piece of printed circuit board and bolted this to the mill table. I centred the rod and magnet over the Hall Effect and then slowly brought the Z height down until the Hall Effect tripped and turned on the LED. At the trip position I zeroed Z and repeated the process a number of times. To my surprise and satisfaction the Hall Effect tripped consistently to within 0.001" of the zero point. Clearly the concept was worth pursuing.

Prototype

I was still reluctant at this early stage to cut metal so a hybrid model was made using a combination 3D printed parts and metal items. Most tool setters work on the principle that when the tool touches the metallic surface of the Tool Height Setter sensor button, it breaks an electrical 'loop' to and from the milling machine electronics. There is usually some form of macro in the software that automates this process. The tool setter buttons are usually spring loaded to avoid the sudden abrupt contact from damaging the tool being measured. Once the loop circuit is broken by the electrical contact, the machine control software retracts the tool and then repeats the contact at a much slower Z feed rate. This delivers the final accurate result of the tool length to the Tool Table in the software.

My design would not use the metallic contact to break the loop but would need to further depress the tool setter button and in so doing would push a magnet down towards the Hall Effect sensor. When detection by the Hall Effect took place, this would open a relay contact which would break the loop to the milling machine sensing circuit.

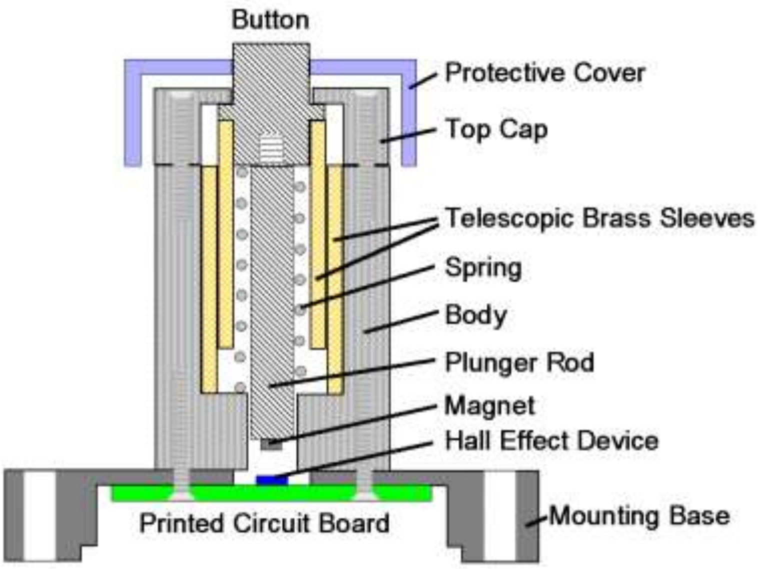
Using the relay to 'drop out' and break a contact rather than make a contact served two purposes. It meant the Tool Height Setter was 'fail to safe'. If the power supply to the Setter failed this would cause the relay to not function and create an open circuit sensing loop. This would trigger a machine alarm. Also by having the relay drop out rather than make its contacts, I hoped to get a more repeatable action that avoided the usual relay activation time delay.

By using a double pole changeover relay the second pair of normally closed contacts would allow a LED to be illuminated. This would show the operator the status of the power supply and the functioning of the relay.

The prototype proved to be just as repeatable in its results as my simple test set up had been. It did however highlight how much axial concentricity was going to be important in the final version. I had to find some method of repeatedly ensuring the Hall Effect always detected the magnet in the same position and that there was no friction on the action.

Production Version

Here is a rough sketch of the concept I had in mind.



In my rainy day materials box I had a number of thin wall brass tubes that were dimensioned to be a sliding fit one into the other so telescopic structures could be made. This looked like a solution to ensuring the Tool Height Setter action became much more repeatable. The tube supplier was K&S Engineering of Chicago. K&S materials are readily available in 12" lengths from worldwide sources. I had ½"OD and 15/32" which looked ideal for the project.

My stock box also had some 32mm aluminium bar for the body and 8mm rod for the plunger rod. Digging further I found a compression spring that would slide up the outside of the 8mm plunger rod and fit inside the inner telescopic tube. The base stock material would be 18mm aluminium plate which would be skimmed to 17mm. The protective cover would be 3D printed.

Production Details

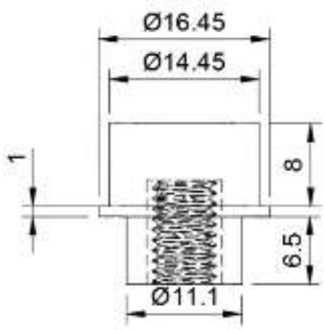
Because I wanted as near perfect concentricity as possible, all the lathe machining (where possible) was done with a collet chuck rather than the usual 3 jaw self-centring version. Where this was not physically possible on the Body and Top Cap I did as many process as possible without removing the stock from the chuck.

I was lazy and did not skim the outer surface of the stock on the Body or the Top Cap.

The three clamping holes holding the Top Cap to the Body and the Body to the Base, were all run with the material held vertically in a chuck on the CNC milling table. This made it easier to get repeatability. The Base has a matching 3 hole matrix that holds it in place to the body. The same three holes are also used to hold the PCB in place inside the base.

Here are some more specific details on each part.

Button

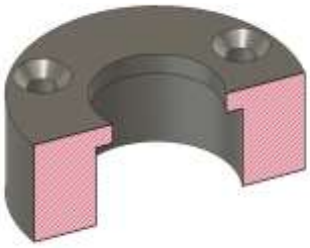


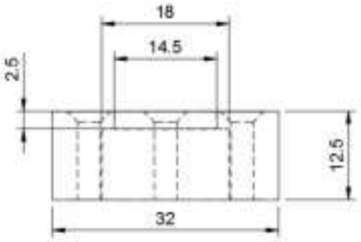
I started by making the Button and the dimensions are as above.

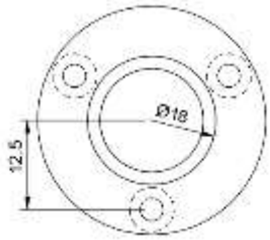
Note that the end that fits inside the inner brass telescopic tube (11.1mm) is a 'machine to fit' taking a few thou per cut in order to get a very tight fit inside the inner brass tube. The 16.45 retaining collar acts as a stop against the Spring inside the Top Cap. The lower end of the Button is tapped M6 to take the Plunger Rod but as an alternative this could be a non threaded section with Super Glue fixing. Threading did give me the option of removing the Plunger Rod from the Button for tweaking the length to match the trigger point over the Hall Effect.

Top Cap

The Top Cap is internally bored to be a good clearance on the Button collar diameter and a few thou clearance on the Button top diameter (16.45mm). It has three matching fixing holes to match those in the Body.



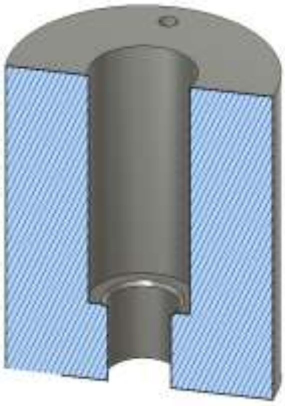


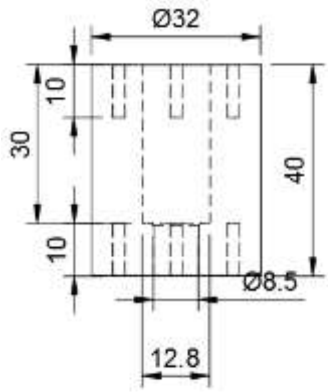


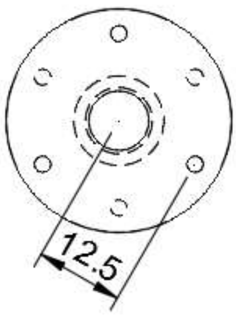
Body

The Body is a simple two diameter lathe boring process. The Body is a similar to the Button in that the inner bore needs to be a 'machine to fit' on the outer telescopic tube outer diameter (1/2"). The lower hole that takes the Plunger Rod should not be too sloppy. If everything on the assembly is truly axial this hole can be quite snug.

This is followed by drilling and tapping 3 x M3 holes to 10mm depth on each end on 120 degree arcs and 12.5mm radius. This was run as a CNC process. The following sectional view and dimensioned drawings will help visualise the Body.





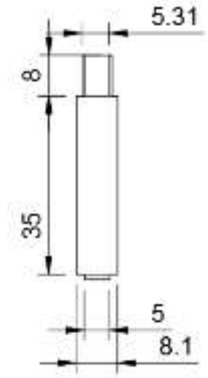


Telescopic Brass Tubing

The Telescopic Tube has very thin wall sections (14 thou) and is very easily crushed and distorted. I first of all cut oversize lengths of both diameters using a small handheld pipe cutter. This left a bevel on the cut ends. I mounted the cut outer tube in a collet in the lathe and put the best sliding fit twist drill (15/32") inside the tube slightly back from the bevelled edge. This gave some protection from crushing when clamped. The bevelled end could then be turn back to full bore. I repeated this process on the smaller diameter tube with a 5/16" support drill.

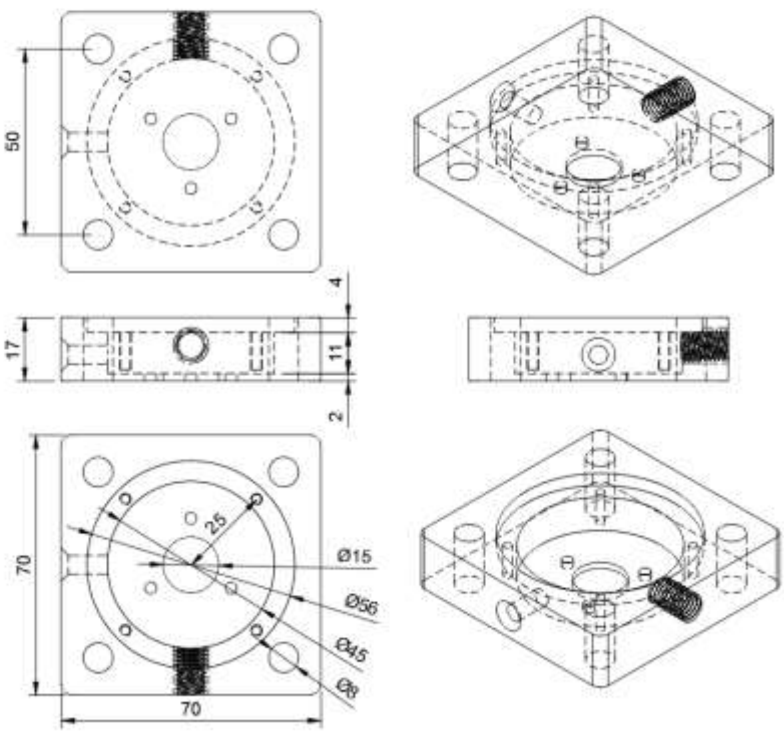
Plunger Rod

The Plunger Rod is 8mm aluminium stock with the top end tapped M6 (or turned to a shoulder dependent on choice of fixing into the Button). The bottom end is drilled to a depth of 3mm to take a small 5mm diameter Neodymium magnet. I had approximately 1mm of the Magnet protruding.



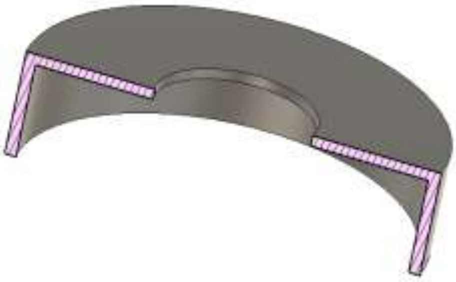
Base

The Base is made from an 18mm block of aluminium skimmed to 17mm and with mounting holes that matched my milling machine tooling plate matrix (M8 x 50mm matrix).



The lower side cavity is machined out to take a circular printed circuit board and cover plate. The Hall Effect device is mounted on the top side of the PCB looking upwards into the Body and the Magnet on the Plunger. All the remaining electronics are on the lower side. There are two side holes on the Base for the cable exit and for an indicator LED. There is a shoulder on the circular cavity wall to allow a cover plate to be fastened in place. The Base was modelled in Fusion 360 and machined using CNC on my Tormach 440.

Protective Cover and Cable Gland



The Button Protective Cover and Cable Gland were both modelled in Fusion 360 followed by 3D printing. The Protective Cover acts as a skirt around the Button to protect the Top Cap from cutting fluid contamination. The centre hole is a tight fit on the Button and Super Glued in place just below the top surface of the Button. This position is an important so the Cover does not interfere with the spindle nose when zeroing the spindle nose in PathPilot.

The Cable Gland is a simple 4mm tube with hexagonal tightening section and a modelled M8 screw thread to match the threaded hole in the Base. The cable is sealed in place with heatshrink tubing.

Spring

The Spring is a standard part from UK supplier RS (751-556). It is specified as 0.49N/mm and measures 10.8mm OD, 0.8mm wire and 45.5mm long for 9 turns. I cut this down to 33mm length (~7 turns) for the best feel on the compression against the button.

Bottom Cover

This is a 1.5mm thickness 55mm diameter aluminium plate with 4 x 3mm holes on a 50mm PCD.

Assembly

The outer Telescopic Sleeve is pushed into the Body and should be flush with the top surface of the Body. If the fit is good there should be no need for any Super Glue or similar to retain it.

The inner Telescopic Sleeve needs care in its fitting. Mount the Button by the top external diameter section in a collet on the lathe. Fit a spare length of the outer Telescope Tube in the tailstock. Slide the inner tube into the outer tube in the tailstock and present this up to the Button. Apply Super Glue to the Button and slide the inner Telescopic Tube over the Button end and slowly rotate the collet for a few seconds to centralise the Inner Tube referenced to the Outer Tube. Leave to set. Alternately you could use a 5/16"drill bit instead of the Outer Tube.

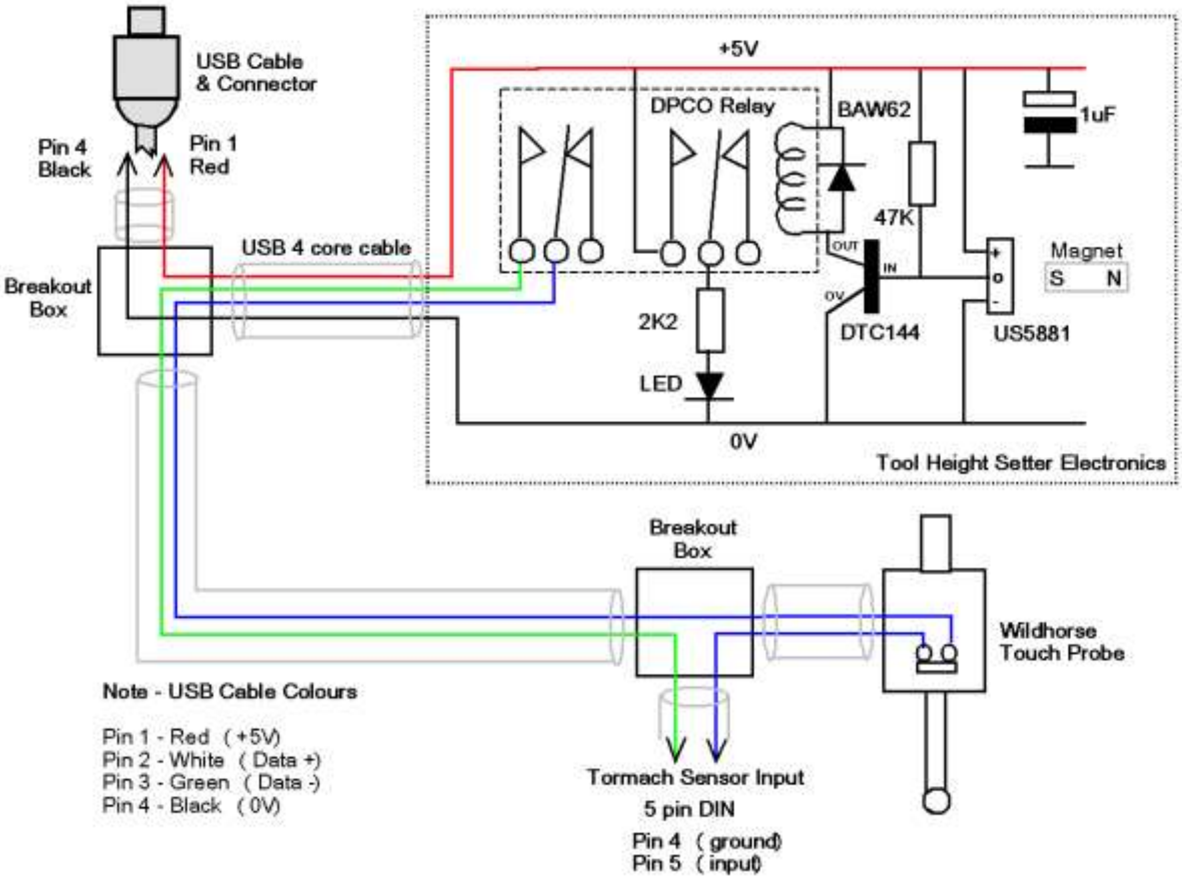
The Magnet should be checked for correct polarity relative to the Hall Effect device and then Super Glued in place in the end of the Plunger Rod. The Plunger Rod can now be screwed in place into the Button and the Spring slid over the Plunger Rod. The Top Cap can be fitted over the Button and the Spring compressed inside the Body with the Top Cap. The Top Cap is fastened in place with 3 x M3 x 18mm countersink screws.

The whole assembly should now be checked for free movement. If everything is axial there should not be a problem. If you think it is binding then disassemble and remove the Spring and then re-assemble to check free movement. The Button should feel as if it is on an air ram as it slides into the Body.

With the Spring in place there needs to be resistance to depression of the Button but not excessively so. Adjust the Spring length if there is too much pressure. Depression of the Button should trip the Hall Effect after 3mm to 5mm of downward movement.

Electronic Circuit

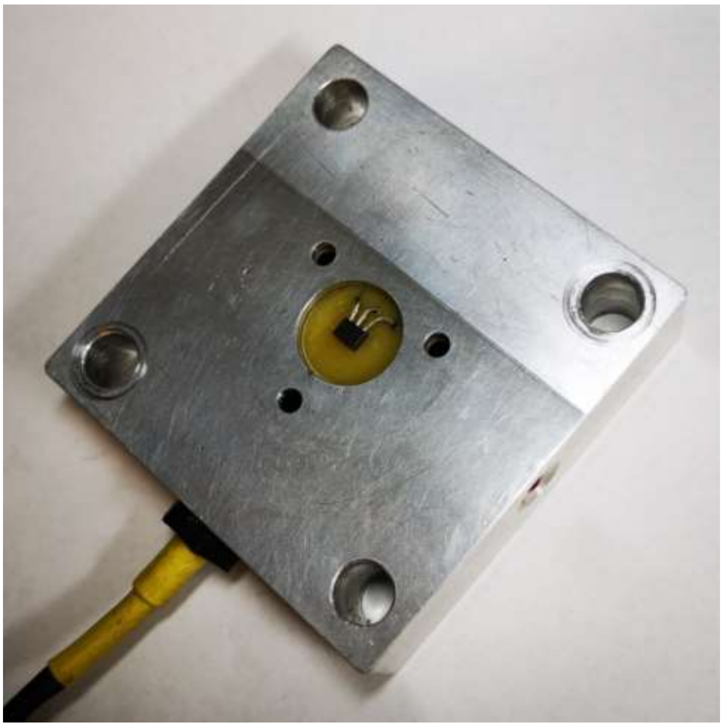
The circuit for the electronics is quite simple and is shown below. A circular piece of blank single sided printed circuit board is mounted inside the Base cavity. The PCB assembly is held in place flat against the inside bottom of the Base using 3 x M3 dome head screws using the three mounting holes that also hold the Base to the Body. The Hall Effect device is the only component mounted on the top, non-copper side of the PCB.



The Hall Effect has three terminals – supply, ground and output. The output pin needs a pull up resistor to the supply pin and a decoupling capacitor. The output feeds a digital transistor that acts as a buffer to drive the relay. Digital transistors have built in resistors so connections are simply in/ground/out rather than base, emitter and collector and separate biasing resistors. The DTC144 is made by Rohm. The DTC will be turned on by the pull up resistor on the output of the Hall Effect device. This turns the relay ON all the time the Hall Effect is not triggered. The relay needs to be a double pole changeover device but does not need high current capacity. A small reed type device is ideal. The relay coil should match the power supply voltage. As I was going to use a USB power supply source I chose a 5V version.

The relay coil needs a transient suppressor diode and any common diode will suffice. The connections to the relay contacts only go to the normally open contact pairs. One pair provides a short circuit for the mill sensing input when the relay is energised. The other pair of contacts turn on an indicator LED that goes out as the Hall Effect trips and the relay drops out.

To locate the Hall Effect device position on the PCB top side, test fit the PCB circular blank into the Base. Scribe round the access hole in the Base top surface where the Hall Effect will be mounted. Remove the PCB from the Body and use the scribed circular witness mark as a location reference, position the Hall Effect centrally and drill three 1mm access holes off centre for the device wires to pass through. If you are using a SMD part this will have to be glued on place and wires carefully soldered to its contacts and passed through the PCB. See the image below.



The remainder of the electronics can be either professionally tracked on a custom PCB or strung together 'bird's nest' style. In my speed to get things working I took a middle road by hand cutting tracks with a burr onto the copper surface. It wasn't pretty but a proper PCB is now underway.

Wiring to the Tool Height Setter is a four wire cable. This is two wires for the loop sensing pair to the mill input and a positive and negative power supply feed. I had a very long USB cable to hand and I chopped the connector off one end and then used a short length of the cable to provide a four wire connection as shown.

I brought the four core cable to a small 3D printed breakout box located on the rear of the 440 milling machine. From this box the sensing pair went to a second breakout box. Here the sensing loop branches off to my Wildhorse Touch Probe and then onwards to the 5 pin DIN connector on the

Tormach. The power supply connection running from the first breakout box used the remaining length of USB cable that still had the USB connector in place. The cut end of this cable was stripped and connections made to the red and black wires. The white and green wires are not used and cut back. (White is shown as Blue on the diagram).This cable can now be plugged into a spare computer port or into a wall socket adapter.

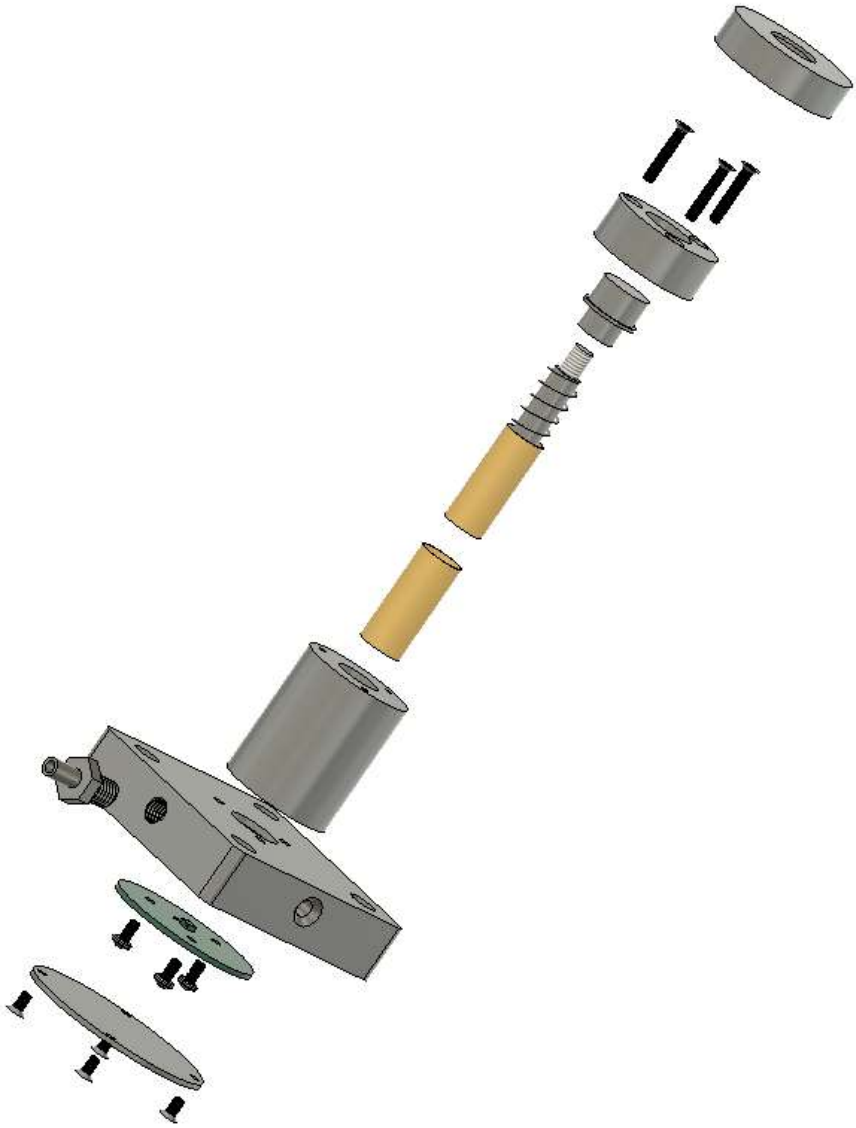
With the PCB in place and the wiring completed, the whole assembly can now be mounted on the milling table and tested for activation and repeatability.

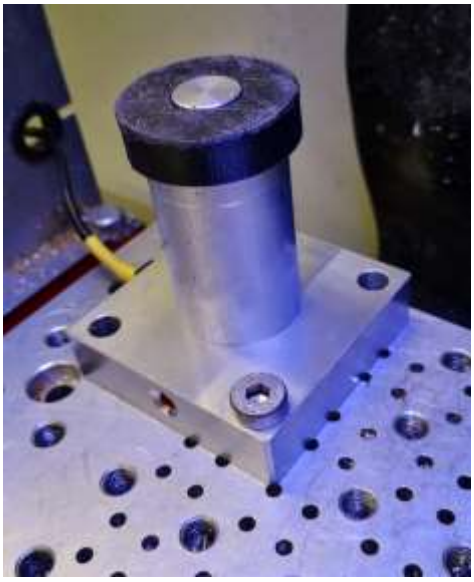
Once everything is functioning correctly a circular cover can be made and put in place on the base to protect the electronics.

The final step is to Super Glue the 3D printed Protective Cover on the Button at a height just below the top surface of the Button as detailed in the text.

<u>Full Assembly Exploded View</u>

Here is a picture of the exploded view as created in Fusion 360 followed by a picture of the finished Tool Height Setter mounted on my Tormach PCNC440 milling machine.





Testing

PathPilot has a Tool Setter set up routine. The first action is to zero the spindle nose on the tool setter. Note that it is important to align the spindle 'off centre' on the tool setter Button so that it only touches the area of the spindle nose that is outside of the area where the collet protrudes.

On the same screen there is a routine for setting up the G37 location. This needs to be with the tool aligned on the centre of the Button not the edge.

Having set the spindle nose zero, create a dummy tool in the tool table and then select this tool in PathPilot. Place a small 1-2-3 block or similar known dimension component on the tool setter Button. (Clearly not too heavy a component or it will trip the tool setter). Once again it is important to offset the component location on the Button so it only comes into contact with the spindle outer edge away from the protruding collet. Click to make a tool measurement in Z only and check the dimension that is automatically entered in the tool table matches the know dimension on the component being used.

If there is a consistent and repeatable error on the known component dimension then suspect the spindle nose zero value. Check the spindle nose and the toolsetter surfaces for any contamination and make a repeat measurement.

Conclusion

The whole activity on this project from testing, 3D printed prototype and final version was put together in less than 16 hours. The repeatability has been found to be excellent using the PathPilot tool height setting routines and gives far more confidence than my previous methods and devices. The use of G37 in-program tool height measurements in PathPilot is now a real practicality.

As emphasised earlier the dimensions of the material used are mainly based on materials I had to hand. There is therefore a great deal of flexibility for anyone repeating the concept. What is important is the use of the telescopic brass tubes to maintain the axial concentricity.

The project is not particularly taxing and makes an interesting few hours of activity with the reward of a useful piece of tooling to make CNC tool height measurement much less frustrating.

APPENDIX NOTE

Measuring Haimer Taster Height

There is one height that is critical and yet difficult to measure using this style of Tool Height Setter and that is the Haimer Taster.

The Haimer depends for its zero measurement through the depression of its spring loaded ball tip. This brings the integral dial gauge to zero. Clearly this would not work with the Hall Effect Tool Height Setter as it will trip the Hall Effect before the Haimer reaches a zero reading.

I had a simple solution to this.

I have my Haimer mounted in a Tormach standard collet. With the Haimer mounted in the mill spindle I brought the spindle Z down to depress the Haimer sensor to its zero reading onto the mill tooling table. I then zeroed Z.

I mounted a piece of Silver Steel with a rounded end that was representative of the Haimer length in a second collet. I only fastened the collet to finger tight but with sufficient resistance to just allow sliding movement back up into the collet. I did not change the Tool Number.

I brought the spindle gently down onto the tooling table such as to push the Silver Steel rod back up inside the collet. I slowly continued this thou by thou until the Z readout once again showed zero. The length of the Silver Steel rod plus the collet should now represented the same as the Haimer plus collet at Z zero. Sadly it doesn't quite as there is a pull-in action by the collet when fully tightened. I had to revert back to the granite block for a small amount of tweaking before I got the two heights to agree.

I could now use the Tool Height Setter to zero the Haimer using the substitute combination of the rod and collet. This works very well and consistently cross checks with other measurements. I agree that there will be temperature related expansion but PathPilot forces you to make a spindle nose calibration each time you boot the machine from cold so I then check my 'dumb Haimer' rod at the same time.