

No.316

THE MAGAZINE FOR HOBBY ENGINEERS, MAKERS AND MODELLERS

MODEL ENGINEERS' WORKSHOP

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JUNE 2022

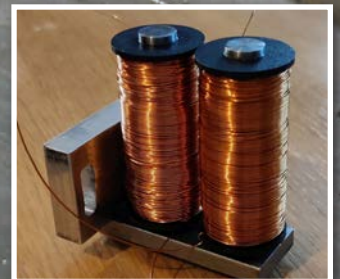
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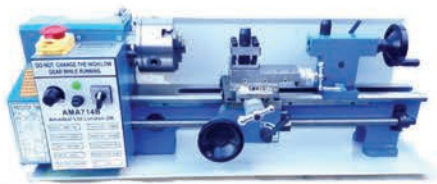


A Free Pendulum

COVER STORY

A Tangential Flycutter

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Range of spindle speeds: 100-2250mm
Weight: 43Kg



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Taper of spindle bore: MT4
Spindle bore: 26mm
Number of spindle speeds: Variable
Range of spindle speeds: 50~2500rpm
Weight: 140Kg

Price: £1,904
W 2 Axis DRO - Price: £2,280



AMABL290VF Bench Lathe (11x27) - power cross feed - BRUSHLESS MOTOR

SPECIFICATION:

Distance between centers: 700mm
Taper of spindle bore: MT5
Taper of tailstock quill: MT3
Motor: 1.5kw
Weight: 230Kg

Price: £2,395
W 2 Axis DRO - Price: £2,787



AMAVM25LV

SPECIFICATION:

Model No: AMAVM25LV (MT3) / (R8)
Max. face milling capacity: 63mm
Table size: 700x180mm
T-slot size: 12mm
Weight: 120Kg

Price: £1,360.00
W AXIS POWERFEED - Price: £1,659
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Weight: 240Kg

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MODEL ENGINEERS' WORKSHOP

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This issue was published on April 22, 2022.

The next will be on sale on May 20, 2022.

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On the Editor's Bench

Print and Digital Versions

It seems that the production of the print version of MEW has continued smoothly with the transition to our new publishers, Mortons. Unfortunately, the change has introduced some delays to the processing of the digital versions for Pocketmags and the digital archive at www.model-engineer.co.uk. There may continue to be some minor delays until the subscription service is brought fully in house at Mortons. Please accept our apologies for any inconvenience and be assured that the difficulties are being addressed.



Tailstock Tales

We are currently running a short series by Murray Lane on his capstan feed tailstock for Myford lathes. This is a beautifully made accessory using the traditional approach of making patterns and having castings made. It's much in the tradition of projects by his late compatriot, J. A. Radford, who featured other ambitious Myford projects in his book "Improvement and Accessories for Your Lathe".

An alternative and somewhat simpler approach, although perhaps less elegant, is to fit a lever feed to the existing tailstock of your lathe. I remember John Stevenson's version for the popular Mini Lathe machines. A design for Myford lathes by 'Hopper' has been featured on the forum. This has been drawn up in detail and a construction article prepared and this will appear in these pages towards the end of the year. In the meantime, John Halfpenny has been inspired by Hopper's work and has made a version to suit the Clarke CL430 and 500M lathes. It's fascinating to see the different but all well-realised approaches to adding this useful function to a lathe. Perhaps I will look at making an SC4 version!

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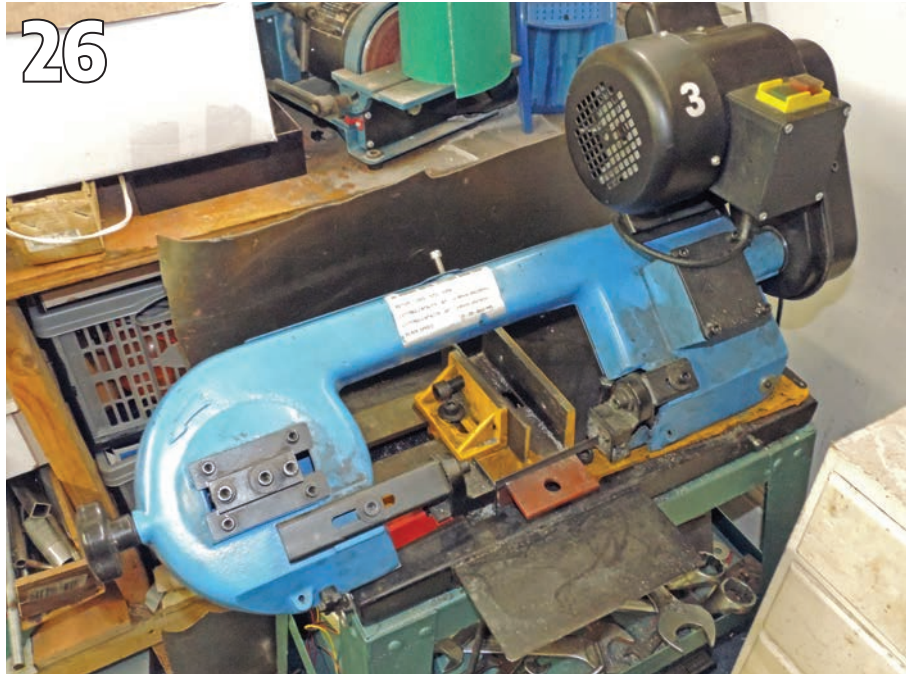
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Coming up...

in our next issue

In our next issue Geoff Andrews suggests some useful improvement for the popular Mini Lathe machines.



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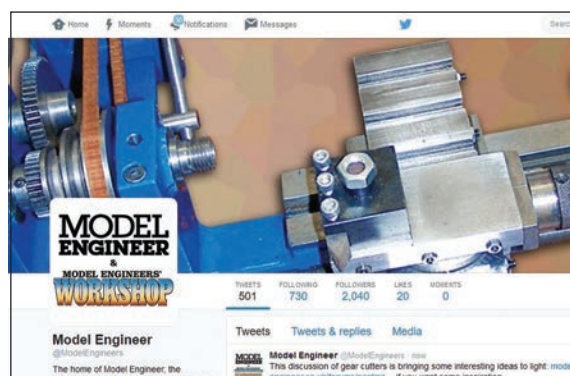


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Other hot topics on the forum include:

Help! how to remove embedded diamond lapping particles on metal surfaces by Y C Lui

A very good question which gives rise to some useful advice on lapping.

Which beginners lathe is best by Phil Ingram

What do you recommend?

3D Challenge - Side Lever Engine by PatJ

Some intricate 3D modelling from Victorian drawings

Making spindle bearings by Jamie Creighton

What are the options?

Come and have a Chat!

As well as plenty of engineering and hobby related discussion, we are happy for forum members to use it to share advice and support. If you feel isolated by the lockdown do join us and be assured of a warm welcome.

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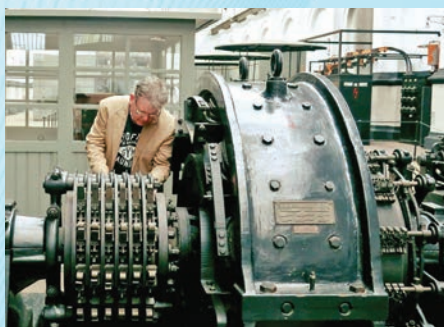
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For the Myford ML7, George and his team produce the AV400, a complete 'Plug & go' solution including a new variable speed motor that meets the original Myford motor specification, has the correct 5/8ths shaft diameter and is a direct fit. The 'AV' range is extended with the AV550 & AV750 for the Super 7 lathe giving a choice of 3/4HP & 1HP motor power. Full Torque is available from motor speed 90 - 1,750 RPM. Advanced Vector control for maximum machining performance. Prewired and programmed ready to go. The AV400/550/750 speed controllers have an impressive 10 year warranty for the inverter and 3 years for the motor (Terms and conditions apply). Over 5,000 units supplied to Myford owners. Speed control solutions also available for other lathes including Boxford, Southbend, Colchester, Raglan etc call or email for details. Technical support available by telephone and email 7 days a week.

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Electroplating 3d Printed Parts



Glenn Bunt describes an interesting new technique possible with the advent of 3D printing.

3d printers are a useful tool. They allow the model engineer, within the confines of our own home, to turn designs or concepts into manufactured objects or prototypes, rapidly, without extensive costs. The downside is that additive manufacturing does not yet produce objects which are made of strong, durable and more robust materials. Because of this their use is limited in the present-day model engineer's workshop. This article does not describe a way around the present limitations but suggests an additional post processing step which changes the characteristics of a 3d printed object to make it more useful in our hobbies and in the workshop. That process is electroplating.

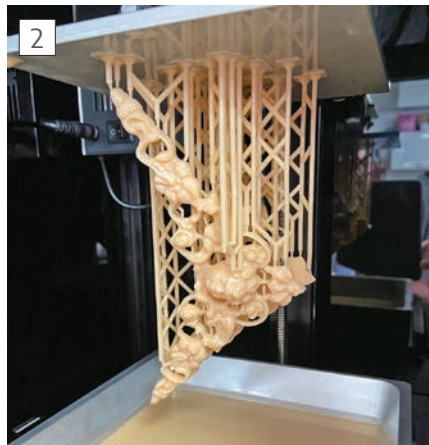
In late 2019, I dipped my toe in the 3d printer market. Rather than invest in a FDM machine (Fused Deposition Modelling), I decided to purchase a 3D SLA resin printer.

In my case the printer was a Peopoly Moai. It works by using a high-powered laser to harden photosensitive liquid resin that is contained in a reservoir, called a vat, to create the desired 3D shape.

The output from your printer, can be extremely detailed, it can produce complex parts with intricate geometries that require very little post processing, compared to FDM but the cured resin is very brittle and has very little strength or durability.



A brass plated clock spandrel.



3D printed part just completed in the Peopoly Moai.

The idea behind the purchase was to make objects that could be used in my clock making hobby. Decorative items that could be used on chapter rings or clock faces or adornments to the cases that would be painted with a brass or

nickel paint effect. I eventually went down the route of experimenting with electroplating, **photo 1**.

Electroplating can be double the strength, increase stiffness and generally improve the mechanical properties of 3d objects, the exterior taking on the colour properties and texture of the coated metal.

Electroplating is a process of applying a metal coating onto the conductive surface of another object, through an electro-deposition process. The deposited metal becomes part of the existing product with the plating/coating.

There is one small problem with 3d print material – its non-conductive!

The dilemma can be resolved by coating the 3d object with a conductive layer. This can include silver or copper conductive paint, graphite spray or graphite power mixed in a binder to form a paint or ink. The silver and copper paints are very expensive and not something you would consider for



Example of dendrites and uneven copper plating.





The 3D printed clock spandrels sprayed with Zinc Primer



large 3d objects to be used in a model engineers' workshop.

For my first attempt at making a 3d object conductive, I tried the graphite aerosol spray. I did some research and decided upon Graphite 33. It's described as a thermoplastic binder with electrically conductive graphite powder and in the instructions, it states that it can be used as conductive coating for electroplating of non-conductive materials. It is also reasonably priced. The average price is about £10 - £15 for a 200ml can. For my experiment, I used a 3d printed clock spandrel as a sample piece. This was a complex shape and would be a more extreme test for the robustness of the process. The spandrel was generated using photogrammetry from an actual 18th century brass clock spandrel and printed by my Peoply Moai, **photo 2**.

In preparation for the electroplating experiment, the 3d part was thoroughly cleaned with hot water and washing up liquid, brushed down with IPA and allowed to dry before applying 2-3 coats of Graphite 33 aerosol spray paint.

The surface wasn't initially conductive but after polishing with a brass wire brush, I achieve results less than 4kΩ.

To test Graphite 33 paint and its properties for electroplating I decided to try copper electroplating (set up described later).

Unfortunately, the results of my first trial were not good, the copper plating was uneven and took over 10 hours to build up. Initially, I started with a low current around 200mA but as the hours went by, I gradually turned up the current to 500mA.

This resulted in some delamination and forming of dendrites (tiny, spiky, snowflake formations), **photos 3 and 4**. I also found that the bond between the Graphite 33 paint and copper wasn't very strong and was easily removed. I had several attempts at electroplating the paint, varying my technique each time. I found altering the tank shape to suite the model shape improved the process,



Flash coating of copper on Zinc Primer

but the quality of the output and the time taken to get a result meant that this was not a viable process. I think the conductive surface oxidised quickly and this resulted in an uneven plating surface.

Next, I tried Graphite powder mixed with varnish and deionised water. Graphite powder is mixed with varnish to make a thick paste and then this is diluted with the deionised water to make an ink like solution that can be painted onto the 3d model. The varnish needs to be a solvent-based product as a water-based solution will dissolve in the electroplating tank. Two to three coats are required to make the surface conductive. The painted surface was conductive after drying and when measuring with a multimeter yielded results of 2-3Ω.

Again, I tested the graphite powder paint solution and its properties with copper electroplating.

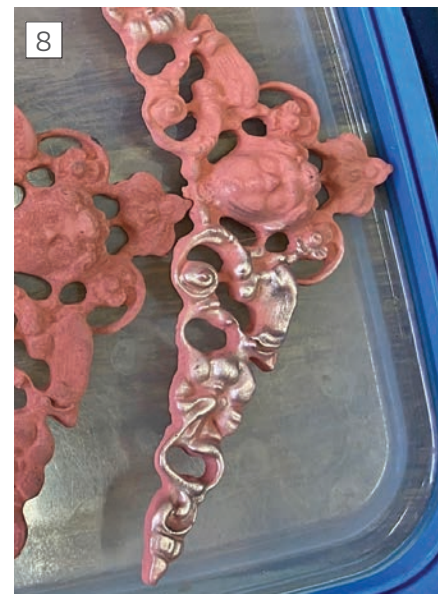
Care had to be taken as the graphite surface was more fragile and prone to chipping or rubbing off, especially when placing the part within the cathode cradle / wire for electroplating and when turning of the part within the cathode wires to gain an even coat during the plating process. The graphite paint

was more successful, but it still took up to 3 - 4 hours to get an even flash coat of copper and 8 -12 hours for a reasonable copper layer to be deposited on the 3d part. The resultant plating also required a lot of post processing, using wire wool and brasso to even out the plated surface and create a highly polished shine. For one offs, this is something that could be considered but having an electroplating tank bubbling away for days on end would, I think, cause problems with the domestic management.

At this point, I paused the project. It didn't seem viable. The copper plating was just one increment in a multi-step process which included additional processes of plating in Nickel and Brass. The end goal was to make reasonably authentic brass adornments and other parts for antique clocks without the hassle of pattern making and casting parts which require a new set of skills and investment in equipment.

Redox reaction

The COVID-19 Pandemic created an opportunity to re-visit electroplating 3d



Result of polishing plated part with brass brush

parts – working from home and without having to commute has meant that I have had more time to spend on my on my hobbies. During more research on the internet, I read about the redox reaction and the transfer of electrons between chemicals / materials. One such reaction was between zinc and copper. Initial trials confirmed the reaction and proved a breakthrough in making my 3d objects conductive.

Several aerosol cans containing zinc primer were purchased and each data sheet scrutinised for actual zinc content in the paint.

For my trial as before, I printed 3d spandrels parts, these were post processed, thoroughly cleaned with hot water and washing up liquid, brushed down with IPA and allowed to dry. The parts were sprayed with zinc primer – just enough to cover all the sides of the 3d printed object without losing detail due to build-up of paint and finally left overnight to dry thoroughly, **photos 5 and 6**.

When testing with a multimeter the 3d printed parts were not conductive.

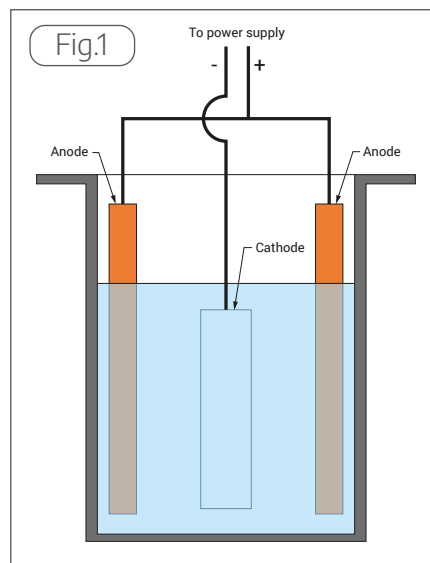
I repeated the same copper electroplating process as before – this time starting at a low current 200 mA and gradually built up to 500mA. Within 20 minutes an even flash coat covered the 3d printed object. I removed the part from the solution and thoroughly washed and dried it.

The multi meter indicated that the part was very conductive (less than .001 Ω) across the widest ends of the 3d printed object, **photo 7**. The finish was a matt salmon pink colour and could be polished by using a brass wire brush, **photo 8**.

Twenty to thirty minutes in the copper electroplating tank resulted in a flash coat of copper, which was highly conductive and ideal to be used with other plating material processes. A thicker copper plate took about four or five hours but not days as before and I guess this could be optimised by using



Copper Electroplating set up.



a stronger acid in the plating solution or buying a readymade solution. This did not concern me as the copper coating was used to make the object conductive, my goal was to create bright nickel and brass objects to be used on the clocks.

Equipment required for electroplating:

Suitable container for the electroplating process.

Storage containers for the solutions.
Some washing line pegs.
Old nylon stockings
Copper wire (can be stripped from old insulated electrical cable)
Crocodile clips.
30v 5amp power supply or a low voltage transformer (i.e., phone charger).
Aquarium Air Pump - Not essential but improves plating results by agitating solution.
Wood rod / small piece of batten (to support cathode)
Fish tank heater – temperature range 25-30 degrees

The Copper Electroplating process Health and Safety

Before I describe the chemical mixing and the processes involved in electroplating, I must first remind the reader about Health and Safety. Do not touch chemicals or processed components with your bare skin. Use rubber gloves and wear eye protection when electroplating, ensure good ventilation and make sure the work area is not accessible to young children or pets. Mark up your storage containers to identify their contents, follow any



Copper Electroplating set up.



Example of copper support cradle for Cathode, during plating

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data sheets for safety and ensure safe disposal of the chemicals. Following these rules, the electroplating process is no more hazardous than any other daily activity we conduct in our workshops.

I decided to use an internet-based recipe for copper electroplating rather than purchase it ready made from a company. For my trials this was the easiest solution, as I didn't know how successful it would be and the cost of the materials were cheap and readily available.

These are the materials I used to make the copper acetate plating solution.

- Distilled Vinegar – white or malt
- Copper sulphate – need 75 grams per litre
- Table spoon of salt
- Polyethylene Glycol
- Deionised water
- Copper (old water or central heating pipe) 2 pieces required.

The vinegar (acetic acid) is readily available from your supermarket or



Nickel Electroplating setup

purchased online. Buy five litres, you will need a minimum of 1.5 - 2 litres for electroplating and the left-over vinegar can be used to top up the solution. To prepare the solution, heat 1 litre in the microwave until the solution is about 50c and then mix in the Copper sulphate. You will need to stir the solution for 20 minutes or more until the sulphate dissolves into the liquid solution.

Add a tablespoon of salt and again stir until dissolved. The salt is used to increase the conductivity of the solution.

Brightening Agent

Brightening agent – this is used as a plating leveller, helping to even out the plating process and produce a brighter plated part which requires less polishing and post processing.

It is made by mixing 2 parts deionised water to 1 part polyethylene glycol by volume and stir until dissolved. The polyethylene glycol will dissolve quicker if the mixing vessel is immersed in hot water. I have read that saccharine sugar alternatives can be used for the same thing, but I have not tested it. You don't need to purchase Deionised water, mine



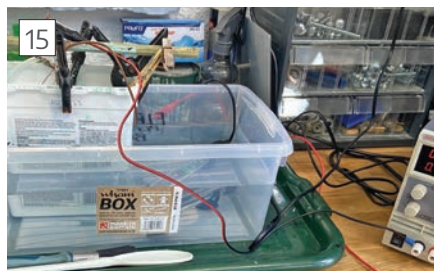
Copper plated spandrel polished by polishing mop

came from the water pumped out from our tumble drier!

50ml of the brightening agent should be added to the copper sulphate solution initially but this will need to be topped up periodically, as it depletes in the plating solution.

For the setup, please see **fig. 1** and **photos 9** and **10**.

For best results the plating tank / container should be slightly larger than the 3d print – the outline should match the shape of model i.e., a rectangular



container for long thin parts (such as my clock spandrel 3d part) or a cylindrical jar for objects with a which are square or circular. Do not use a large bath as you would for general electroplating. It will result in an uneven layer and require a higher current. The material used in 3d printing acts as an insulator. A high current will result in heating within the plated layer causing delamination and burning. I used a container which held laundry capsules (washing machine

capsules) for the plating vessel. This was immersed in another tank, again plastic, which held warm water and an aquarium heater.

Pour copper acetate into the electroplated vessel. Use two anodes (copper pipe) fully immersion in the solution, cover with stocking or material to insulate anodes from cathode and help retain any debris in the solution. Connect the insulated positive supply wire to the top of the anodes using crocodile clips. The part to be plated (the cathode) is suspended in the plating solution by a copper wire cradle attached to a wooden rod which rests on the top of the vessel. The negative supply is attached to the copper wire cradle via a crocodile clip. Do not wrap the copper wire cradle too tightly around the part to be plated or you will end up marking the plated surface. The copper wire cradle should support the 3d part in the solution but not clamp it, **photo 11**.

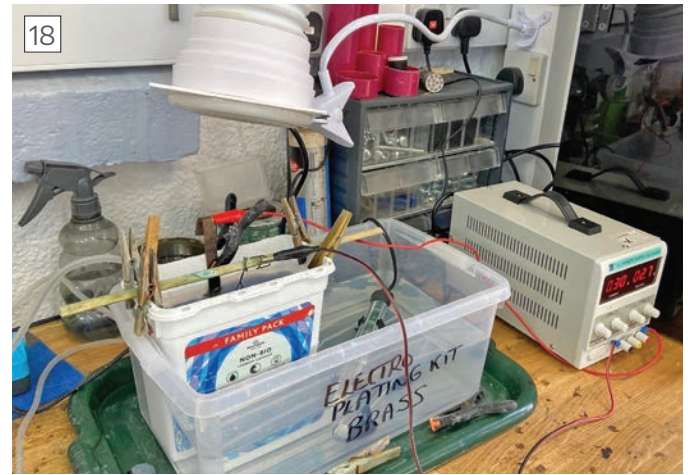
Use a fish tank aerator to move the plating solution around. Start off with a low current around 200mA. Turning the current up too high will result in delamination of the 3d print and burning



Nickel plated 3d clock spandrel



Nickel plated 3d clock spandrel



Brass electroplating setup

/ uneven coating of copper.

The voltage from the power supply is not important but current should start off low (around 0.2Amps) and gradually increase current as the copper layer builds up. As a general rule current should be 0.1Amps per square inch of surface to be plated. You can use a low voltage transformer for electroplating, I used a variable 30v 5amp power supply as this allows me to adjust the current during the Plating process.

A thick coating of copper would take 5-6 hours to build up this could then be polished by a light polish with a brass wire brush or via a polishing mop, **photos 12 and 13**. Be careful using a polishing mop the parts can still be fragile - don't ask me how I know!

As stated earlier my end goal was to plate 3d printed parts in nickel or Brass. So, for my trials most of my parts were flash coated in copper. This resulted in them being highly conductive and perfect for other plating processes.

Nickle plating solution

Instead of opting to make my own plating recipe for nickel, I opted to buy a solution from a company called Youplate.co.uk. They have their own website and also a presence on ebay. They supply a ready-made bright nickel solution which should produce a shiny nickel finish. This would provide a useful option for plating numbers and other decorative items for the clock faces, but it could also be used as a background colour and surface finish when flash plating with other material coatings.

These are the materials required for bright nickel plating.

- Bright nickel-plating solution – www.Youplate.co.uk
 - 1mm 99.5% Nickel (Ni) sheet plate for electroplating anode 100x100mm - Ebay
- Cut the plate into 25mm wide strips to



Bronze sample part showing plating burns



3D printed clock spandrel Brass electroplated

use as anodes.

After several trials I found the optimised setting for my 3d printed spandrel which had previously been flash coated with copper.

Nickel plating optimised settings

I used the same rectangular plating vessel I had previously used for copper plating. The Nickel anodes need to be fully immersion in the plating solution. Cover with stocking or material to insulate anode from cathode and retain any debris from anodes, **photos 14 and 15**. On some plating processes it is not critical to have two anodes in the tank, you can get by using one only. It is important to have anodes on both sides of the part for nickel plating to stop any potential plating shadows forming. The initial current needs to be higher for nickel to deposit on the 3d printed object, I found 0.75 – 0.8 Amps was a good starting point– be careful not to increase it too

much or you will get delamination or burning. Too low a current will mean poor coverage and a dull finish.

One other point! If you attach a retaining wire to the anodes, ensure its not in the solution as this will contaminate the Nickel-plating solution. If you need to use retaining wires to your anodes, fasten them with titanium wire as this does not affect the solution.

I found that I could produce bright highly decorative 3d Nickel coated objects with the above set up in about 30 minutes to 1 hour. After this plating process you could feel the component was heavier and had improved strength and robustness.

A brighter / glossier part was achieved by removing the top matt surface of the copper plating carefully with a brass wire brush. This helped to emphasize the highlights of the 3d printed part against the recesses and inner surfaces of the holes. Resulting in a part that looked more like it was cast in a mould, and then polished with a polishing mop.

I now had several trial parts, some flash copper plated with a matt salmon pink surface, others, with highlights polished with a brass wire brush, and then several each of the latter which were Bright Nickel plated, **photos 16 and 17**. I wanted to see what they would look like after plating a Brass solution on top!

Brass electroplating

Brass is an alloy. Historically, the ratio between copper and zinc was controlled using a cyanide-based solution, this is not something one could consider in a domestic setting. Gateros Plating Ltd, sell cyanide free brass plating kits. This is advertised as a flash plating process and it is used to create a brass finish in which the colour and brightness is affected by the base plating. Bright nickel or zinc plating leading to a brighter yellow / golden brass finish and a darker slight



Zinc plated 3d printed clock spandrel



Zinc 3d part polished with brass wire brush

green tint when plating on copper.

These are the materials required for brass plating kit;

- Brass Plating Kit - 5L -

www.gaterosplating.co.uk

Anodes are supplied as part of the kit.

Both the Copper and Nickel-plating processes were relatively easy to setup and achieve good results. The Brass plating process is critical in its set up, slight variations from the optimised setting will leave you with bronze or even black coloured plated parts!

The kit is supplied to make 5 litres of brass plating solution. Also supplied, is a plating vessel, voltage regulator and acid pickle cleaning solution – very useful for clean your parts before plating!

Ingredients should be mixed as per details supplied with kit.

The plating setup is identical to the copper process, but I found that one anode only worked better and only 2cm of it immersed in the solution. Do not cover the anode, as you will need to see and monitor the colour of the anode immersed in the solution. Current should be set at about 0.2 – 0.3 Amps. A sacrificial part should be run in the solution for a few hours to prime it. Ensure the anode runs clean – the colour will vary depending on current. The anode immersed in the solution should be a brass colour and not black. Add brightening agent described earlier periodically to the solution. Plating solution should end up a dark blue colour, **photo 18**.

I cannot stress the importance of following the plating instructions carefully. It is critical to find the correct current and ratio of anode within the plating solution, to create a brass finish on the part. The bronze finished sample part in **photo 19** is in fact, a result of this. I had too much anode immersed in the brass solution whilst plating. It also shows an area of burning where I set the current too high. It is important to have sufficient current to keep the anode clean and stop it going black. I found that slight changes to the current would result in a variation in the brass colour result – with colours ranging from brownie green to bright golden yellow, too little current

rendering the part grey or black.

Set up as per copper plating but with one anode only the size of a little finger and about 2 cm into the solution to maintain it and the ratio of solution. Current about 200mA -300mA – ensure anode runs cleanish – the colour will vary depending on current. Add brightening solution periodically.

The finished result creates a bright brass finish if previous plating coat was bright nickel, **photo 20**. A matt Brass finish will be the result from a flash coated matt copper finish. Use wire wool and Brasso to brighten the surface if required. I have not, to date, tried Zinc plated parts in the Brass solution.

Zinc plating

This was a homemade recipe, these are the materials I used to make the Zinc plating solution.

- Distilled vinegar – white or malt
- Table spoon of salt
- Polyethylene glycol
- Deionised water
- 2pcs Pure Zinc (Zn) sheet plate electroplating electrode anode 1mm 100x150mm - Ebay

Cut the plate into 25mm wide strips to use as anodes.

I used the same rectangular plating vessel I had previously used for copper plating. The Zinc anodes need to be fully immersion in the plating solution. Cover with stocking or material to insulate anode from cathode and retain any debris from anodes. A sacrificial part should be run in the solution for a few hours to prime it. I found 0.5 – 0.6 amps was a good starting point– be careful not to increase it too much or you will get delamination or burning.

The plating solution resulted in a disappointing matt grey finish, **photo 21**. After buffing with a brass wire brush it resulted in the highlights of the 3d printed spandrel obtaining a silver finish and the recesses of the part staying a matt grey, helping to emphasise the 3d properties of the part, **photo 22**. I haven't got around to it yet, but I want to try flash coating the polished zinc

surface with the Brass plating process to see what the result is!

So, there you have it, the outcomes of all my trials electroplating 3d printed objects. Zinc primer applied to a 3d printed object and then copper plating to make it very conductive, transformed the options for further processing. Albeit, Bright Nickel, Zinc, Brass, Gold, Silver and chrome, the options are endless.

The copperplate adhered quicker on high zinc content primers. Other Zinc primers still worked but they just took longer to plate. I did try plating with other materials onto the Zinc primer but with no result.

The plating process certainly resulted in stronger, less brittle parts, which had a solidity that felt more like cast parts. The colouration looked pretty genuine as well, with slight colour variations resulting as a by-product of the plating process, **photo 23**. Hopefully it will inspire some of you to review the usefulness of your 3d printers and perhaps re-look at the opportunities that could be achieved with 3d Printed objects that are electroplated. Either to aesthetically change their colour to look more like cast items or change the objects properties of strength and durability. ■



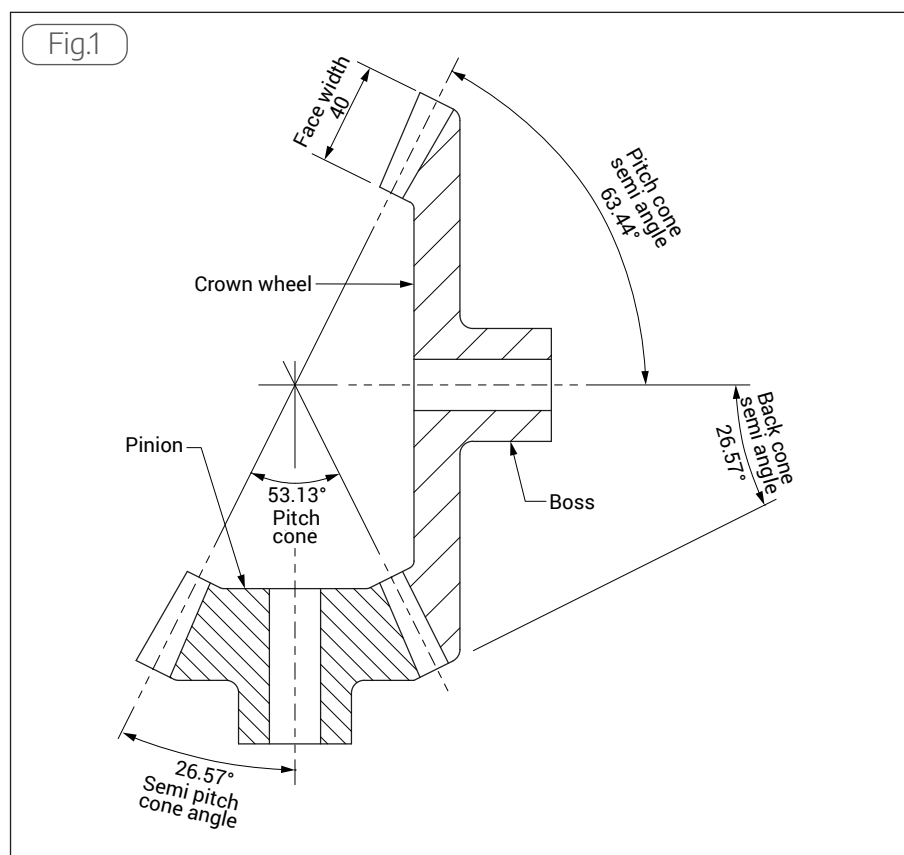
Results of my trials, the bottom left-hand corner was the original cast brass spandrel from an antique clock.

Bob's Better Bevels Part 1



Bob Reeve explains the maths behind making accurate bevel gears.

My attention was drawn to the rather specialised area of bevel gears by friend Pete. He had been approached by a relative wishing to build a model traction engine. Unlike model railway locomotives, these are fitted with a differential gear, usually housed in a rear wheel and containing a number of bevel gears. Knowing my interest in gears, ref.1, it seemed reasonable that I might be able to help. It soon emerged that I could not! But Pete had done a lot of research and provided me with a number of useful references. That sparked my interest, but not much understanding. I then had to spend a few hours with ref. 2 getting to understand the nomenclature and find what constituted current practice for a model engineer.



Bevel gears come in all sorts of shapes and sizes, **photo 1**. They have been around for a long time, sometimes seen driving the governor on a stationary engine, or sometimes hidden in an IC engine driving the cam shaft. They feature in both model and full-size practice, but are always more of a challenge to the manufacturer than a simple spur gear. The difficulty lies in creating teeth that will mesh satisfactorily even though they are constantly changing in section across the face of the gear. These teeth vary in both width and depth along their length.

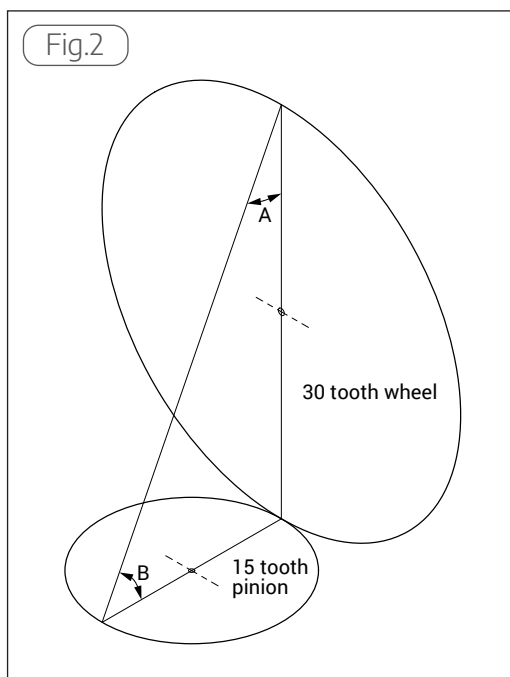
Specialist gear manufacturers have dedicated machines for the purpose. These are generally large, expensive, and require special cutters. They are definitely not suited to those needing only an occasional pair of bevel gears to be manufactured in the garden shed. But Model Engineers are not the only people that have needed to produce bevels with minimal equipment.

In wars gone by, the demand for bevel gears increased rapidly because of their use in military equipment. The specialist manufacturers and their

specialist machines were unable to respond quickly. An approximation attributed to AD Pentz (ref. 4 p144) was developed to enable bevels to be cut on a milling machine fitted with a dividing head. The method involved cutting teeth of constant depth so the roots of the teeth were parallel with the surface; usually known as parallel bevels. It was a great improvement on even earlier methods which could involve a lot of manual filing. It did produce useable bevel gears but with noticeable degradation of performance compared with those produced on the more sophisticated machines. It is the method currently used by many Model Engineers.

One initial result of my investigations was that, over the years, errors had crept into accepted sources of information on how to make parallel bevels. Another result was that some of the limitations of the original method can now be overcome by the use of CNC machines. What follows explores both of these aspects. However, one of the sources of error is the confusion of the sine/cosine functions. When dealing with 1:1 bevels at 90° (also known as 45° or mitre), these two functions have the same value, which is possibly why the error was not initially spotted. Such bevels are the most commonly used, but the examples given below are mainly 2:1 bevels to minimise the opportunity for errors, some of which originally occurred in the calculation of the PCD.

The essential starting point for



me was to get to grips with the nomenclature. **Figure 1** shows a pair of 2:1 bevels destined to run on two shafts at 90°. The figure is based on industrial practice for gears that would have probably been in cast iron. Model gears are of course smaller and more likely to be machined from bar in mild steel or brass. Although the tooth geometry needs to be precise, strict adherence to the overall shape and style might only be necessary if the gears were a prominent feature on the prototype; for example to drive the governor on the boiler barrel of a traction engine.

Pitch cones are an important concept

for bevel gears and are shown as dashed lines in fig.1. They are the equivalent of the pitch circle for spur gears. A section through a pitch cone, at right angles to the axis, is a circle. The circle at the small end is treated as a pitch circle for the purposes of calculating the diameters at the small end of the bevel.

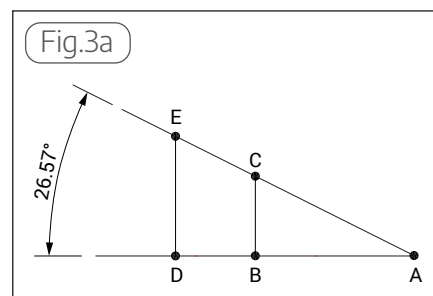
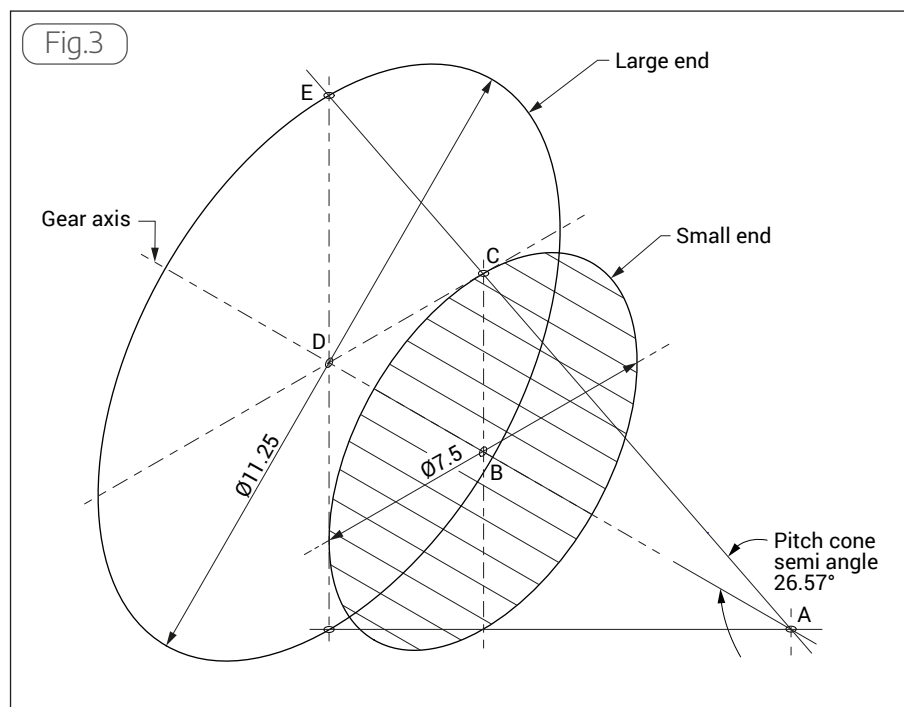
The pitch cones represent the smooth surfaces that will run together without slip and give the right gear ratio. It should be apparent that this theoretical concept does not lend itself to being measured directly with a digital calliper.

Another important concept is the back cone, formed by the end of the gear face at the large end. This face is at right angles to the pitch cone and is used in calculating the gear cutter to be used. However, for small bevels hidden from sight, the back cone (and front cone) may not be as in the diagram but the calculations will need to be done as if it were.

Figure 1 illustrates a section through a commercial bevel gear as machined by one of the processes giving fully formed teeth. Note that the tooth depth varies along the length of the tooth, unlike parallel bevels which do not. For that reason if the pinion had 15 teeth starting at approx. module 5.0 at the small end it would increase in cross section to about module 7.33 at the large end. Therein lies the difficulty in producing such a gear with a single gear cutter.

2 : 1 Bevel Gear 15 & 30 teeth 0.5 module

The design of a pair of bevel gears is more involved than for spur gears. It is important to identify the constraints early so as to avoid too much iteration. This usually starts with a requirement to give the right ratio, the right angle between input and output (usually 90°) and approximate dimensions that will fit the space available. For the latter, the size of the bevel is primarily determined by the number of teeth and their size. Diametral pitch, circular pitch and module have all been used as a measure



of tooth size. Module is used here because when the module increases the gear tooth size increases, so its use is more intuitive and easy to scale. It also seems to be the preferred measure for metric gears.

There are also restrictions on the minimum number of teeth, normally 12 but preferably higher. There are additional requirements for high torque or high power applications, but these will not normally be of concern for small models.

A typical starting point for a Model Engineering application might be a pair of 2:1 bevels at 90° with 15 & 30 teeth of module 0.5, which will produce gears of the sort of size used by model engineers.

The next stage is to calculate the basic pitch cone geometry for each gear. It is easy to get the angles confused so, as a check, the smaller angle is associated with the gear that has the smaller number of teeth.

Figure 2 shows an easy to visualise approach to calculating semi-pitch cone angles for 90° bevels by using the pitch circle diameters which are proportional to the number of teeth. Strictly speaking this requires the pitch circle radius as in fig. 1, but the result is numerically the same doing it this way.

From fig. 2, Angle A = Semi pitch cone angle 15 tooth gear: $\arctan 15/30 = 26.565^\circ$

Angle B = Semi pitch cone angle 30 tooth gear: $\arctan 30/15 = 63.435^\circ$

Note that these angles are the same as in fig. 1 and that one angle is the complement of the other. The latter is another possible source of the sine/cosine error mentioned earlier.

Next comes the detailed design of the gear blank, starting with the small end of the small gear.

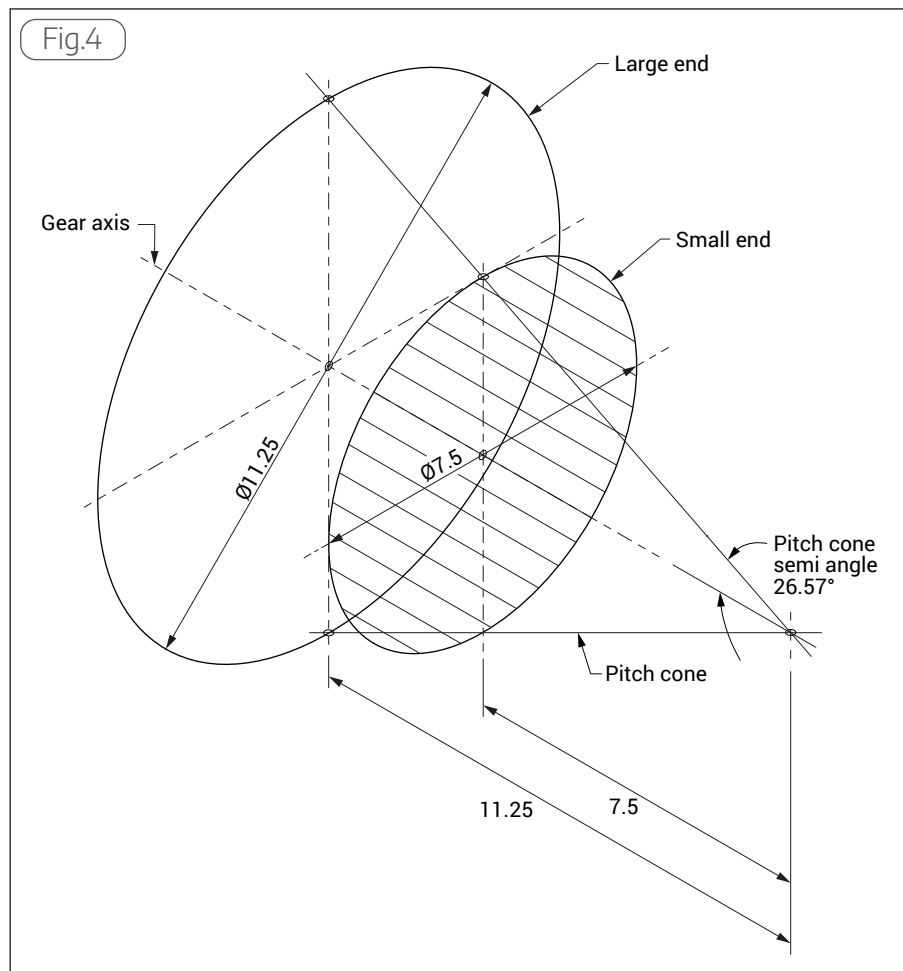
Pinion 15 teeth

One convenient way to design a gear blank is to start with an idea of what the pitch cone looks like, then add the teeth.

The pitch cone angle is as calculated above. Next is the calculation of the pitch circle diameter at the small end. This is treated as if it were a thin gear of the same diameter, module and number of teeth. In which case the usual formula applies:-

Pitch Circle Diameter small end = $N \times M = 15 \times 0.5 = 7.5\text{mm}$ diameter Where N = no teeth & M = module

The pitch circle diameter at the large end is derived from the face width, which in general should be no more than $\frac{1}{3}$ rd of the distance from the back cone to the apex along the pitch cone.



This rule of thumb is intended to avoid very thin and delicate teeth which could be created by having the face width extend too close to the cone apex. Such teeth would not be able to transmit much torque and be prone to accidental damage. At the large end of the cone the teeth would have an exaggerated stub form discussed in Part 4.

Figure 3 shows the geometry with the available dimensions at this stage. The diameter at the large end is calculated next. The pitch cone apex is at A and the face width is CE. So CE should be no more than $\frac{1}{3}$ of AE. It is required to find DE the radius of the large end and hence the pitch circle diameter which will be $2 \times DE$.

Figure 3A shows the relevant geometry stripped out from fig. 3 for clarity.

ABC and ADE are similar triangles in the mathematical sense (i.e. same angles but different side lengths). So the ratio of any two equivalent sides of the triangles will be the same:

$$AC/BC = AE/DE$$

So:

$$DE = AE \times BC / AC$$

The rule of thumb gives $CE \leq AE/3$ ($\leq$ means less than or equal to). But

inequalities such as this are not familiar territory to many model engineers and for the sake of simplicity it is probably better to deal with the limiting case, then apply the inequalities in the rule of thumb at the end. So for the limiting case $CE = AE/3$

$$AE = 3 \times CE$$

$$CE = AC/2$$

$$AC = 2 \times CE$$

substituting gives

$$DE = BC \times 3 \times CE / 2 \times EC = 1.5 \times BC$$

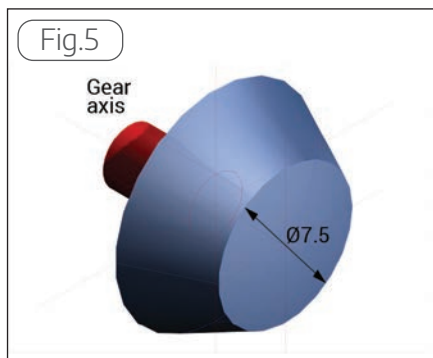
Applying the rule of thumb at this stage indicates that DE can be equal to, or less than $1.5 \times BC$ if it were necessary to design it that way. Expressed mathematically this becomes

$$DE \leq 1.5 \times BC$$

An alternative and quicker route to the same conclusion is to use similar triangles again. So that if the rule of thumb gives AE as $3/2 \times AC$ then DE is $3/2 \times BC$.

However, there appears to be some flexibility in the rule of thumb. Some commentators suggest $\pm 1/32$ inches (0.8mm) would be acceptable.

To be consistent, since it was the diameter of the small end that was calculated, the diameter of the large end should also be used i.e. $2 \times DE$ as above.



So the large end diameter becomes $2 \times DE \leq 3 \times BC \leq 11.25 \text{ mm}$.

For the current example of 15 & 30 tooth bevels at 90° , the next step is to calculate BD which is one of the dimensions required for determining the size of the blank required. Again, the calculation is for the limiting case where the face width $AE = 1.5 \times AC$ and the pitch cone semi angle is that calculated from fig. 2, i.e. 26.565° .

From fig. 3A:

$BD = AD - AB$

By similar triangles:

$AD = 1.5 \times AB$

$BD = 1.5AB - AB = AB = 2$

And:

$AB = 2 \times BC$

But:

$AB = BC / \tan 26.565$

From fig. 2:

$\tan 26.565 = 1/2$

Substituting:

$BD = BC = 3.75 \text{ mm}$

ie. the small end pitch circle radius

Figure 4 is an updated version of fig.3 with the additional dimensions added. It is drawn to scale so will represent the

appearance at this stage

So for a 90° 2:1 bevel, the smaller gear blank always has a thickness numerically equal to the smaller pitch circle radius. However this shortcut is not available for different ratios or bevels not at 90° .

It would then be necessary to use the more general form of the equation:-

$BD = BC / 2 \times \tan \theta$ where θ = semi-pitch cone angle

Note that the face width CE has not been calculated. But the calculation above ensured that it was less than $1/3$ of the distance to the apex (EA). However, the face width will be required later to ensure it matches the face width of the crown wheel and it is convenient to calculate it here. This is made easier having now calculated BD since the angle between them is the pitch cone semi-angle.

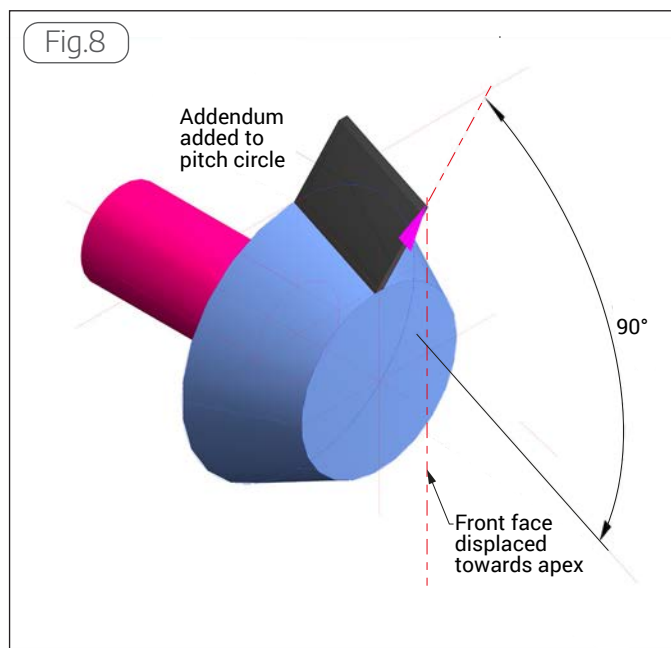
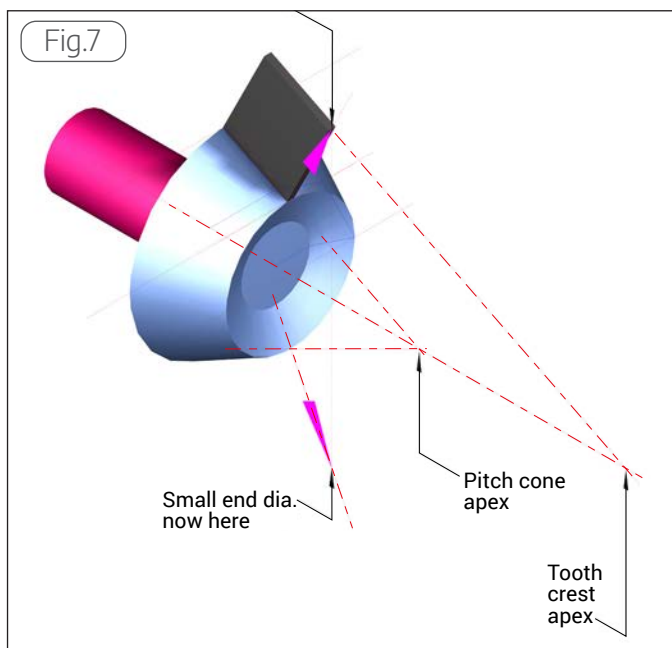
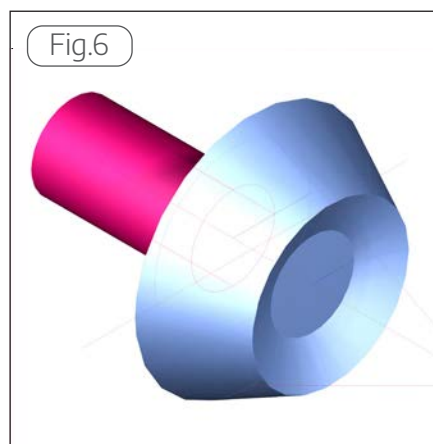
Face width $CE = BD / \cos 26.565 = 3.75 / \cos 26.565 = 4.193$

To the dimensions of the pitch cone, the dimensions of the gear teeth must be added to arrive at the dimensions of

the gear blank. To be more exact, the addendum of the gear teeth must be added, since the dedendum is the bit below the pitch cone surface and will not add to the dimensions. Theoretically the addendum and the dedendum are the same as the module in this case 0.5 mm. In practice the dedendum is increased slightly to allow for a little clearance at the root of the teeth which will help with the circulation of lubricant and removal of wear debris. Commercial Brown & Sharp style gear cutters are often marked with the depth of cut required and is sometimes designated as D+F. The 0.5 module (20° Pressure Angle) cutters used in this article were designed to cut 1.1 mm deep. The outside diameter of the gear blank does not need to be changed to allow for this. The clearance is generated at the root of the teeth and the crest stays where it is.

Curiously, in my experience, parallel bevels, when installed, seem less sensitive to tooth depth than spur gears. For the latter, the spacing between two gears running together alters with the cut depth unless the blank size is corrected accordingly. However, the inter-gear distance is fixed by the position of the two shafts carrying them and is often difficult to alter. This is not true for bevel gears where the meshing of two gears can be changed by sliding them along the shafts slightly. The equipment used for determining this is described later.

The next step is to calculate the size of the blank needed for the teeth to be machined. The pitch cone diameters need to be increased to accommodate the addendum. The increase in diameter



of the small end will need to be the same as the increase for the large end, otherwise the result will not be a parallel bevel.

The addendum is 0.5 mm but this must be added normal to the pitch cone surface and there are variations on exactly how this is done.

Figure 5 is the solid model derived from fig. 4. It shows a simplified version of the pitch cone as a truncated cone with flat ends. Allowing for the dedendum, the 7.5 mm diameter pitch cone at the small end leaves little room for a shaft passing through the centre or a front cone face. So a flat front face might easily become a welcome simplification. A flick through the bevel gear section of a commercial gear catalogue will reveal this simplification to be present on most of the smaller bevels.

However, if circumstances demand it, the pitch cone could be provided with front and back cones as in the full size example of fig.1. The result would be as in **fig. 6**.

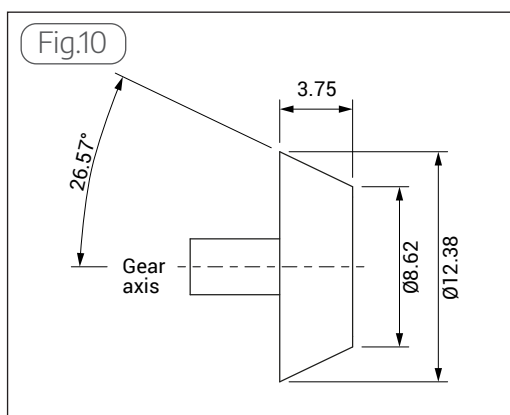
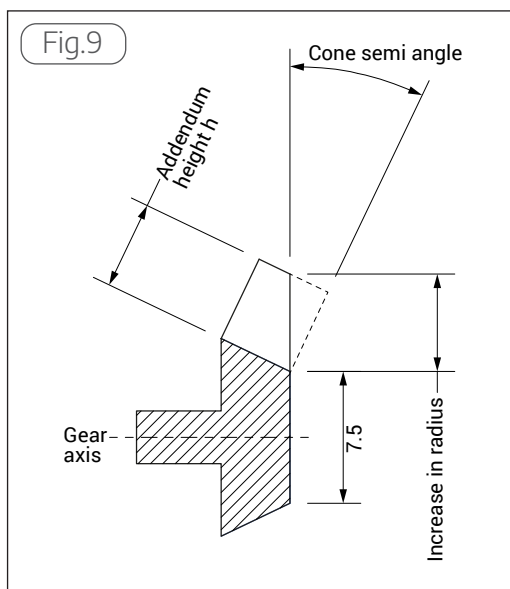
If the front cone is not present, then cutting the dedendum will need to extend slightly further forward towards the pitch cone apex. In the small sizes used by model engineers this will probably not be significant.

In either case, the next step would be to add the gear teeth addendum to the pitch cones so the outside diameters of the gear blank can be calculated. For the purposes of illustration the tooth height has been exaggerated by a factor of ten to highlight some of the implications.

The first of these (**fig. 7**) is that, for parallel bevels, the apex of the pitch cone is not in the same place as the apex for the tooth crest cone. The latter is extended beyond the pitch cone apex. This is not the case for the fully formed bevels in fig. 1.

This is not the only geometry extended forwards. The coloured arrow represents the (exaggerated) addendum of teeth with their roots on the edge of the gear face at the small end. As can be seen, the arrows line up with the front cone but the tips of the teeth are not in the plane of the cone lip, but beyond it. It does raise the question of what exactly is meant by "the outside diameter at the small end" and where it should be measured.

Overall the gear will be slightly



longer and heavier than might be expected from fig.3. Not by much, but in the timing cover of a model aircraft IC engine, space is tight and weight is the enemy.

The situation is much the same if the plain pitch cone of fig. 4 is adopted, as can be seen in **fig. 8** (still with the

exaggerated tooth height).

However, most Model Engineers are pragmatists and if the size or weight were a problem, they would just machine a bit off!

In which case why put it on in the first place? Since the pitch cone has a flat front face all that is required is for the flat to continue across the addendum.

The calculation to do this is simple, but did not occur in any of the reference works I accessed. The corrected diameter at the small end was not there either. But for a quick & accurate bevel, this is the way to go.

Figure 9 is a cross section of fig. 7. Note that the part of the tooth within the dotted red outline will not be created.

The increase in radius of the blank at the small end is given by:

Increase in radius = Addendum height

$\cos(\text{cone semi-angle})$

So the small end diameter becomes:

$$D = (M \cdot N) + 2(h / \cos \theta)$$

Where:-

θ = pitch cone semi-angle as before.

M = module

N = no. teeth

h = addendum height.

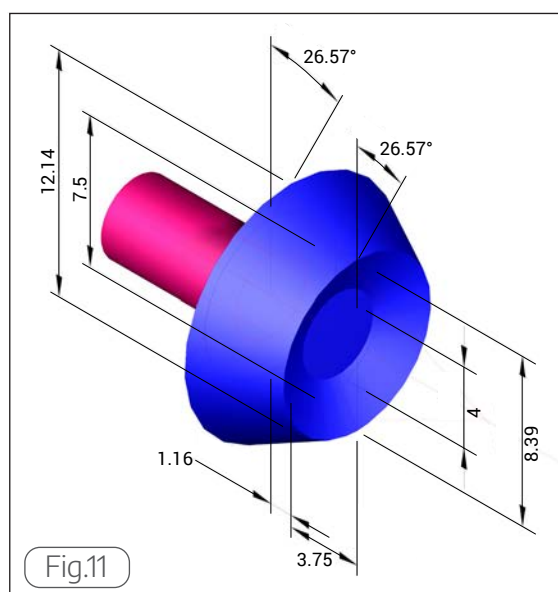
For the small end of the 15 tooth bevel mod 0.5

$$D = (15 \cdot 0.5) + 2(0.5 / \cos 26.56) = 7.5 + 1.118$$

$$= 8.62 \text{ mm}$$

For the large end, the diameter will be $11.25 + 1.118 = 12.37$.

Figure 10 shows the sizes required for the simplified blank. Note the slight chamfer on the large diameter has been removed to further simplify manufacture.



However, in the case of a bevel which will be a prominent feature of a model and needs to be faithful to its industrial prototype, then the gear blank needs to be slightly larger. There needs to be a slight extension towards the apex to accommodate the front cone. So, for those looking for a gold medal from the judges, **fig. 11** gives the dimensions as generated by the CAD model. A diagram similar to fig. 10 could be used to calculate these manually if required. Note the 4mm dia at the small end is sized for a 3mm shaft and the outside diameters at both ends are reduced because the corners of the teeth are now nearer the cone apex, as discussed earlier.

For those that doubt that such a small component would attract much attention, this might be a good point to introduce Bob's Beautiful Bevel Theory. The key is that bevels, especially small ones, have the same geometric elements (concentric rings and radial petals with a contrasting centre) as daisy-like flowers. Since these attract the attention of pollinators and humans alike, they will surely attract the attention of the Judges!

The next stage is the calculation of the cutter to be used. I found the logic for this to be particularly obscure. The same methodology appears in ref. 2, ref. 3, ref. 4 & ref. 5 but some have errors. The methodology has clearly been around for a long time, but I found the explanations less than convincing. In order not to disrupt the manufacturing sequence, I have added my own rationale to follow in Part 2.

The cutter to be used will be selected from the set of 8 that form the Brown & Sharp set (Ref 2 p64). Cutter No.1 is for racks down to 135 teeth and cutter 8 is for 12 or 13 teeth. The cutter selection is based on the diameter of the large end, despite the fact that the gear blank was originated from the diameter of the small end.

Figure 12 shows a cross section of a 2:1 parallel bevel pinion. BD represents the pitch circle diameter at the large

end. BC and CD are projections of the back cone to intercept the gear axis. It is these lines that are used to represent the hypothetical radius of the effective pitch circle for which the cutter will be chosen.

This pitch circle diameter has a larger diameter and could accommodate more teeth of the same size. 15 teeth occupy diameter BD with radius BE.

$$\cos 26.57 = BE$$

$$BC$$

$$\text{So } BC = BE \cdot$$

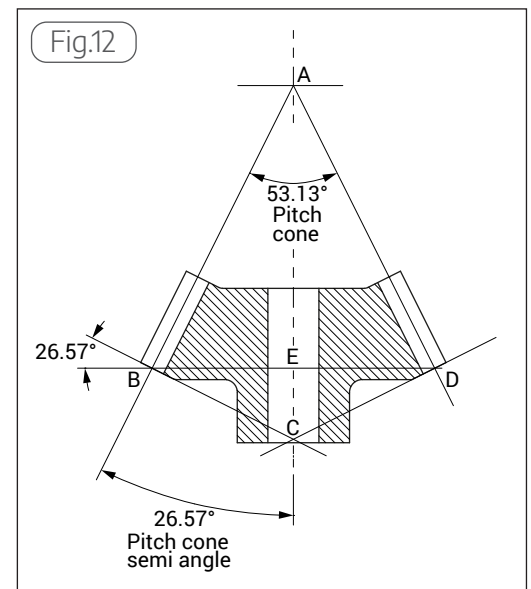
$$\cos 26.57$$

The diameters are in the same ratio, as are the circumferences, so the new number of teeth is:

$$= 15 \cdot = 16.8$$

No 6 cutter covers 17 to 20 teeth and is therefore the one to be used.

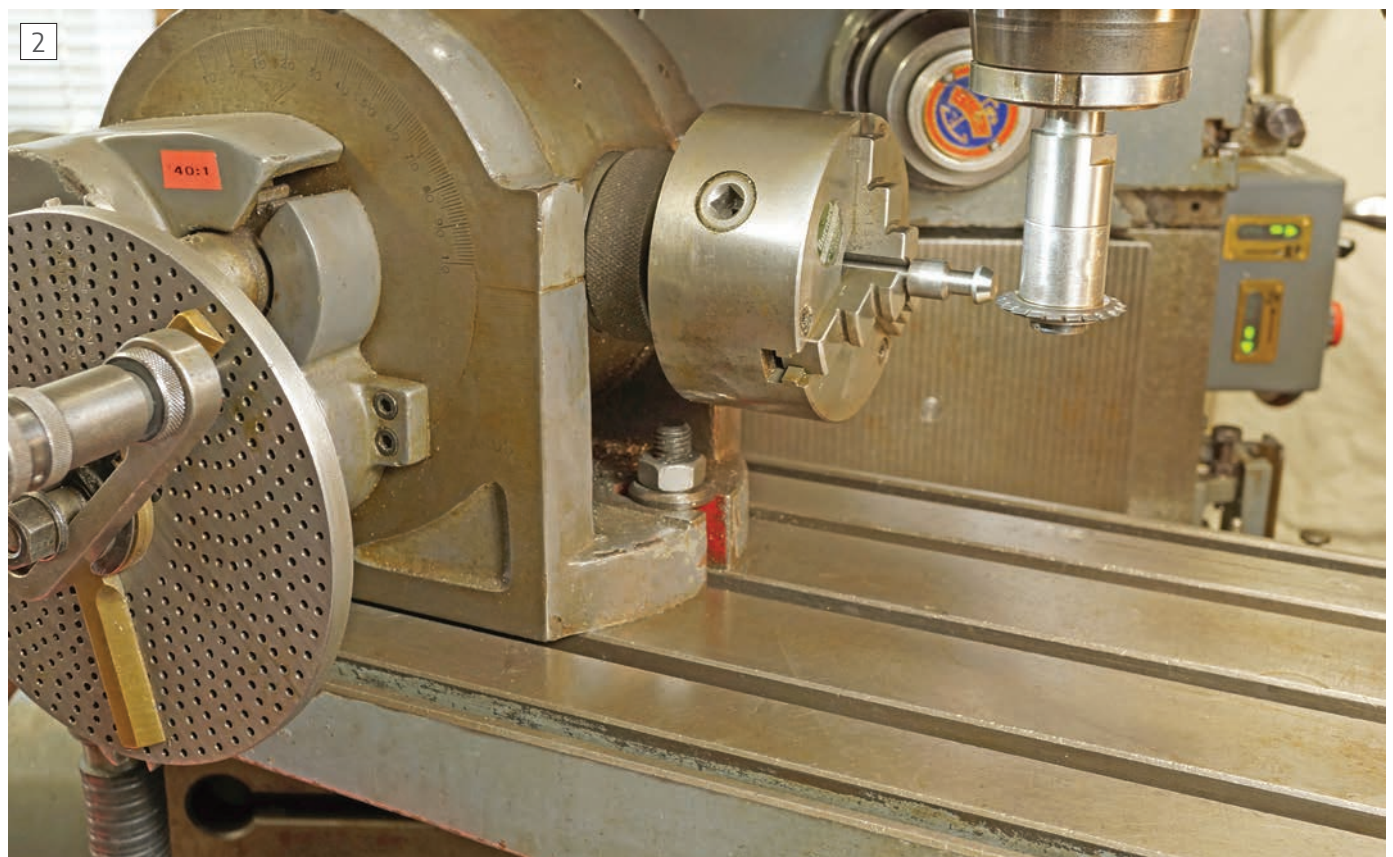
Having established the blank dimensions and selected a No.6 0.5 module cutter for cutting the teeth, the details of the cutting procedure need to be calculated. This is more complex than would be the case for a spur gear. It uses a milling machine equipped with a dividing head much the same as for a spur gear, but there are additional linear and rotary movements of the workpiece. This is sometimes referred to as Pentz's Parallel Depth method (Ref. 4). There is a more detailed examination of the



method in part 3.

A minimum of three cuts per tooth are required. The first cut is on the centre line of the dedendum. The next two cuts are on either side and effectively widen the cut at the large end only. Gears made by this method have a characteristic "stub" tooth shape at the large end.

The procedure is necessarily more complex than for cutting spur gears. The gear blank of the correct dimensions (eg fig. 9 or 10) is mounted on an indexing head. For vertical mills, usually the dividing head axis is horizontal but



skewed to the X-axis by the semi-cone angle of the gear, **photo 2**. Note that for the machine shown, the dividing head axis is parallel to the table slots. The required angle is achieved by rotating the table about a vertical axis. However, smaller mills are unlikely to have this facility.

For horizontal mills the dividing head axis would be in the same vertical plane as the centre line of the table and the cutter, but angled upwards at the semi-cone angle. **Photograph 3** is a posed one of the required set up (with a commercial 45° bevel). It shows the same mill as in photo 2 but configured as a horizontal mill. Note that considerable Z height is required. Neither the table nor dividing head are rotated about a vertical axis.

The machining descriptions that follow are for a vertical mill.

The initial cut is on the centre line of the tooth. Two additional movements are required for cuts to each side. For the setup on a vertical mill, one rotational movement (blank roll) moves the cutter off the centre line then a second translational movement (usually vertical) aligns the cutter back onto the centre line of the tooth space, but only at the small end. That way the tooth space is only widened at the large end.

The movements required are as follows:

Blank roll: $1/4$ tooth indexing angle = $1/4$ * $1/N$ rev Where N = No of teeth.

= $1/60$ rev

= 6.0 deg. clockwise

Vertical Offset of cutter: half the chordal thickness

Angular separation of teeth = $360/N$

Angular separation tooth sides at pitch circle = $360/2N$

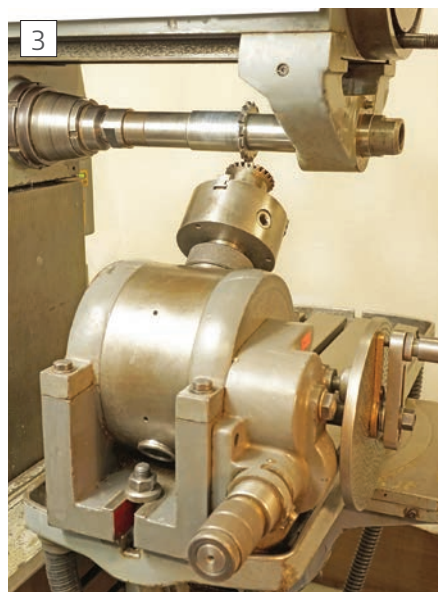
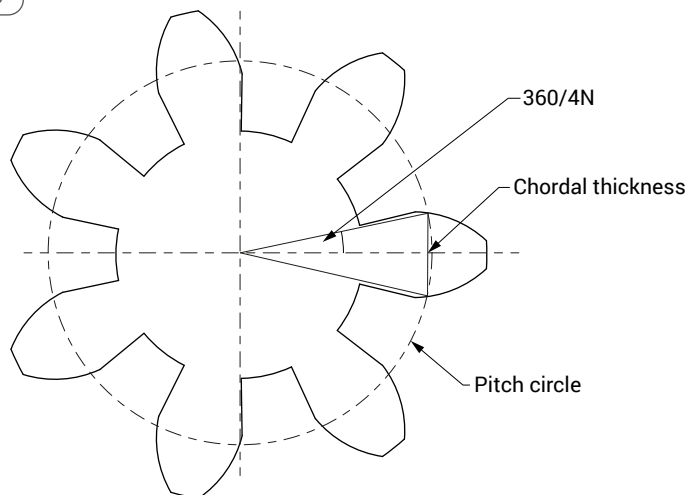


Fig.13



Tooth thickness = length of arc subtended by tooth on pitch circle at the small end
Chordal thickness tooth = straight line subtended by thickness arc, shown green in **fig. 13**

Angular separation of $1/2$ chordal thickness = $360/4N$

$1/2$ * Chordal thickness = $0.5 * PD * \sin(360/4N)$

= $0.5 * 7.5 * \sin(90/15)$

= $0.5 * 7.5 * \sin 6.0$

= 0.392 mm.

The cutter should be moved cutter down (or component up) and cuts taken on all the teeth. The process is then repeated on the other side of the tooth space centre line.

Crown Wheel 30 Teeth

The sequence is the same 7 steps as for the 15T pinion but with dimensions based on 30 teeth ie

- Calculate small end pitch circle diameter
- Calculate face width
- Calculate large end pitch circle dia
- Calculate outside diameters
- Lay out blank
- Calculate cutter required
- Calculate blank roll and vertical offset.

Pitch Diameter small end

= $N * M$

= $30 * 0.5$

= 15mm diameter, see **fig.14**.

The same face width of 4.19 mm is used as for the pinion but the semi cone angle is now 63.435°.

The distance of the cone apex to the small end PCD is

$15.00 / 2 * \sin 63.435 = 8.385$ mm

PCD Diameter Large end:

= $2 * (\text{face width} + \text{dist. to apex}) * \sin 63.435$

= $2 * (8.385 + 4.19) * \sin 63.435$
= 22.495 mm.

Other dimensions are usually not critical

Figure 15 shows the blank required calculated (as for the 15T pinion on P 8-10) as follows:-

Outside diameter small end:

OD = $15 + (2 * 0.5 * \cos 63.435)$

= $15 + \cos 63.435$

= 15.447 mm

Outside diameter large end:

Face width = 4.19 mm as before

Allowance for teeth

Dist. to apex = $15.447 / 2 * \sin 63.435 = 8.635$

OD = $(\text{face width} + \text{dist. to apex}) * 2 * \sin 63.435$

= $(4.19 + 8.635) * 2 * \sin 63.435$

= 22.942

Cutter required:

No. teeth equivalent OD = $30 / \cos 63.43 = 67$

55 – 134 teeth = No 2 cutter

Vertical Offset of cutter:

Angular separation of teeth = $360/N$

Angular separation tooth sides =

$360/2N$

Tooth thickness = length of arc subtended by tooth on pitch circle

Chordal thickness tooth =

straight line subtended by thickness arc

Angular separation of $1/2$ chordal thickness = $360/4N$

$1/2$ * Chordal thickness = $0.5 * PD * \sin(360/4N)$

= $0.5 * 15 * \sin(90/30)$

= $7.5 * \sin 3.0$

= 0.3925 Move cutter down

Blank roll:

$1/4$ tooth separation angle = $1/4 * 1/N$ rev.

= $1/120$ rev = 3.0 deg. clockwise

Results

My first parallel bevels made were exactly as described in Ref 2. These were 1:1 bevels of 24 teeth which can be seen in Photo 1, and were run together over a range of speeds. One noticeable degradation in performance was that they were not as smooth running as fully formed commercial gears and there was also a noticeable increase in backlash which could not be adjusted out. For most applications they would be satisfactory but for mechanisms where noise or backlash needed to be a minimum, they might be unsuitable.

Having spotted and corrected the Sin/Cos confusions, plus some other errors, 2:1 parallel bevels (photo 1 bottom) were made as a more severe test of the process. The backlash was no better and possibly slightly worse and the smooth running was definitely worse. In fact if the crown wheel was driving the pinion, they were sometimes reluctant to run at all. They would however, run together at relatively high speeds.

It was noticed that the source of the backlash appeared to be the dedendum had been cut too wide and as an ad hoc attempt to improve matters some experimentation with the selection of the cutter was tried. Some improvement could be made to the 1:1 bevels but not the 2:1 bevels. It was also apparent that a better testing jig would be required for consistent results. The original device did not provide the fine adjustment necessary to evaluate backlash consistently.

At this point an appraisal of the theoretical basis of the parallel bevel was attempted, the results of which comprise parts 2 & 3. In parallel with this, the test rig was re-designed to provide a fine adjustment of the meshing.

Summary of Findings

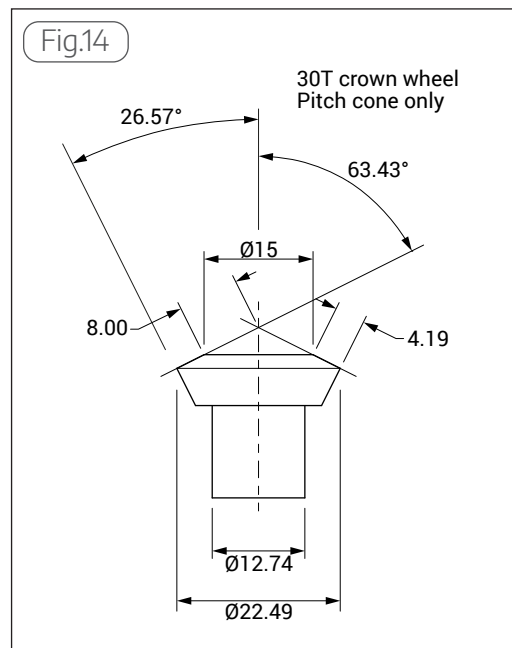
There are several instances of the Sin/Cos confusion. This confusion sometimes has no effect for 1:1 bevels at 90°, but for other ratios and angles it does.

There are other slight errors in the calculation of the large and small diameters of the blank.

1:1 90° Bevels made exactly as described in ref. 2 will work successfully, but will have some backlash which cannot be adjusted out.

Bevels that are not 1:1 will show a further degradation in performance to the point where it may be difficult to use the larger bevel to drive the smaller and backlash will be present.

Correcting the blank diameter errors



alone does not improve the backlash, if anything it is slightly worse.

The backlash error appears mostly due to the dedendum as cut, being too wide. For some 1:1 90° bevels it is possible to improve the backlash by changing the cutter selection, but this was not found to be possible with bevels that were not 1:1.

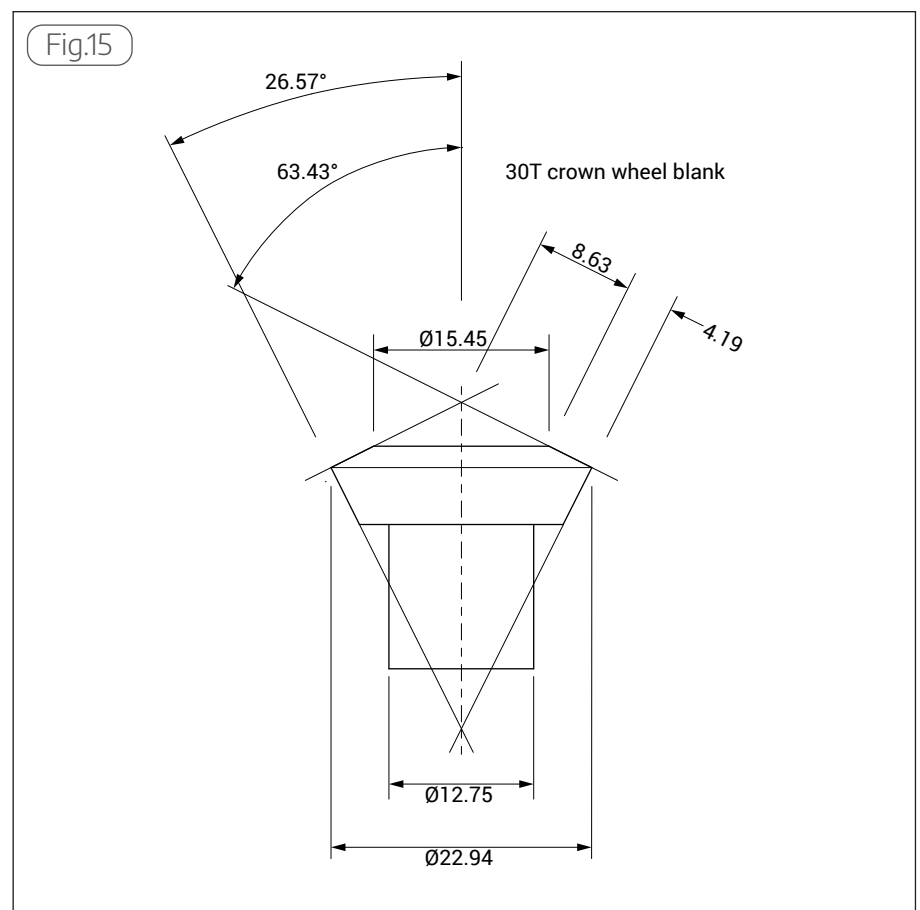
The cutter selection based on the back cone projection in ref. 2 is presented

with little justification. Further work was needed to evaluate this and any limitations that might apply. See Part 2.

An improved design of the test rig used was required for better consistency.

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- 1 *New gears for Wally*, Bob Reeve. ME4572, 4573, 45786, & 4578, 2017-18
- 2 *Gears and Gear Cutting* by I Law 1988, No 17 in the Workshop Practice series Reprinted 2003 Special Interest Model Books ISBN 978-0-85242
- 3 *Gear cutting Practice*, Colvin & Stanley 1937 Lindsay Publications Inc. Reprint of original Mc Graw-Hill publication. ISBN 1-55918-088-9
- 4 *American Machinist Gear Book*, C H Logue 3rd Ed 1922 Reprinted by Lindsay Publications. Original publication Mc Graw-Hill. ISBN 1-55918-381-0
- 5 *A Treatise on Gear Wheels*, GB Grant 1907. Reprinted by Lindsay Publications. Original publication Grant Gear Works, Boston. ISBN 0-917914-55-4



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PRICE: £3,107.13 INC VAT

Technical data

Swing over bed	310 mm
Swing over cross slide	190 mm
Centre width	900 mm
Bed width	180 mm
Spindle bore	38 mm
Spindle tip	MK5
Spindle speed	80 – 2000 rpm (adjustment in 2 ranges)
Metric thread	(18) 0.2 – 3.5 mm/turn
Inch thread	(21) 56 – 8 TPI
Longitudinal feed	0.085 – 0.832 mm/turn
Transverse feed	0.01 – 0.1 mm/turn
Maximum upper slide travel	65 mm
Maximum transverse support travel	210 mm
Maximum longitudinal support travel	650 mm
Tailstock spindle travel	100 mm
Tailstock quill diameter	38 mm
Tailstock quill taper	MK3
Motor power	1.5 kW / 230V
Dimensions	1520x675x1320 mm
Weight	295 kg

Machine Features

- Precise design
- 2 axes digital readout
- Large spindle bore – Ø 36 mm
- Heavily ribbed prism bed made of Gray iron
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- Accuracy of lathe chuck speed better than 0.04 mm
- Left/right switch on the control panel
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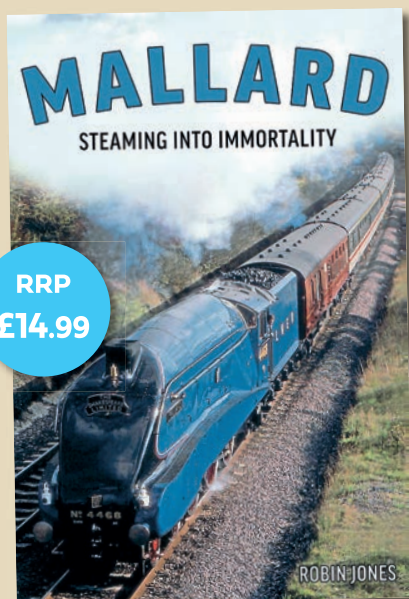
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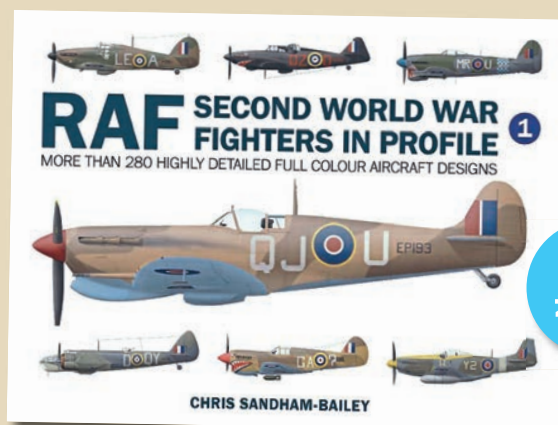
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On the Wire

NEWS from the World of Hobby Engineering



MIDLANDS MODEL ENGINEERING EXHIBITION

THURSDAY 13th to SUNDAY 16th OCTOBER 2022

WARWICKSHIRE EVENT CENTRE

www.midlandsmodelengineering.co.uk

The Midlands Model Engineering Exhibition

Meridienne Exhibitions will be presenting the Midlands Model Engineering Exhibition from Thursday 13th to Sunday 16th October at the Warwickshire Event Centre. This is likely to be the only major model engineering show to be held in 2022.

The exhibition enjoys tremendous support from nearly 30 clubs and societies. Talk model engineering with other enthusiasts, pick up tips and share experiences. There are demonstrations by leading model engineers on the various aspects of the hobby.

See up to 50 of the specialist model engineering stockists and the vast range of products on offer as well as wide variety of steam traction and road vehicles presented by the 'Fosse Way Steamers'. Each year sees nearly 1,000 superb models on display, from stunning locomotives to horology and maritime models.

Tickets are on sale NOW and must be purchased in advance at present via the website to guarantee entry to the show in 2022. The organisers hope to sell tickets on the day but this decision will not be made until 3rd October 2022 pending any changes to the Covid-19 restrictions.

Why not be part of the show and enter your work in the 32 competition and display classes? Cash prizes and trophies will be awarded to the best entries.

See www.midlandsmodelengineering.co.uk to book tickets, for full competition details or further details of the show and exhibitors present.

Mintronics News

Alibre 3D CAD was the original and remains one of Mintronics key software solutions. Over the last 14 years, we have placed Alibre into the hands of literally thousands of customers - from multinational corporations to individual hobbyists. One of the key strengths of Alibre is their focus on continuous development of the software, providing enhanced software capabilities at a speed that I don't see from our competitors. Version 25 is on the way and will be released soon.

From customer feedback, the flexibility in regards to licencing has always been a major advantage for Alibre. Unlike other options available on the market, the software does not stop at the renewal date. If you buy it, you own it forever! In addition, customers are not required to pay for missing years of maintenance if they have that option.

This month Alibre have a promotion for Alibre Atom 3D with maintenance 20% reduction to £215.20 plus VAT .

Alibre training course-

A two day course for new starters, "come back" or just refresher training. The courses are held by trainer Rob Footitt and accredited. Where - Darlington

When - 14th 15th June 2022

<https://www.mintronics.co.uk/alibre-training-reg>

More Machines for your Workshop



Stub Mandrel looks at some of the equipment you might want when you start to grow your workshop.

Once you have fitted out your workshop and obtained commoner workshop machines, such as a lathe and milling machine you may well want to just put some time into your new hobby. Sooner or later, however, you will come across jobs that would be made easier by some more specialist equipment. Here is some other equipment you may want to consider finding a home for in your workshop.

An obvious accessory is a decent bench vice. A 75 to 100mm (3 to 4") vice is the ideal for most workshops. Make sure the vice is securely attached to the bench and that you have plenty of space on both sides of it and fix it so that anything held vertically in the jaws hang down in front of the bench this will make it much easier to work on large objects. The jaws of some vices are heavily serrated for grip, but this means they mark work badly, consider unscrewing the supplied jaws and replacing them with plain mild steel or even aluminium jaws that will be much kinder. You can also obtain fibre or rubber inserts for holding delicate objects, **photo 1**. Finally, don't forget



A pair of magnetic soft jaws for a bench vice.

that a bench vice can also function as a small press.

A powered bandsaw may seem like a luxury, but anyone who has sawn through a 50mm bar by hand will appreciate the

contribution that can make to workshop productivity, **photo 2**. It is worth investing in decent quality bimetal blades, which have surprising long life compared to, say, hacksaw blades as the bandsaw uses the



A metal cutting bandsaw can make projects that require big chunks of metal to be cut to size achievable.



An alternative to a bandsaw that requires rather less space is this power hacksaw from Axminster Tools.

full length of cutting edges and works the blade very steadily. Alternatives are cut off saws and powered hacksaws, **photo 3.** Cut off saws with tungsten carbide blades are to be preferred over those with abrasive wheels as the latter are notorious for producing huge showers of hot sparks.

Over time you will, no doubt, accumulate blunt tools, fortunately most tooling can be resharpened to extend its life. While many types can be resharpened using jigs and a bench grinder, the task is greatly eased by using a dedicated tool and cutter grinder. The surface grinder is a specialised machine for finishing parts to very accurate thickness.

Belt sanders, often referred to as finishers (a trade name), although usually sold for woodworking can be useful in the workshop. Those fitted with red aluminium oxide belts can provide a quick and surprisingly effective way to finish metal parts or even sharpen small tools. Many machines combine a belt with an abrasive disc and have adjustable work tables to facilitate the grinding of angles.

An angle grinder can be a godsend for tasks such as chopping up odd lengths of scrap material, they are also useful when welding, either for dressing surfaces before you weld or cleaning up afterwards.

Most hobby workshops build up a stock of what might be described as DIY tools such as power drills that also come in handy for other tasks from time to time. These days almost all



This popular belt sander has a 25mm wide belt as well as a 100mm abrasive faced wheel.

woodworkers rely heavily on a router these can be used for things like making display bases and cases for models, making 'workshop furniture' as well as benches and toolboxes.

If you make models, you will probably want to paint them. Many people use cans of automotive spray paint, which

is durable and available in many colours. If you want the maximum flexibility and to achieve the best possible results, consider getting a spray gun or an airbrush for delicate work. An airbrush will run off a miniature compressor but if you choose a spray gun will consider getting a compressor large enough to operate air tools such as impact wrenches. A modest compressor may not be able to keep up with running air tools continuously, but may still be a boon for car restorers, for example.

An ultrasonic cleaning tank is a useful device if you regularly need to clean up small or awkwardly shaped parts. They are an ideal approach for cleaning gunked-up carburettors, for example. Used with a weak detergent solution it will rapidly clean many items, and for duties such as corrosion removal or de-fluxing electronics you can obtain specialist fluids.

A flypress or arbor press can have many uses, from fitting and extracting bearings through to punching shaped holes. A shaping machine works by drawing a tool across a surface; a relatively slow alternative to a mill but capable of leaving a very fine finish. Once popular, they have now largely been superseded by milling machines and good second-hand examples can be very desirable. ■



This ultrasonic cleaning tank from machine-DRO has digital control of temperature, intensity and timing.

Theasby's Wrinkles

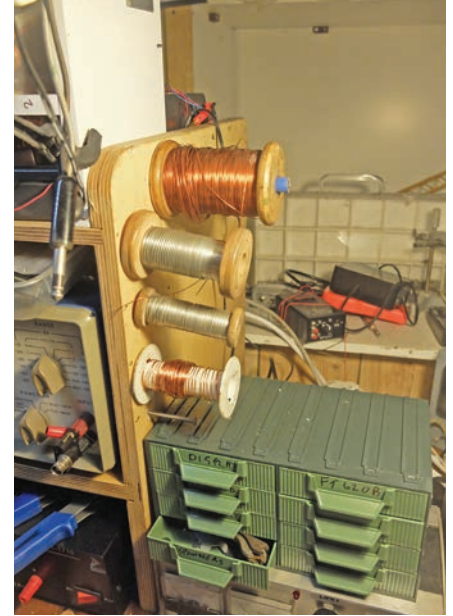
Geoff Theasby on organising wire reels

I was constantly moving piles of wire on reels about my bench, or they vexatiously fell over, so I designed a stand which would keep them in order and be readily available. My wire 'tower' resembles a kitchen mug tree. The 'arms' are angled upwards so that the reels do not walk off the ends, and are spaced every 100 mm, 120 mm would be better. It could also be more substantial. As it is, it is bolted down to the bench and restrained at the top.

My spools of enamelled copper wire needed storage, but not dispensing, as they are small enough to be taken down when required, so I used No 8 x 50 mm woodscrews suitably spaced in the end of my bench shelving. One spool was too large and heavy, so I made a sleeve from ¼ inch bore air hose x 100 mm long. This supported it better. I had to grind down the screw head to make it fit. ■



Wire tower



Enamelled wire storage

NEXT ISSUE

Pennies from Heaven

Brian Baker revisits the Penny Arcade, with his restoration of a Scooter Racer machine.

GL5 Rally

John Arrowsmith pays a visit to East Somerset again to attend this year's GL5 rally.

Mabel

Eddie Castellan builds LBSC's gauge 1 LNWR 'Jumbo' locomotive.

Viljoen

Luker continues his occasional series on great South African model engineers with the story of Charles Viljoen.

Bristol Foundry

Graham Gardner pays a visit to a busy foundry in Bristol.



Content may be subject to change.

ON SALE 3 JUNE 2022

BEGINNERS WORKSHOP

These articles by Geometer (Ian Bradley) were written about half a century ago. While they contain much good advice, they also contain references to things that are out of date or describe practices or materials that we would not use today either because much better ways are available or for safety reasons. In particular, never use abrasive cloth on a lathe without a backing board. These articles are offered for their historic interest and because they may inspire more modern approaches as well as reminding us how our hobby was practised in the past.

CUTTING and FITTING GASKETS

GEOMETER gives some advice on an operation which is needed in the workshop from time to time

JOINTING MATERIAL in sheets permits the cutting of various types of washers' and gaskets which are unobtainable or not to hand when required. Not so many years ago, in fact, it was common practice to do this, except in the case of car cylinder head joints. Nowadays, there are gasket sets, but they do not necessarily contain all joints, and on occasion it is necessary to cut one's own.

Ordinary thick note paper or brown paper is suitable in many instances, apart from the available special materials-toughened papers, fibre, cork sheeting and-to resist heat-asbestos-base sheeting such as Hallite.

Holes and perimeters

First thing with sheeting, having obtained a piece of suitable size, is to mark the shape of the joint, which is best done on the component containing the holes, not on that with the studs. The material is held flat on the face, or a piece of board is placed on top one end. If the material is thin, pressure of the fingers will reveal the position of holes, but if thick so finger pressure is inadequate, a small hammer is necessary-one with a flat and a ball end.

On a small joint, all holes and the perimeter can be marked, and the sheeting removed for cutting. On a complicated joint, two opposite holes can be marked, these punched, then the material located with bolts, while the remainder of the holes are marked. Where there is a spigot or protruding diameter, the sheeting is marked and cut first to locate on it.

There are various ways of cutting holes. For small ones, from about 3/32 in., there is the plier-punch, A, producing six different sizes. Tubular punches, B, can be bought in all standard sizes, or made from steel pipe or rod-by drilling the centre. They can be chamfered on a grinding

wheel to keep sharp. The punching block can be hardwood on the end grain, or a lump of cast lead-kept flat by hammering. In cutting round washers, the bores must be punched, then the outsides; if done the other way, they often split. Large holes can be cut with the compass-type cutter, C, this having a blade or sharp disc set to required radius from a rule. The material should be on a flat board, and the spike of the tool well pressed in.

Subject to there being no damage to components, holes can be cut in thin material using the ball end of the hammer, and outside perimeters with the flat, D. If the material is thick, it is depressed at the end, made ragged or broken, so punching is advisable.

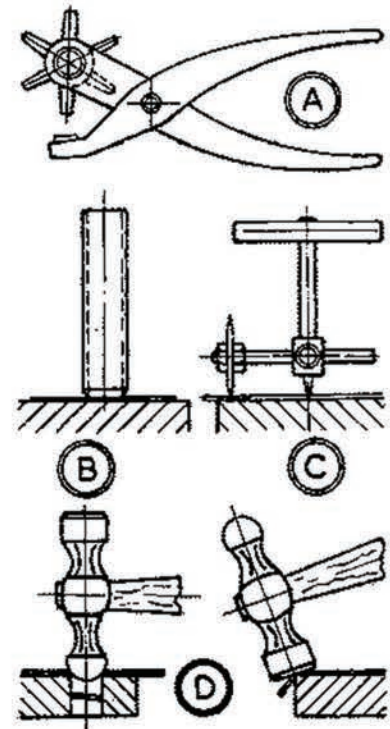
Cutting and securing

The inside perimeter of narrow joints should be cut first, and often the outside can be trimmed when the components are assembled, using a sharp knife or scraper. Thin material can be cut with straight and curved-blade scissors, thick material with flat and half-round wood chisels on a board or block.

Where dismantling without difficulty is necessary, joints may be fitted dry or lightly oiled. If there is the possibility of leakage, jointing compound should be used, but on manifolds where there is heat, jointing compound should not be used. On cylinder head gaskets, jointing compound is used, or ordinary grease-this helping the joint to slip during tightening.

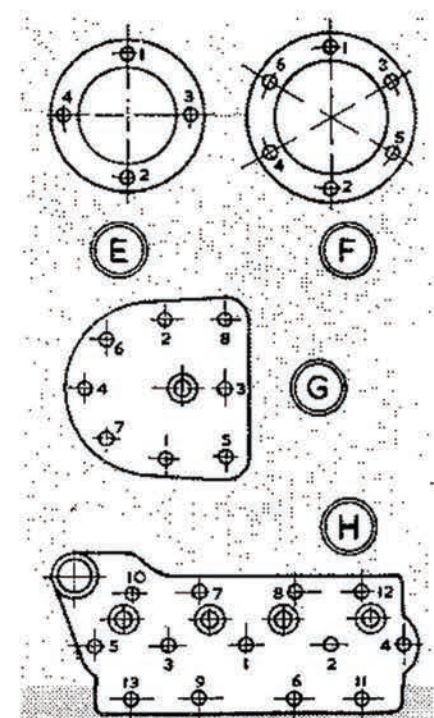
In assembling, it is very important to 'employ a suitable order of nut tightening, and to tighten gradually which means going over the nuts in the given order, tightening each a little at a time until secure.

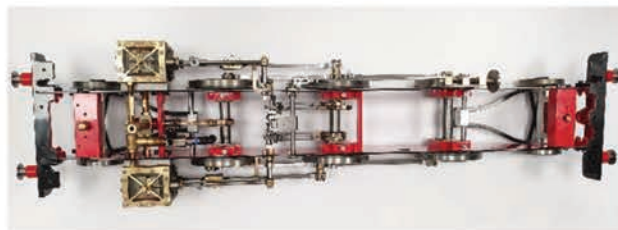
The general principle is to provide balanced tightening, or on stud joints like car cylinder heads to tighten from the centre outwards. □



Above: Tools used in cutting gaskets

Below: E and F are typical four-stud and six-stud joints. G, side valve motorcycle cylinder head and H, small car cylinder head





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An Improved Tailstock for a Myford Lathe - Part 2



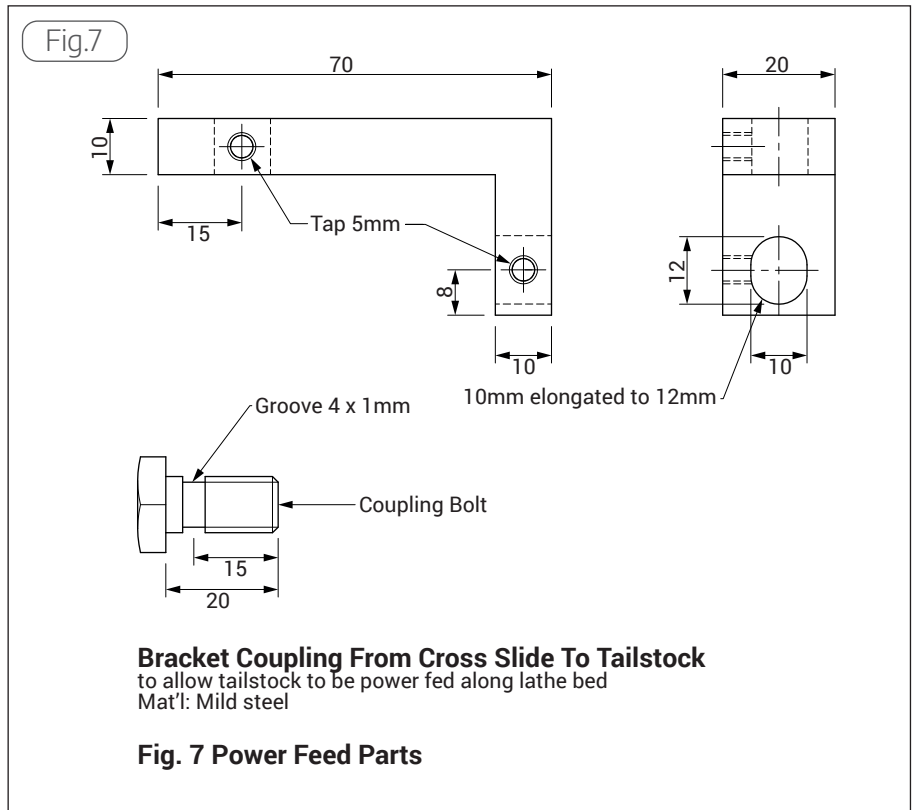
We are pleased to feature this improved tailstock for a Myford lathe, designed and built by Murray Lane. Using castings from his own patterns, this article echoes some of the ambitious projects of the past.

The inside faces at these points of the casting are machined to take the head of the pull bolt **photo 18**. The cam shaft position grub screw was then drilled and tapped **photo 19**.

Multi carbide insert cutters were used for much of the machining as they can cut over a wider area and remove metal quicker as well as staying sharper for a longer time than high speed cutters. However, when sharp corners and close tolerance requirements are required HSS cutters were used.

The boring of the barrel hole through the tail stock body was carried out in the lathe that the tail stock was going to be used on. This ensured that the tail stock barrel bore would be truly in line with the headstock centre line; hence the requirements for minimum side play

The boring of the barrel hole through the tail stock body was carried out in the lathe that the tail stock was going to be used on.



with the body between the bed shears.

There are two major requirements before this can be done.

1 The clamping system for locking the tail

stock to the bed will need to be made.

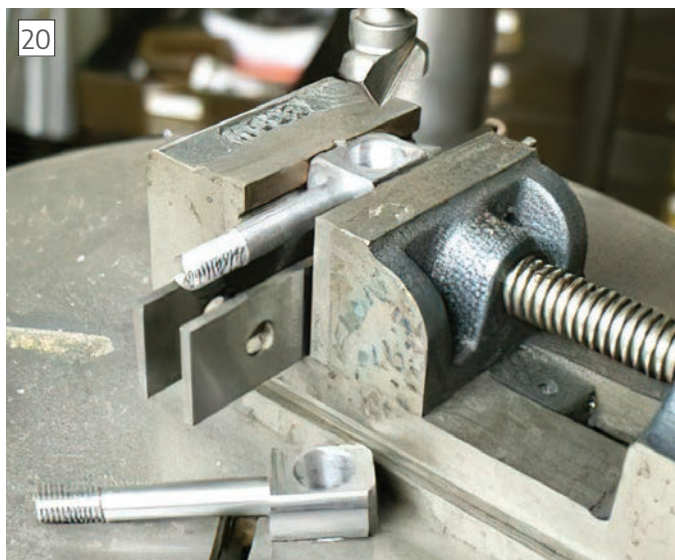
2 There will need to be provision to be able to power feed the tail stock body up and down the bed.



Milling the inside faces of the bosses.



Tapping hole for locating grub screw.



Machining and boring the pull bolt.



Handle with cam and stop.

Make sure that the handle is in the correct position first and do not fully tighten; put in a locking grub screw above it so that it cannot unscrew.

Fig. 6 Tailstock clamping parts

This is the same system that was used in the original Myford tail stocks and all the parts are made of mild steel; the plastic balls were bought commercially. The positions of the locating pin (3mm diameter x 12mm) is to be loctited in the groove later with the cam and handle positioned to allow the handle to be in about 25° to the bed when unlocked. The angles are shown on **fig. 6**. Turn the end of the 12 mm long 5mm Allen grub screw with a 3mm pip 2.5mm long on the end, to locate the cam shaft in the correct position, into the 3mm groove. Make sure that the handle is the correct position first and do not fully tighten; put in a locking grub screw above it so that it cannot unscrew. When the nut under the clamping plate is adjusted the position of the tailstock handle should be about 55° to the bed. The clamping plate has a bevel on one side to clear the lead screw hand wheel when removing.

The pull bolt is drilled for the 16mm diameter pivot and the corners are to be chamfered, **photo 20**. **Photograph 21** shows the handle. The clamping plate is



View showing the clamping plate in place.

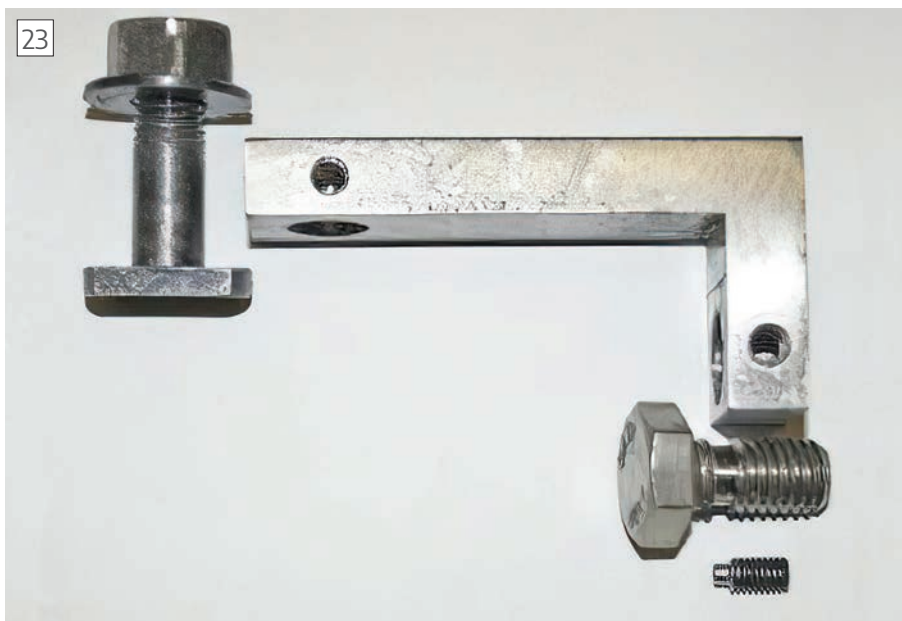
beveled on one edge to clear lead screw hand wheel when removing tail stock from bed of lathe, **photo 22**.

Fig. 7 Power feed parts

The small extension on the leading edge of the tailstock was drilled and tapped 10 mm (26) (2mm off centre see fig. 5), and a bracket made, **photos 23, 24** and **25**, to connect to the cross slide and needs to long enough to straddle the DRO scale **photo 26**. The bracket bolts had grooves with Allen grub screws to hold them lightly in place. Without these it was almost impossible to start the bolts as can be seen in the photographs.

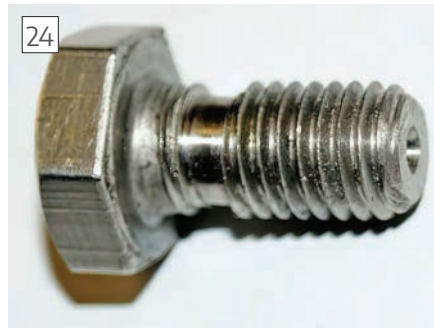
Boring the barrel bore

The ends of the rough bores were chamfered to give a centre for the core drill, **photo 27**.

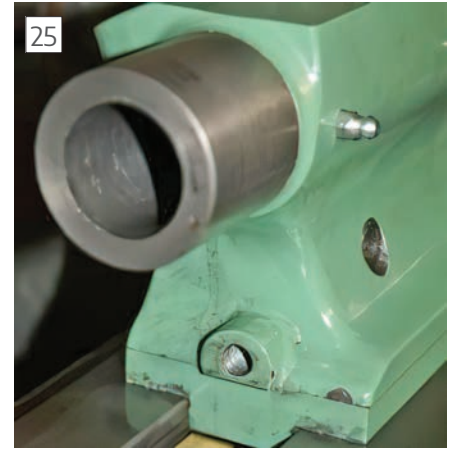


Bolt modifications.

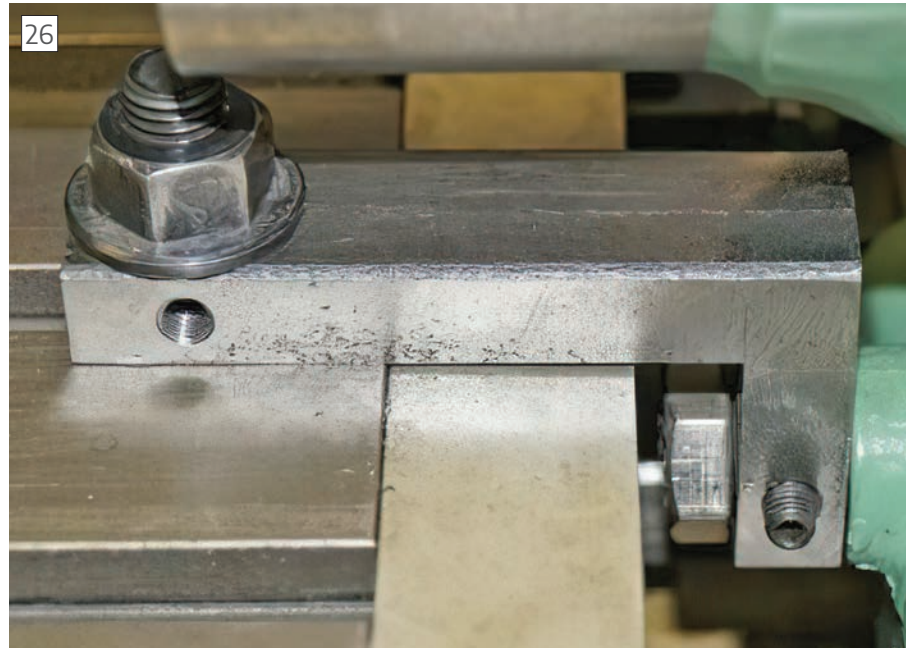
Clean both ends of the barrel bore faces, **photo 28**, with a suitable cutter in the boring bar shown in the lower boring bar. With the original long castings this was done in the milling machine. Chamfer the left-hand end with the tailstock mounted on the lathe bed with a large diameter chamfer cutter, **photo 29**. This helps centre the pilot drill. Due to poor mould preparation the holes in both patterns were much smaller than the core pattern. In this



Coupling bolt.



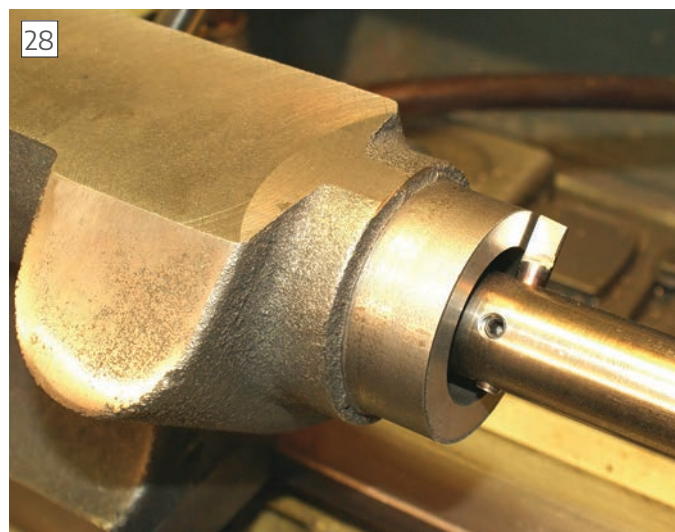
Tapped coupling hole.



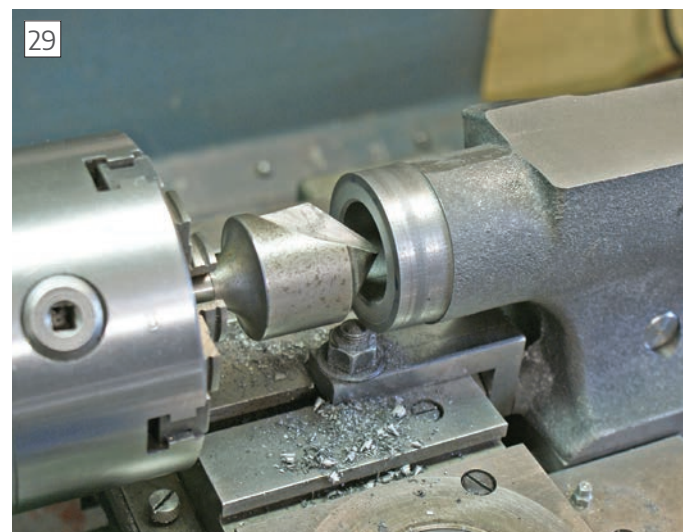
Straddling the DRO scale.



One inch diameter core drill, note the cutting faces are similar to a machine reamer.



Facing the ends of the bore holes.



Chamfer edge of barrel bore.

case I used a one-inch core drill which has four flutes and is much stiffer and does not drift around like a two flute drill. This acts rather like a reamer and will clear out any imperfections in the barrel bore and will allow the clearance for the 21mm diameter boring bar with cutters to move through it.

A 22mm diameter boring bar 435mm long with multiple places for holding the cutters was used to open out the bore on the original castings shown in the photograph, **photos 30** and **31**. This was later changed to a similar 25 diameter to open out the bore out to the full diameter, **photo 32**. A 30 mm long bar would be OK for the modified tailstock body which is only 200mm long.

The bottom bar was used for the initial boring and facing of the ends. The top larger bar has a screw backing on the cutter which allowed a more precise adjustment on the position of the cutter.

The barrel bore will need to be bored from both ends with the boring bar being reversed for each end. The machining of the barrel bore was done in situ with the tailstock body



Tail stock centre inside bore.

Fig.8

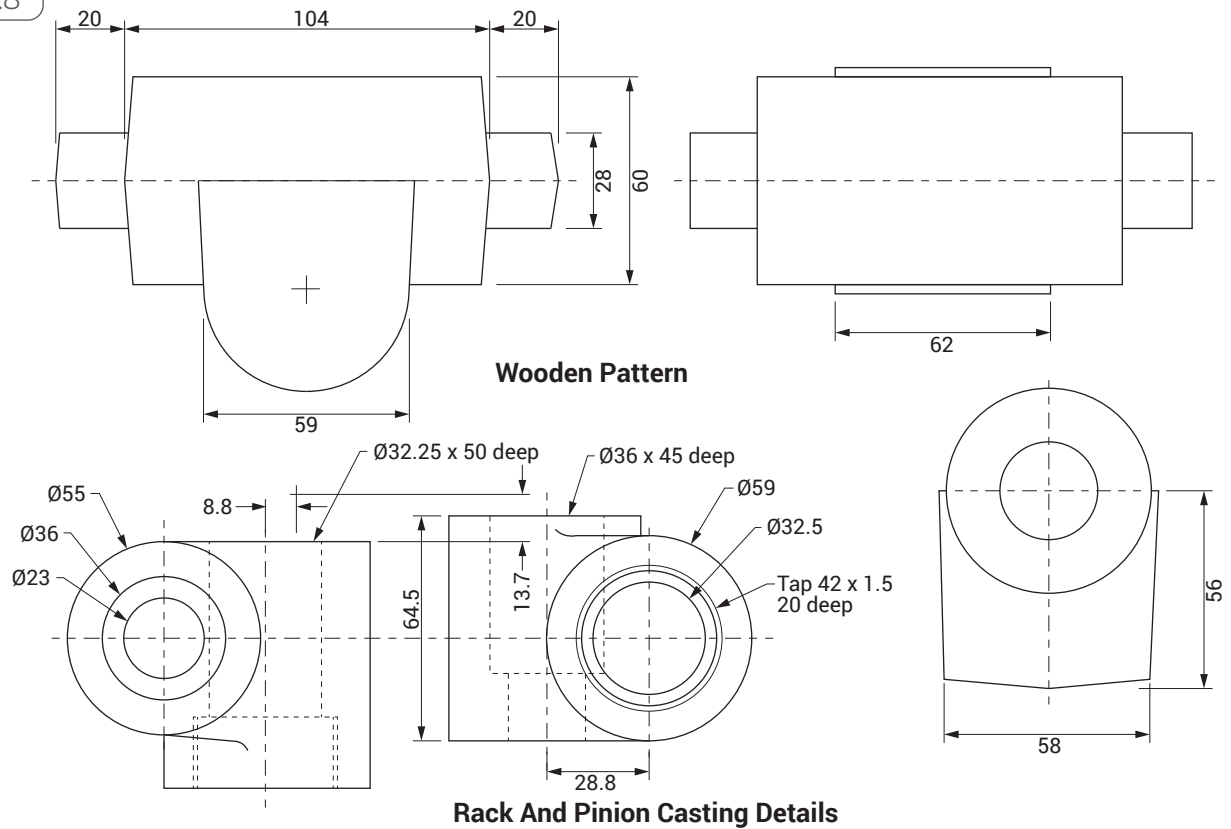


Fig. 8 Rack And Pinion Gearbox Pattern And Details



Tailstock being bored.

lightly clamped to the bed with a slight pressure being applied on the body locking handle and it was pulled along with power feed applied to the apron; this worked very well. Doing a job like this ensured that bore was truly central to the lathe centre. The ends were faced in situ as previously mentioned. The two tailstocks made were bored out on the individual lathes they were being made for. Reverse bore the right-hand end, **photo 33**, 23 deep and 40 diameter for the 42 x 1.5 thread. Chamfer the edge so that the tap will start true, **photos 34**



Boring bars.

and **35**. I had the tailstocks bore honed by a professional firm out but was not happy with the result as there was bellling at each end of the bores.

Remove the locking system and base

plate from the body; reverse in the lathe and hold the body in a three jaw chuck and support the other end in a centre to machine the outside of the nose, photos 37, at a very slow speed. I have made



Boring out end for the thread.

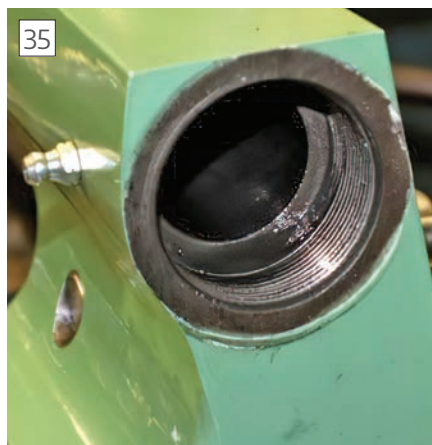


Starting to tap thread.

several large centres with a centre in the middle for larger holes, photo 36, than the normal centre. Finally drill and tap for two grease nipples as shown in fig. 5.

Fig. 10 Rack and Pinion gearbox pattern and details, photo 38 and 39.

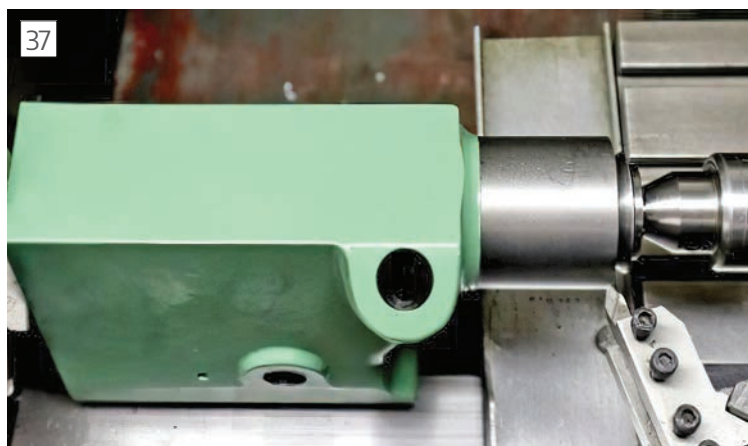
After the casting was roughly bored, photo 40, through for the barrel and faced at both ends, photo 41, it was clamped on the mill table and bored to size and the end was opened out to 40mm diameter and 23mm deep, photo 42. It was not practical to screw cut the tailstock castings due to the



Finished thread.



Expanded centre for larger holes.



Machining the outside of the nose of the tailstock.



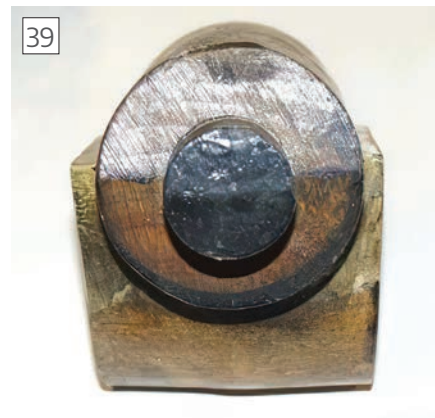
The barrel hole core.

huge eccentric weight distortion when rotating. So, a special 42 x 1.5 pitch HSS tap, photo 43, was bought. It was used to tap the five holes for the two tail stocks are and the joint locking rings and test nut, photo 44. A word of warning back the tap off regularly or it will jamb.

The pinion was faced for the end of the bore and a close-fitting reference mandrel was turned to fit in the barrel bore, photo 45. The height gauge is then set to zero and half the diameter subtracted. This reference is then used to mark the pinion bore, photos 46

and 47, care need to be taken for this as it controls the meshing of the rack and pinion.

The pinion was mounted on a rotary table, photo 48, and bore was then opened out to 23mm diameter right through and the countered bored out to 36mm diameter 45mm deep as shown on the pinion housing drawing. The housing was then re-clamped and machined around the outside of the gears shaft hole with a radiused cutter and then around the outside lip with a bevel cutter, photos 49 and 50.



End view of pattern.

Fig.9

ø32.5 - the bore of the joiner ring & the rack & pinion gearbox to be honed when assembled with barrel bore in main casting in the final assembly

Screw cut 42 x 1.5mm thread to fit tapped holes

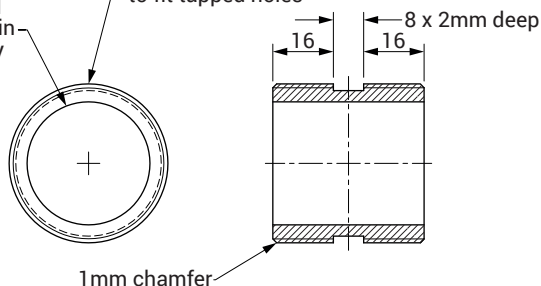


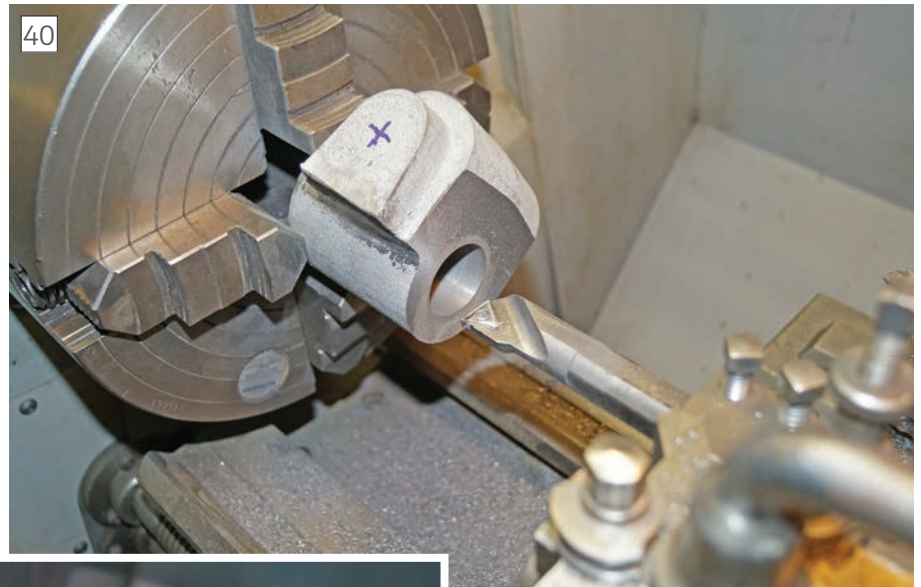
Fig. 9 Joint Tube
Mat'l: Mild steel

Fig. 8 Joint tube

The mild steel joint tube was screw cut, **photos 51 and 52**, for a 42 by 1.5mm thread using the test nut, **photo 53 and 54**, for sizing the thread. As there were two locking rings required, they were machined together to 60mm OD around 35 long on the outside and bored 40 ID long and tapped with the 42 x 1.5mm tap. The OD was knurled, **photo 55**, and parting grooves cut 3mm deep and the four corners chamfered before parting off and re-facing the ends.

Fig. 9 Rack and pinion gearbox angle locking ring and lever

The locking system depends on two systems to prevent the rack and pinion



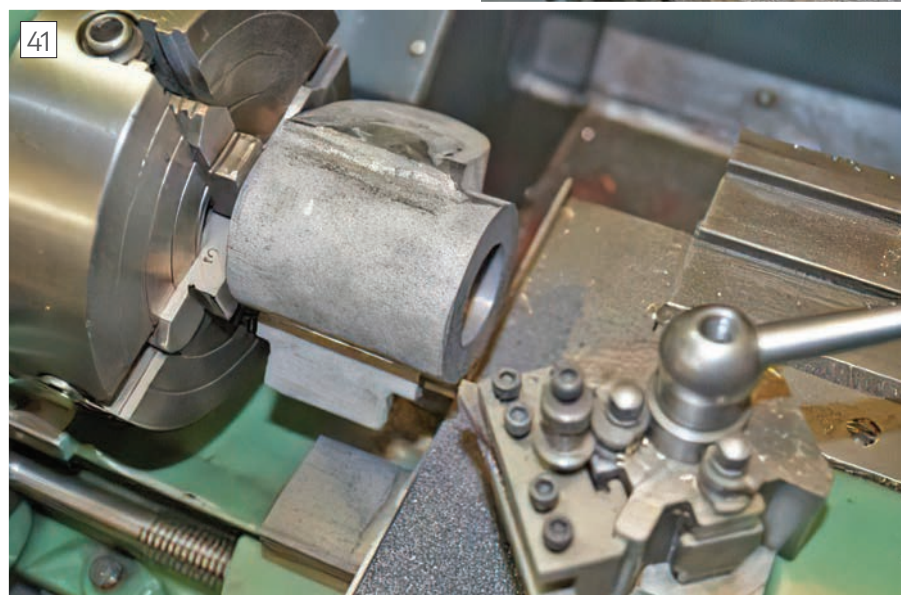
Boring the barrel hole.

gearbox turning when drilling with larger drills. This depends on the friction of the locking ring against the tailstock body, **photo 56**, and the locking lever, **photos 57 and 58**, screwed into the groove in the joint ring as shown above.

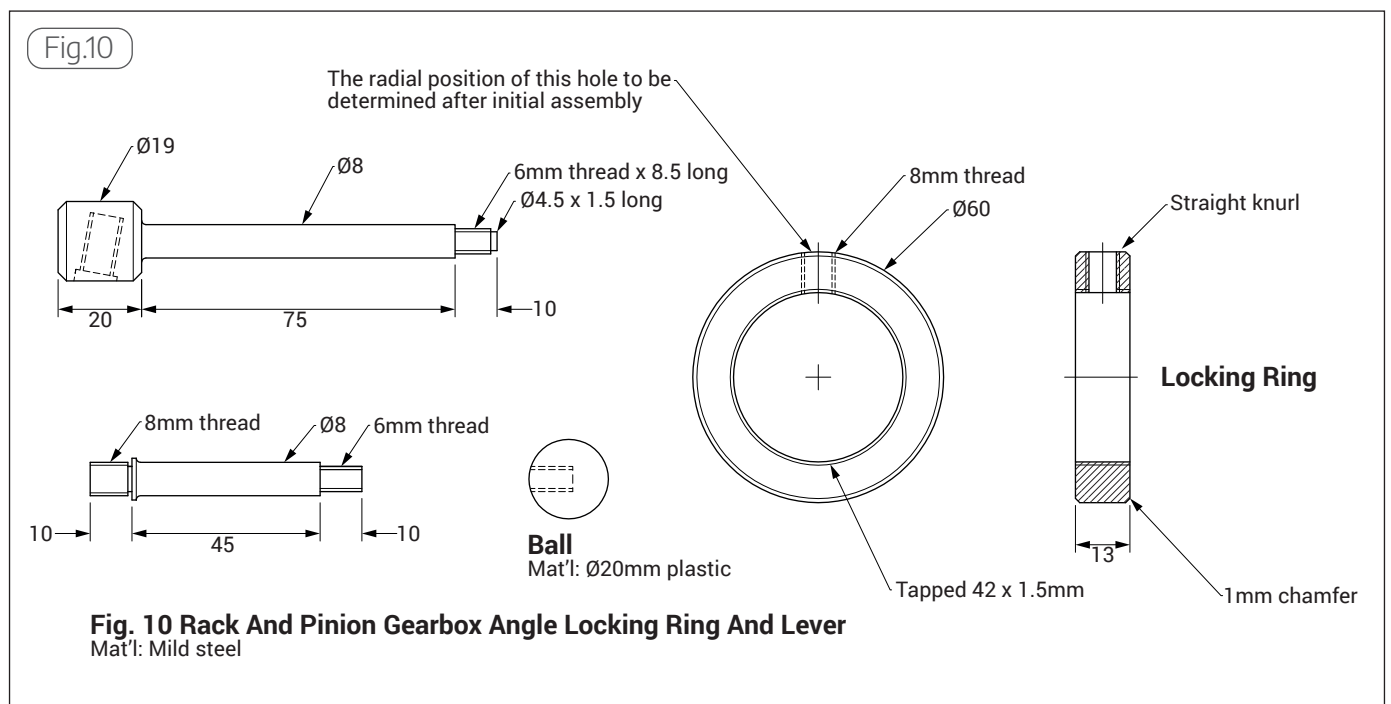
The new system allows the more pressure can be applied between the ring and the tailstock and the arm can be screwed in much tighter into the groove in the ring. Ensure that the tip that goes into the groove is long enough.

●To be continued

The photos in this article are too numerous for us to keep them all with the relevant text in this instalment. The next part will include the remainder.



Facing the end.



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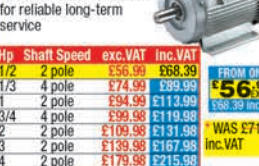


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Readers' Tips



Chester DB10 Lathe Stop

TIP OF
THE MONTH
WINNER!



This month's winner is Howard Dean with a tip for a lathe stop that can also be used on many other machines.

Sometimes when working on projects which require repetitive machining it is nice to have a lathe stop, the attached pictures are of a simple stop I have made for my Chester DB 10 super B lathe. When not in use it is locked under the chuck and having an aluminium locking piece it cannot hurt the bed. Simple but effective.

We have £30 in gift vouchers courtesy of engineering suppliers Chester Machine Tools for each month's 'Top Tip'.

Email your workshop tips to meweditor@mortons.co.uk marking them 'Readers Tips', and you could be a winner. Try to keep your tip to no more than 400 words and a picture or drawing. Don't forget to include your address! Every month I'll chose a selection for publication and the one chosen as *Tip of the Month* will win £30 in gift vouchers from Chester Machine Tools. Visit www.chestershobbystore.com to plan how to spend yours!

Please note that the first prize of Chester Vouchers is only available to UK readers. You can make multiple entries, but we reserve the right not to award repeat prizes to the same person in order to encourage new entrants. All prizes are at the discretion of the Editor.

Worden Point Grinding Jig



Laurie Leonard adds a new accessory to this popular tool and cutter grinder.



Automatic centre punch.

Marking out has never been an activity that I have excelled at but it is a fundamental activity and its accuracy determines the success of most jobs. Two basic operations are scribing lines and centre potting hole centres. The former utilises the trusty scribe and the latter a centre punch. For many years I have used an automatic centre punch for most jobs although I purchased one of the optical assisted ones where a Perspex viewing piece is exchanged for a punch when the hole has been centred on the job. This is particularly good for use on large area work. The sharpness of the point on the scribe and centre punch has a large bearing on the accuracy and although



Exploded view of automatic centre punch.

I touched up mine many a time on an ordinary bench grinder the results were never that good. In the case of the centre punch if the point is fine and sharp the cross of the marking out lines can often be felt thus ensuring accuracy when punching and the punch is less likely to slip when pressure is applied.

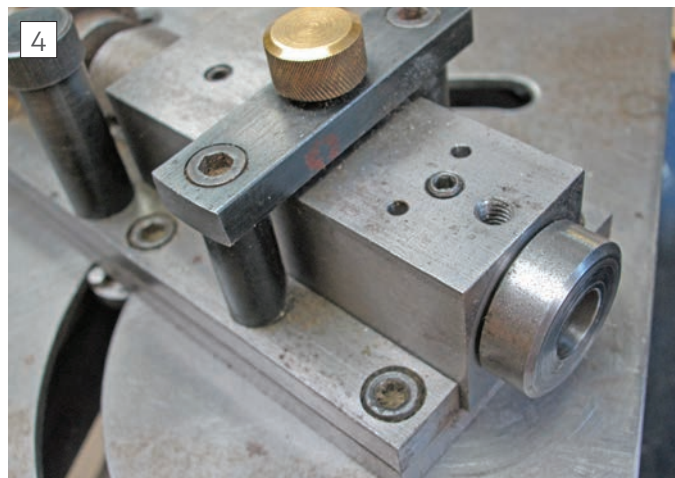
Having constructed a Worden Tool and Cutter Grinder I set out to make a jig that would utilise the accuracy afforded by the machine.

Construction

Starting with the items to be sharpened, **Photographs 1 and 2** show the centre punch. Photograph 2 shows that the actual punch is a thin rod. The scribe,



Scribe.



Worden tool and cutter grinder tool slide with adaptor for end mill/slot drill machining.

photo 3, similarly has a thin rod at the straight business end. I reasoned that if I could make a jig in which these items could be rotated and offered to the grind stone I was in with a chance of getting my fine, central sharp point.

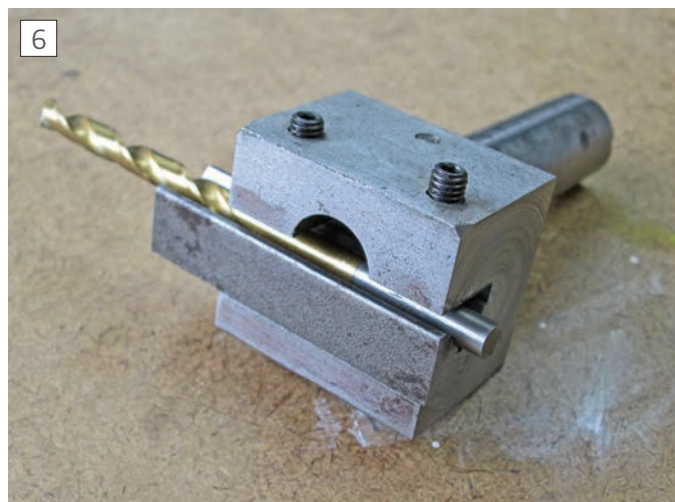
The work slide assembly of the grinder is shown in **photo 4** carrying one of a

series of adaptors for end mill/slot drill machining. The $\frac{3}{8}$ bore adaptor is shown in **photo 5** and the plan was to utilise this with an inner sleeve/jig to carry the points to be sharpened. However, the geometry of the fitted wheel meant that I needed the adaptor to be at 90 degrees to the slide assembly. The lathe

tool holder, in **photo 6** (shown set up for another job), presents work at 90 degrees but does not have the $\frac{5}{8}$ bore hole in it needed for the adaptor and so a similar holder was made with the required hole, **photos 7 and 8**. It was made from workshop stock hence the need to add the packer shown to get



Worden adaptor for 3/8 end mill/slot drill.



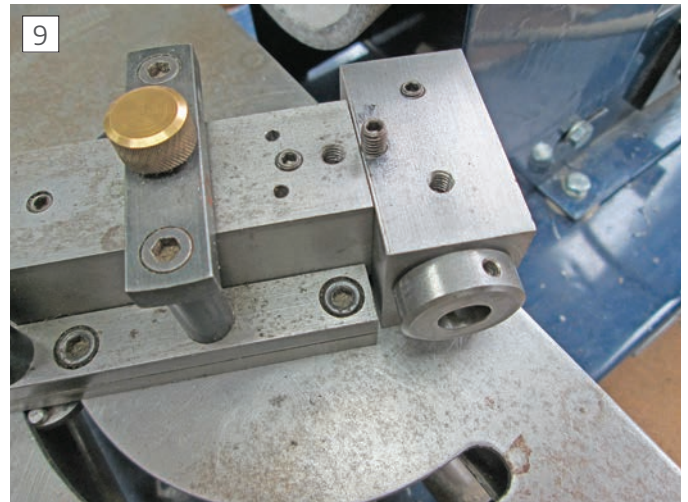
Lathe tool adaptor for Worden.



90-degree adaptor for Worden.



Another view of the adaptor.



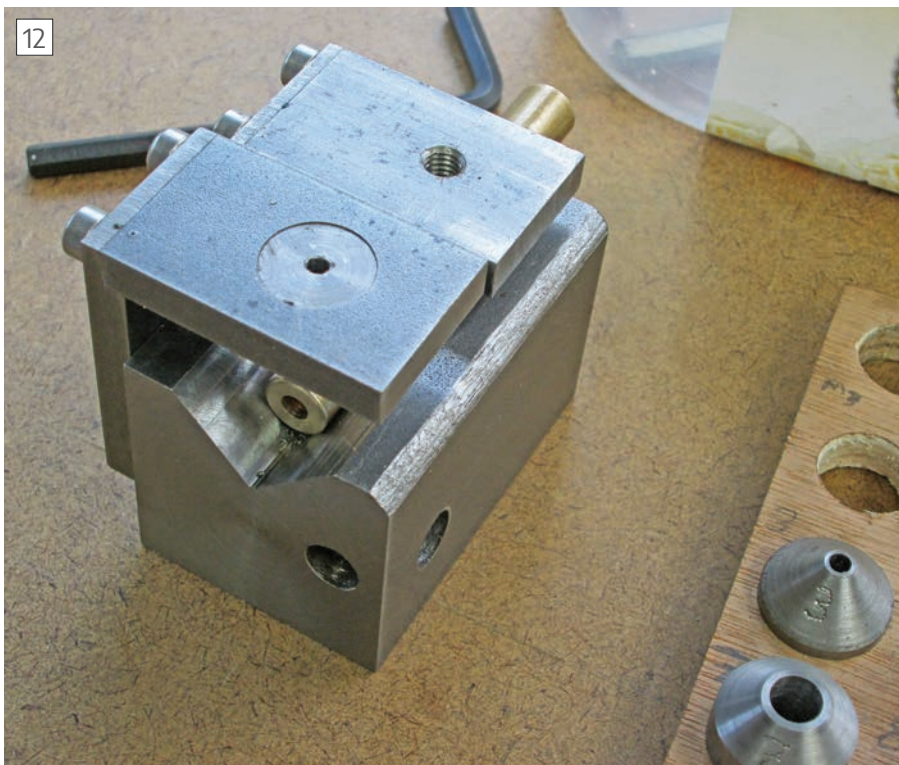
90-degree adaptor on the tool slide carrying end mill/slot drill adaptor.



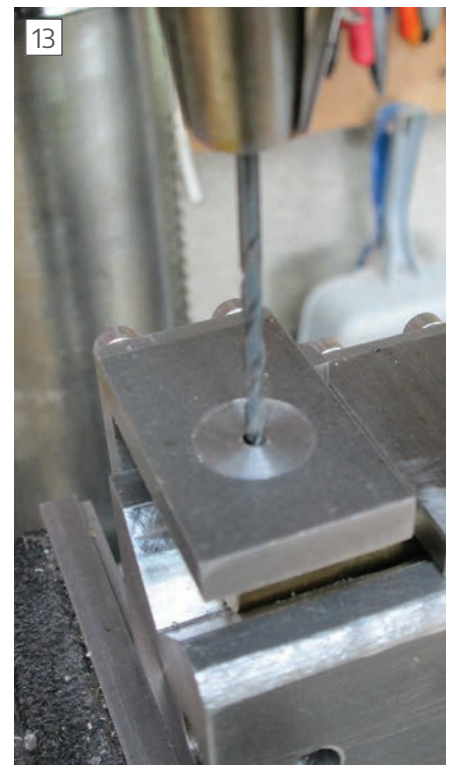
Point grinding jig.



Cross drilling kit.

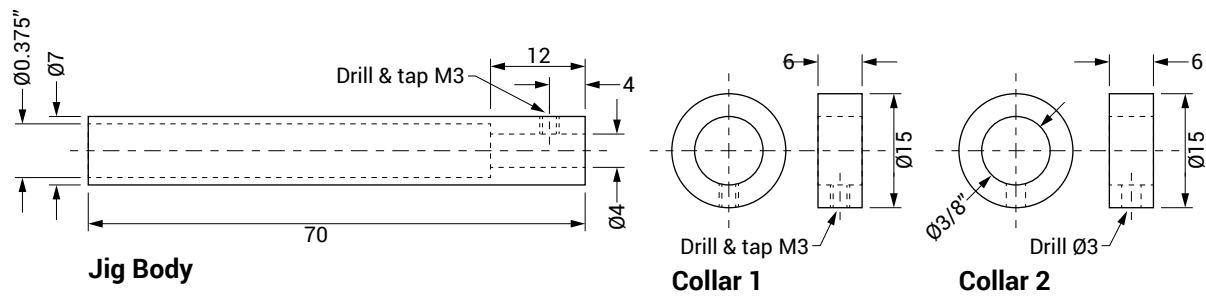


Closer view of jig.



Cross drilling jig in use.

Fig.1



Mat'ls: Brass

Dims. in mm

Note: the size of the jig is made to suit the points



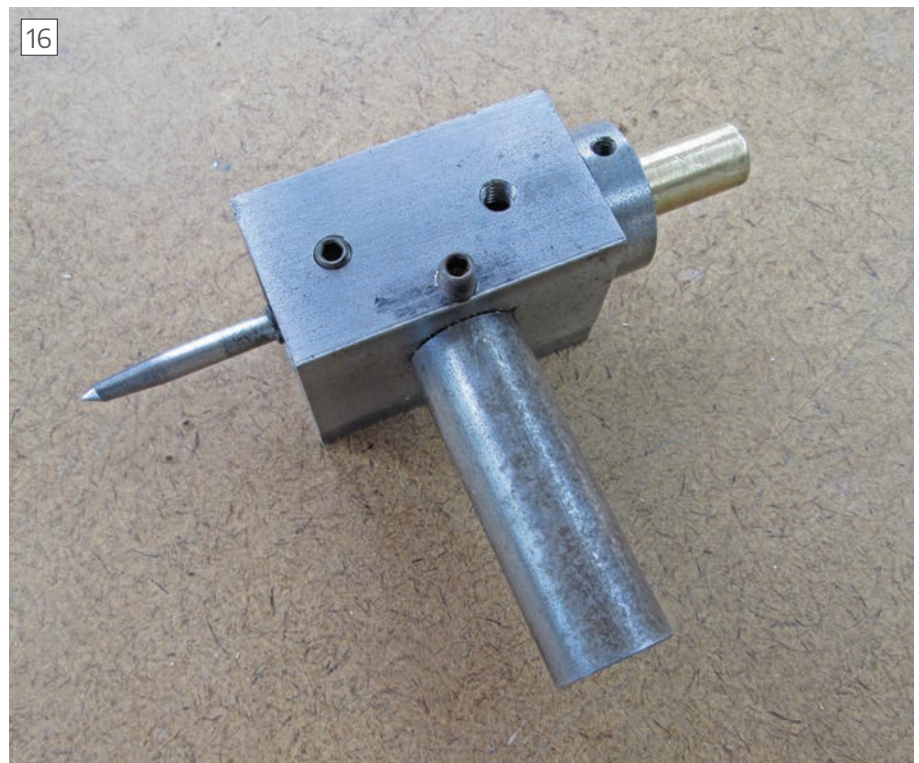
Scriber mounted in grinding jig.



Centre punch point mounted in grinding jig.

the required height for it to sit on the table, **photo 9**. The original instructions/drawing can be utilised to make it substituting the hole instead of the tool platform.

A jig was now needed to hold the scriber and punch which could be rotated/spun. The bore of the $\frac{3}{8}$ adaptor is reamed so to preserve the accuracy of the bore the jig was made of the softer material, brass, photo 10. The centre punch point was measured at 3.9mm diameter where as the thin portion of the scriber was 4mm diameter with a 7mm diameter in the knurled area. I decided that I could live the slight inaccuracy on the centre punch point that may be caused by inserting it into a slightly large hole to cater for the 4mm. The actual dimensions of the adaptor are shown in **fig. 1**. Constructing the jig is a simple matter of turning/drilling with a cross drilled tapped hole. For the latter I utilised the cross-drilling jig as described in Ref 1. A jig like this may not be used that often but to have the right tool for the job is always a pleasure.



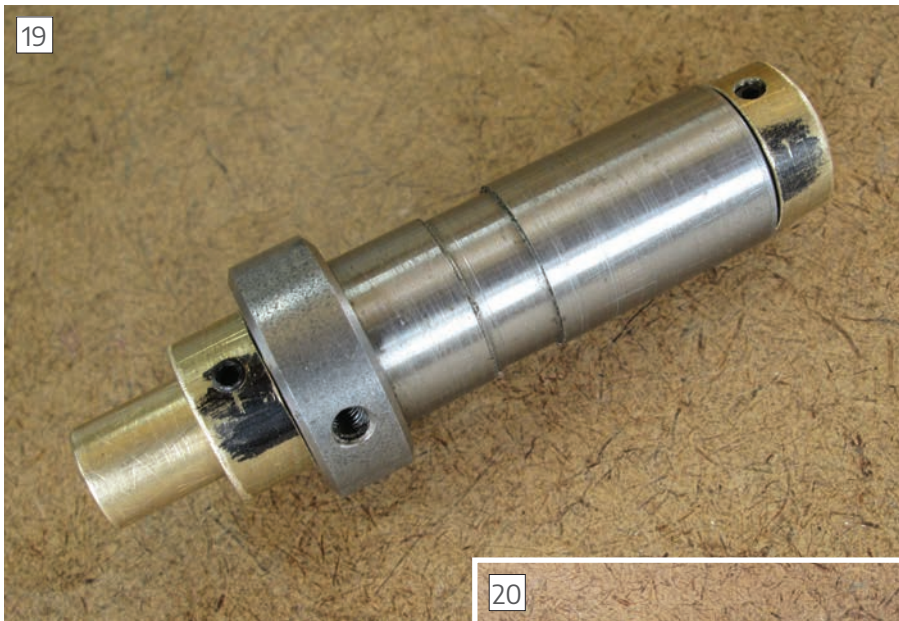
Point grinding jig trial assembly.



First test.



Point grinding jig with locating collars.



Point grinding jig mounted in adaptor showing locating collars in position.

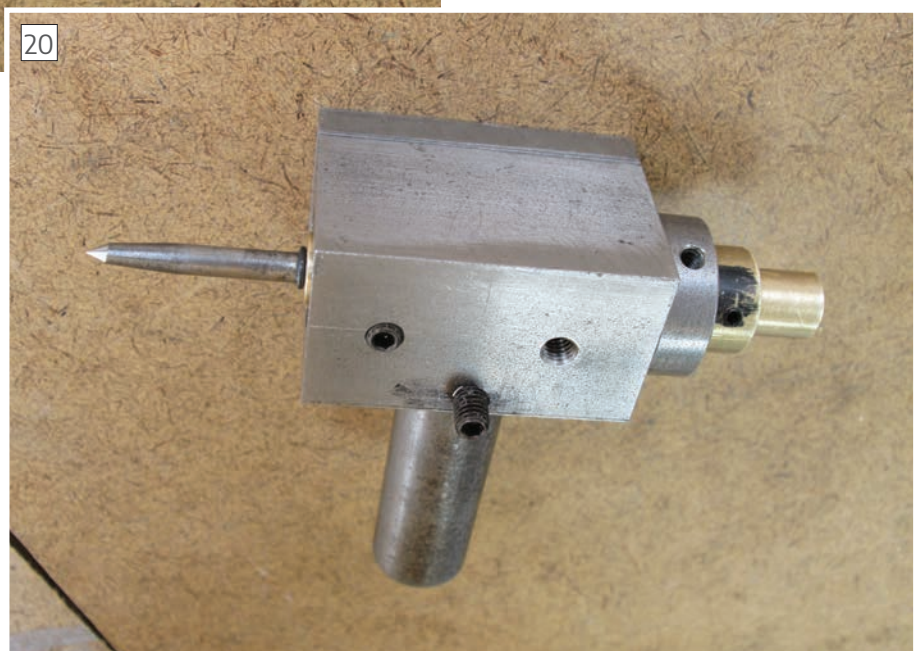
Photographs 11 and 12 show my kit and in operation in **photo 13**. I took the trouble to make a range of guide bushes and a rack to hold them. The holes in the rack were a good fit to stop them falling out in storage but the dreaded rust took hold and jammed them in the rack. Cleaned up and waxed the trouble seems to have abated.

The points are slid into the jig and held in place with the grub screw, **photos 14 and 15**. A quick test, **photos 16 and 17**, confirmed the principal but a means of definite location of the work in the adaptor was required so that a controlled feed could be put on. Locating rings were made, one fixed and one adjustable. These can be seen in **photo**

18, and are shown in fig. 1 and in their operating position in **photo 19**.

To grind the point, it is held in the brass jig by the grub screw which is then fitted in the adaptor. The grub screw is used to locate the fixed ring via a radial clearance hole drilled in it. The moveable ring is then set so that the jig complete with the point can be rotated but with minimal play and the ring is held in place with its own grub screw. The assembly ready to be fitted to the tool slide is shown in **photo 20**.

In operation the point is offered to the grind stone and an initial cut is taken, spinning the point by hand via the jig. It can be useful to black the surface to be ground using a felt tip pen, **photo 21**,



Point grinding jig and adaptors assembled ready for mounting on Worden tool slide.

21



Blacked centre punch point ready for initial grind.

so that the cut area will show up, photo 22. In the last photograph it can be seen that the cut is only partial. The two main reasons for this are bad previous grinding and slight lack of concentricity of the point with the main body. The scriber fell into the last category being slightly bent but in practice it has not

been a problem. Grinding continues until a complete cone of shiny surface at the point is obtained.

Conclusion

The jig was well worth making. The most work involved in making it would be in the 90 degree adaptor. In my case

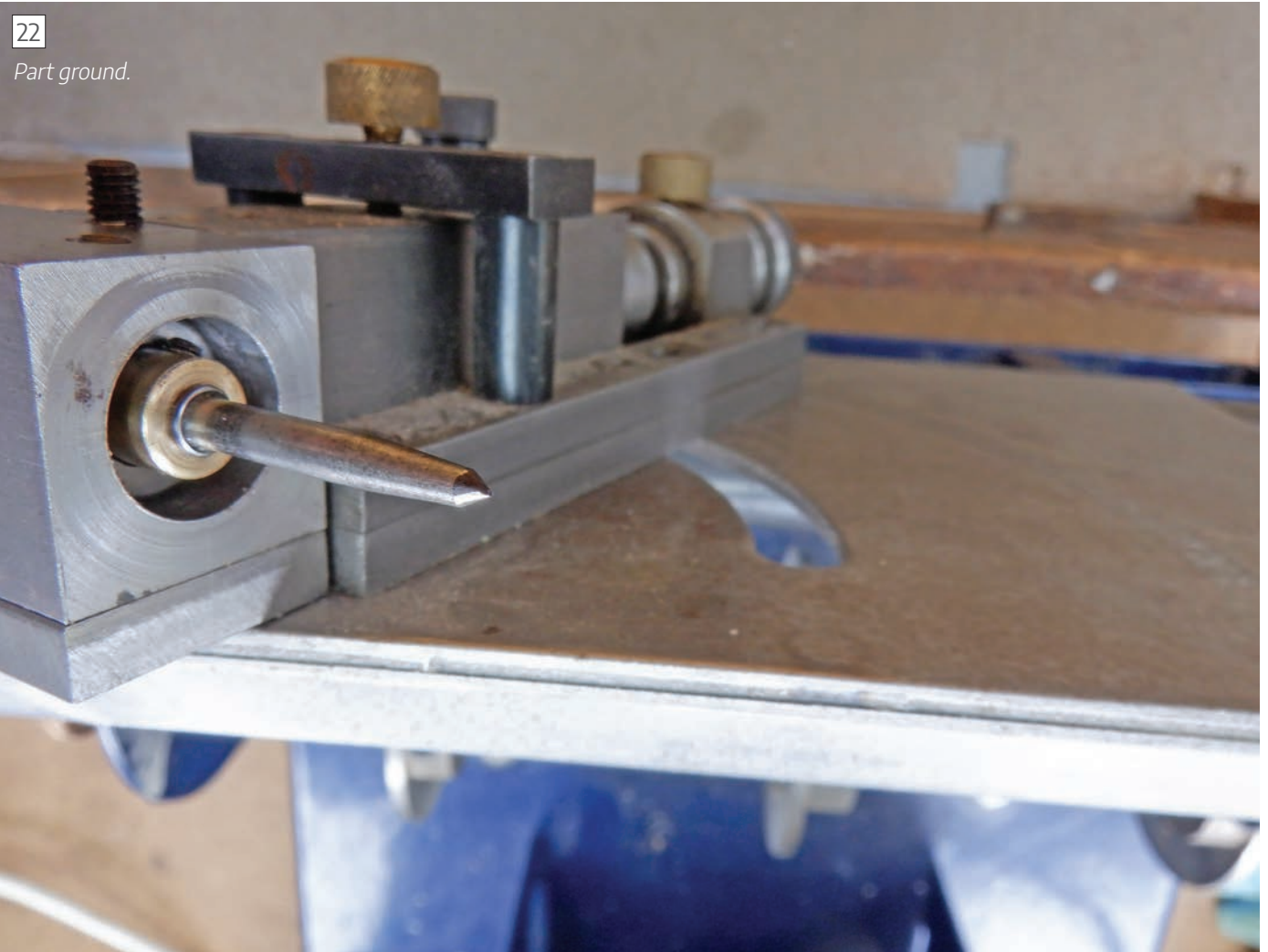
it was already to hand having been made for another job. ■

References

- 1 MEW 149. Alex du Pre: "A Design for a Cross Drilling Jig".

22

Part ground.



Scribe a line

YOUR CHANCE TO TALK TO US!

Drop us a line and share your advice, questions and opinions with other readers.

Sulphuric Acid

Dear Neil, not sure how much help this is to Mr Farrant, but it's my understanding that possession of any amount of sulfuric acid (I prefer the old spelling, but that's the international standard) of 15%w/w or higher concentration is a criminal offence under the Poisons Act 1972 (Explosive Precursors) (Amendment) Regulations 2018 [SI 2018 No. 451] - unless a licence is held, and delivery of same to residential premises is an offence under the Offensive Weapons Act 2019 regardless. This might explain why he's had a problem getting hold of the stuff.

I never needed to use it myself, so I have no idea as to how onerous are the licensing conditions in practice. I'm not a lawyer by the way (Chartered Mechanical Engineer and fairly regular reader) so please don't take the foregoing as definitive.

Here are the web addresses of the relevant bits of legislation. gov.uk:

<https://www.legislation.gov.uk/ukxi/2018/451/contents/made>
<https://www.legislation.gov.uk/ukpga/2019/17/contents>

Had a quick look on Espacenet (www.worldwide.espacenet.com/classic) to find out about the Siddells/Biddells Patent gadget (Two Oddities) but couldn't find it. Not entirely surprised; people used to be quite cavalier about claiming

a thing had been patented when in fact it hadn't. Once you understand how to use it, it's an interesting site (European patent agency, but in practice you can find patents from all over the world).

Thanks for a great magazine!

Richard Allton, by email

The regulations only apply to individuals not businesses and the licence has an annual cost. My own solution was to dilute all my stocks to 13% as I have no need for a stringer solution. I understand Doug Farrant was able to order his through a business which then diluted it below the 15% concentration for him.

I would also like to thank reader M. Hopkins, whose letter arrived to late for inclusion; he reiterated much good safety advice, the most important of which is to always add acid to water, not the other way around, so any splashes are diluted. He also points out that concentrated sulphuric acid is very heavy and also that for most uses of it in hobby engineering, such as pickling, it can be substituted with other equally effective chemicals, Neil.

Earth Bonding

Dear Neil, I felt compelled to drop a quick note on Steve Skelton's series of articles (MEW #310) explaining the ins-and-outs of Mains electricity and his particular emphasis on electrical safety. I do feel he has made a very important omission that deserves mention, concerning plumbing pipework as Earth bonded conduits. It is part of standard plumber's training, in Australia at least and, I suspect in most parts of the world that before any worker attempts to cut a metal pipe it is required safety practice to clamp a shorting cable to either side of the cut prior to the actual cutting operation. This is to avoid electrocution just in case the line of pipe is carrying a fault current at the time which may very well kill.

In a similar vein, I would also refer to Adrian Garner's article on his construction of a motorised milling head for use on his lathe. He has used rubber O-rings on the motor-mount to achieve a degree of vibration isolation. In his case, because the motor is separately mains powered then an Earth safety

pathway is assured. However, some types of independently powered accessories may draw their electrical supply from the lathe or other machine's load circuit, in which case insulating rubber mounts can be potentially lethal in fault situations. For these types of installations, it is essential to connect a heavy-gauge stranded copper cable from the motor frame to the machine chassis to ensure Earth continuity. Failure to do so may result in electrocution.

Andre ROUSSEAU. Papakura, New Zealand

Hi Andre, on your first point there seem to be different practices in the UK, possibly because of different regulations around earth bonding. It would be useful to get a perspective from a UK electrician. On the second point, proper earthing of all mains powered equipment is indeed essential, and if readers aren't sure they should consult a competent electrician, Neil.



Workshop Cranes

Dear Neil, having just received the March issue of Model Engineers' Workshop I note that the next issue will include an overview of workshop cranes. This will probably arrive too late for inclusion but may be of interest. One point to always be aware of and to treat with caution is the ability of the supporting structure to carry the loads imposed on it.

I have included photos of my own workshop gantry crane installed primarily to allow removal of the vertical head of my Victoria U1 mill (just visible in one of the photos).

Initially my thoughts were to have a simple rail running parallel to the mills horizontal axis to allow this but a dodgy lower back suggested that in time, lifting the chucks on and off my 6" Chinese lathe would also become an issue so the decision was made to make it a gantry that covered the lathe as well.

Construction is of 'Unistrut' an industrial racking and equipment support system that I have been familiar with for several decades.

While potentially a little expensive, the ratings of it as a simply supported beam (P1001) and that of its' fittings (P2950 Trolleys) are readily available.

The roof trusses that support it were tested to 300kg each on the vehicle side of the double garage where they are visible and could be monitored for distress. Note the load is transferred to an upper node of the trusses using the builders bracing strap visible in several of the photos and 150 x 50 rafters previously added to support the ceiling contribute to the load bearing capacity of the support structure. Hence, I have every confidence in a SWL rating of 200kg.

To ensure the gantry remains parallel to the wall and doesn't crab (and jamb!) a parallel cable system as used on one type of drawing board has been included.

Brett Lilley, Whakatane, New Zealand

Missing MEWs

Dear Neil, the Society of Model and Experimental Engineers members are sorting out our copies of Model Engineer and Model Engineer's workshop magazine so that we can send them off to be properly bound and put in the library at Marshal House. We are still missing two copies of Model Engineers' Workshop: Vol 264 February 2018 and Vol 288 January 2020. If anyone has spare copies of these that we could have could you please let me know.

Jonathan Tickner, SMEE

If anyone can help, please email me in the first instance and I will pass on your details to Jonathan, Neil.

1

The flycutter in use



A Tangential Flycutter

Howard Lewis applies the benefits of tangential tooling to fly cutting.

Having been impressed by the performance of the tangential turning tools that I have made, as well as purchased; whilst doing some fly cutting, the thought came that maybe a tangential flycutter might be a useful tool.

The eventual result, although not that initially envisaged, is shown in **photo 1**

A little thought showed that the relative motion between a milling cutter and the workpiece is the same as that of a lathe tool and the work in the chuck.

The first thought was to modify a

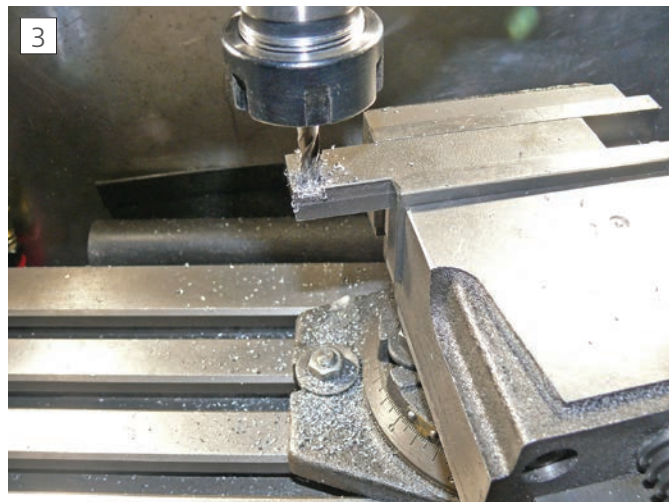
number 3 Morse taper (3MT) stub arbor to carry a holder for the toolbit, in an angled slot. This would provide a means of adjusting the swept radius of the cutter and make the toolholder simpler to make, by removing the need for machining at compound angles.

2

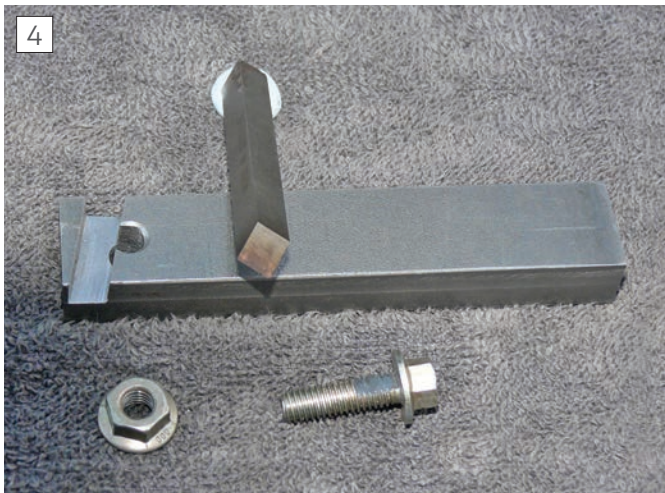


The ER 32 3 MT Collet

3



Cutting the slot in the initial tool holder



The initial toolholder



Completed initial toolholder

So, a 3MT stub arbor was set up in a shop made ER collet. The collets are part of a floating reamer holder, made previously. Hand or chucking reamers are held in standard ER25 collets, by their parallel shank, but since no one offers ER collets to hold machine reamers, with morse taper shanks, collets for these would have to be home made.

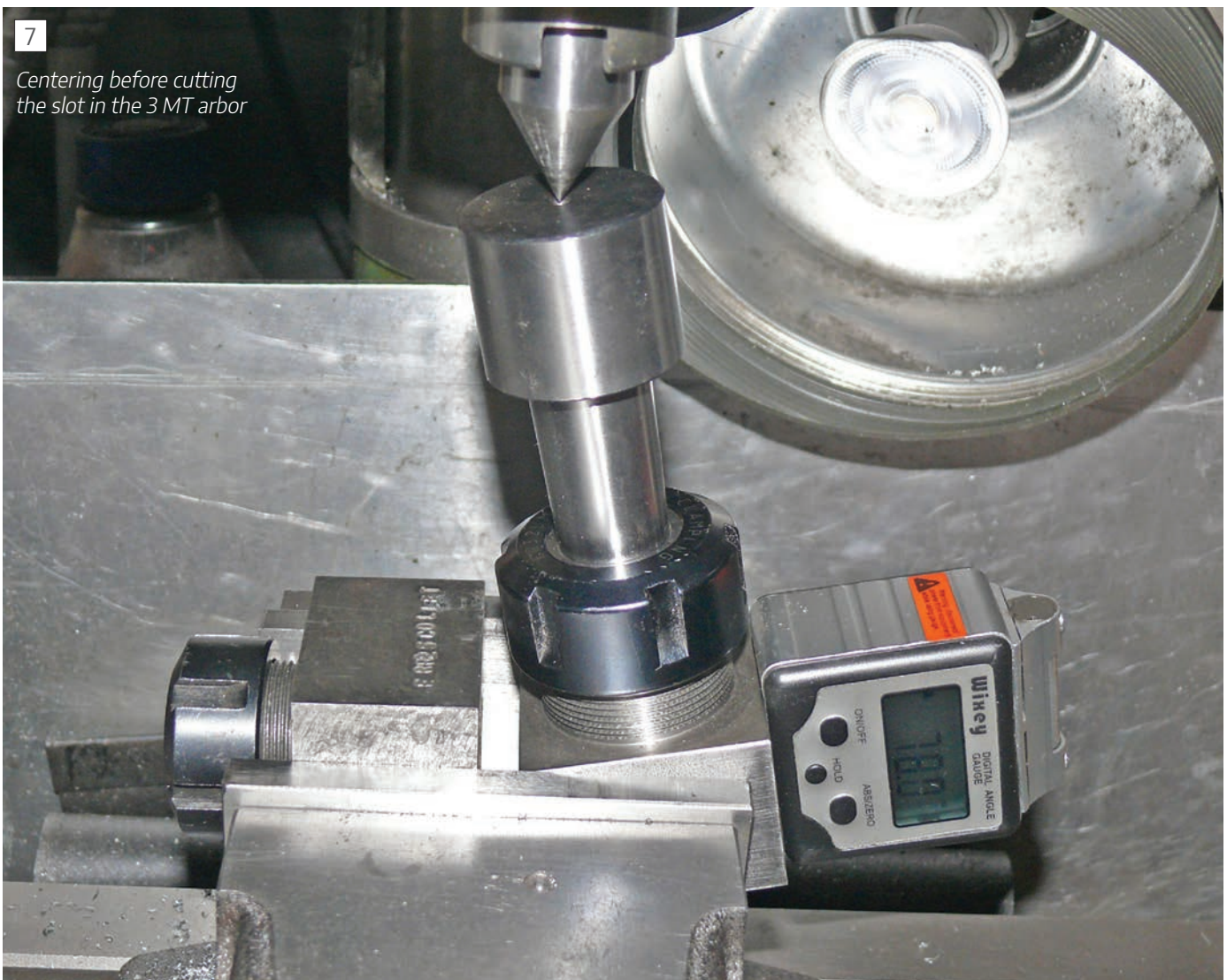
Consequently, three ER32 collets were made up to take 1MT, 2MT and 3MT shanks. The 3MT collet is shown in **photo 2**.



ER 32 collet block

Work was started by making a holder for a $\frac{1}{4}$ inch toolbit, by cutting a slot across it at 12 degrees, **photo 3**, to produce a toolholder which would look like **photo 4** and **photo 5**. This should have fitted into an inclined slot in the 3MT arbor, and being secured by grub screws, would have allowed the position of the toolholder to be varied.

For this task, the intent was to use the 3MT collet to hold a stub arbor in an ER collet block, **photo 6**. This was set up under the mill ready to mill a slot, offset from the centreline, across the end, at 12



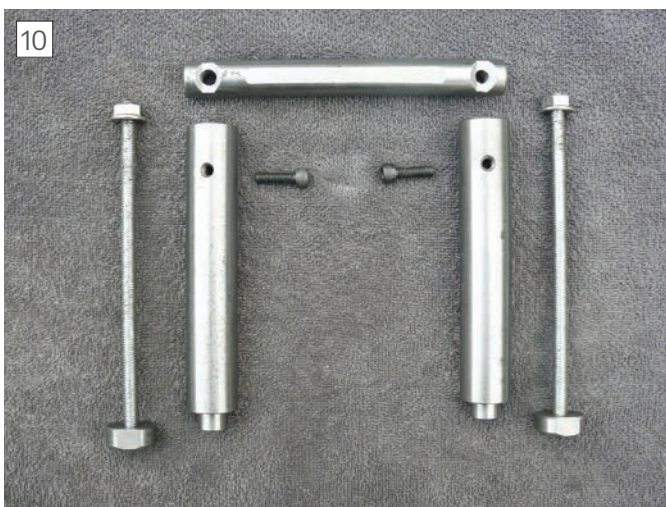
Centering before cutting the slot in the 3 MT arbor



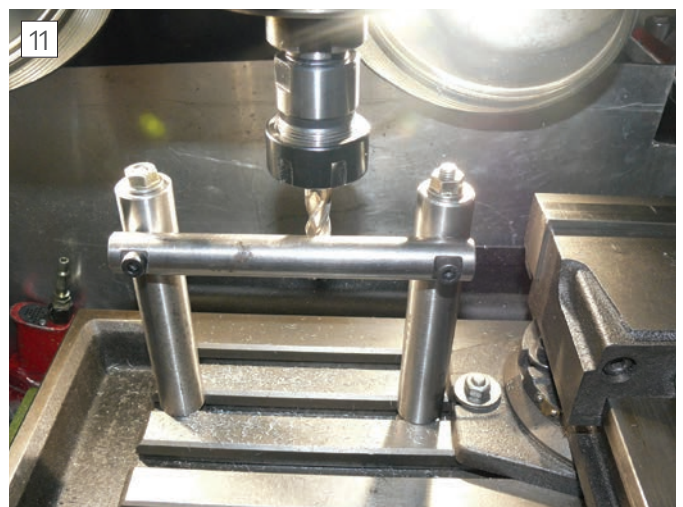
Turning the pillars for the vice alignment fixture



Vee in the cross bar



Fixture awaiting assembly



Cutting the alignment face

degrees, **photo 7**.

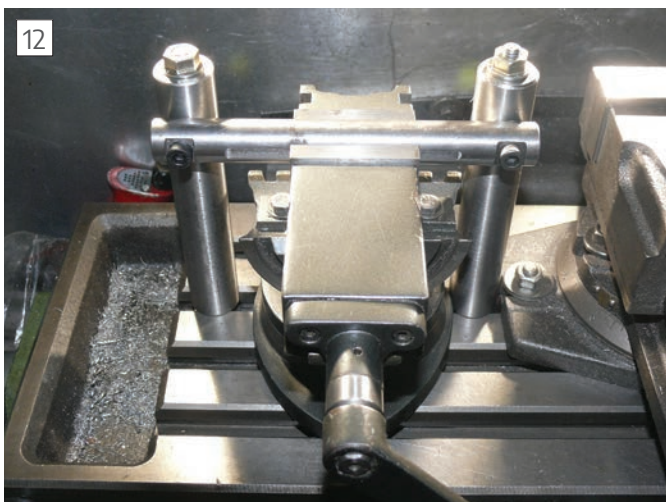
Unfortunately, as soon as an attempt was made to start cutting, it soon became apparent that the block could not be held tightly enough to prevent movement under the cutting forces. This approach had to be abandoned, and a toolholder made which involved

machining at compound angles.

To ensure that a 3-way vice could be set parallel on the table of the milling machine, an alignment fixture needed to be made. This would require two pillars with the lower ends a snug fit in the tee slot of the table. The turning operation for this is shown in **photo 8**. To locate

the cross bar to the pillars, a slot was cut at each end, followed by changing the slot into a vee to ensure that there would be no relative movement, **photo 9**. The parts prior to assembly are shown in **photo 10**.

The final operations were to assemble the parts and fit to the table, before



Aligning the vice for clamping



Cutting the tool slot in the final toolholder



Milling a 12 degree face



Milling the second 12 degree face



Toolbit clamp setscrew



Tapping the 3 MT arbor

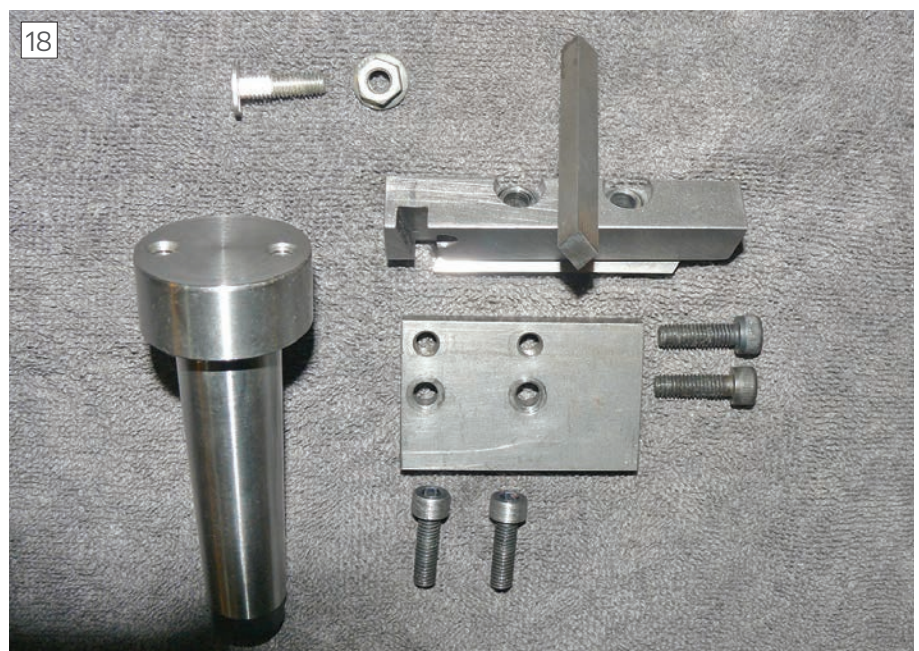
taking a cut along each side of the crossbar, **photo 11**. All the scales on the vice were set to zero, before it was clamped to the fixture. Once this had been done the vice was clamped to the table of the mill, **photo 12**. A predrilled piece of metal, destined to be the toolholder was clamped in the vice, which was then rotated so that a slot could be cut at an angle of 12 degrees to the to the long edge. The slot was shallower than the toolbit, and positioned so that it broke into the drilling for the setscrew, so as to clamp the toolbit, **photo 13**. The vice was then reset, so that the narrow edge of the toolholder could be machined at angle of 12 degrees, **photo 14**.

Once this had been done, the metal was moved to the other vice, and the other edge machined to the same angle. To allow a workpiece of this length to be held in the K4 vice, the jaws had to be removed. The check that the angle was correct, before machining, is shown in **photo 15**. By making the shank of the toolholder trapezoidal, the need to mill

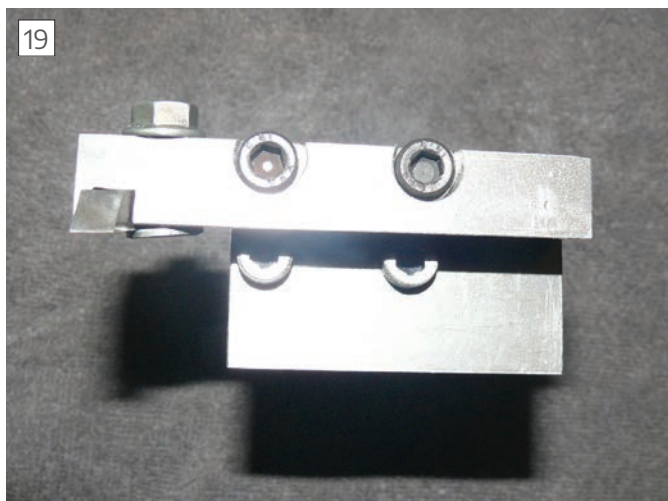
the slot for the toolbit at a compound angle was avoided.

After machining, two holes were

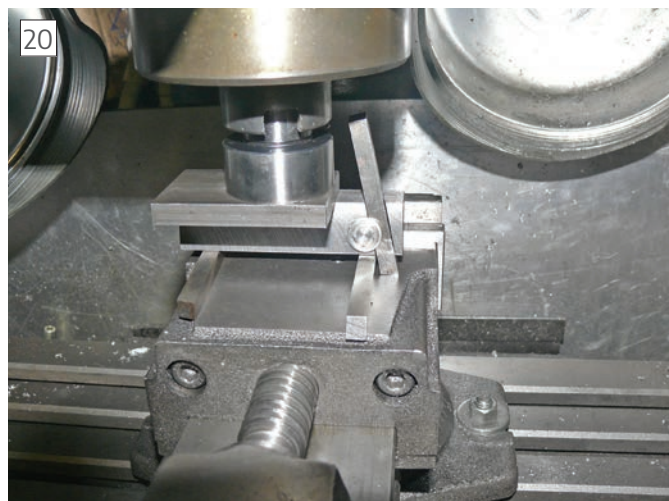
drilled through, and counterbored, for M6 capscrews, which would secure the holder to the plate which would offset



Kit of parts awaiting assembly



End view of the flycutter



Setting the toolbit protrusion

the holder, to bring the cutting edge of the tool to the centreline of the arbor. The M6 setscrew to clamp the toolbit was faced to thin the head, and a flat filed beneath the head, so that it would bear against the toolbit, and be prevented from rotating, **photo 16**.

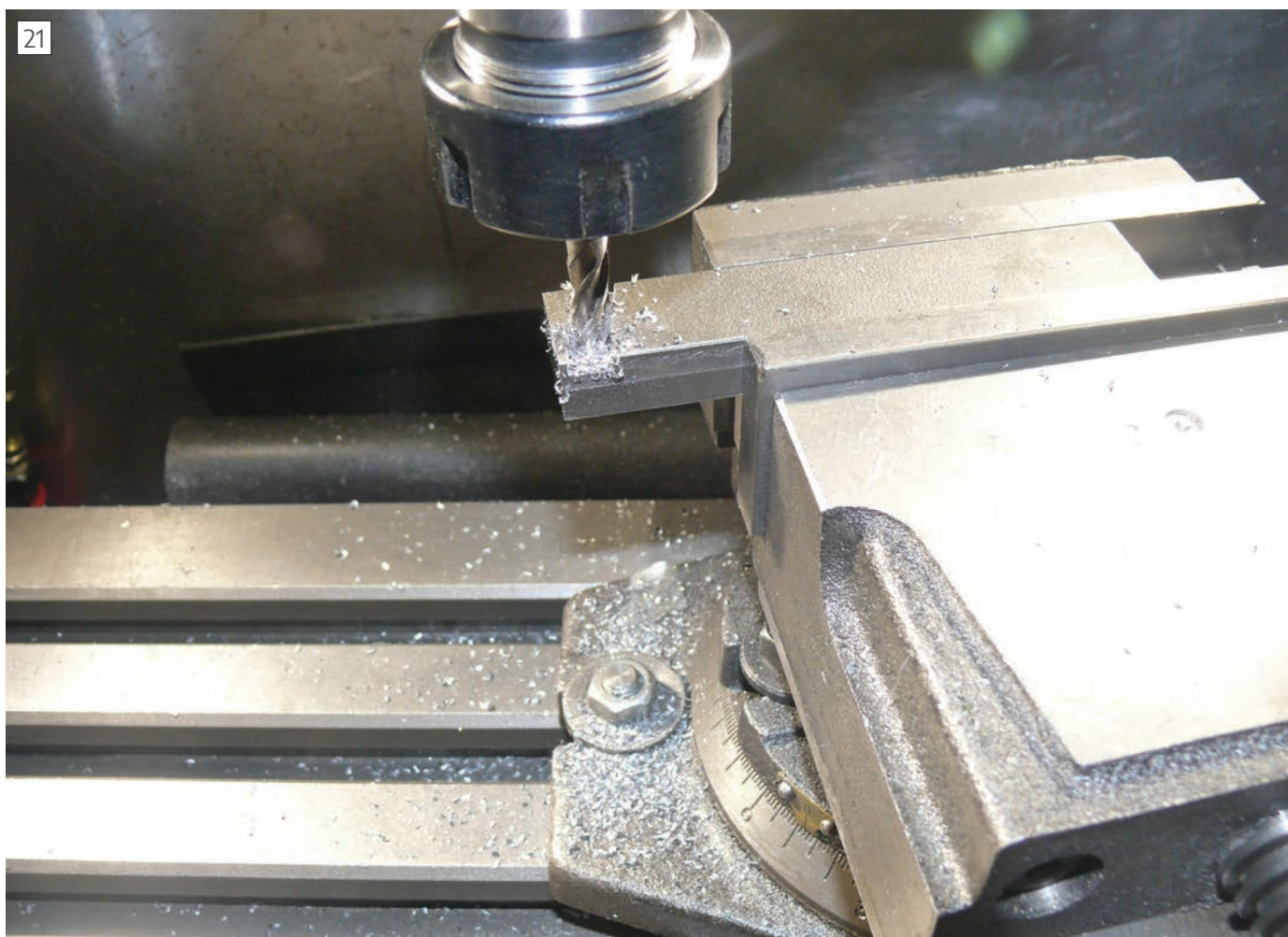
The 3MT arbor, having been shortened to remove the damage done during the initial attempt to mill

a slot at an angle, was again set up in the 3MT collet in the ER32 collet block, but with its axis vertical. Two holes were drilled and tapped M6, for capscrews to secure the offsetting plate, **photo 17**.

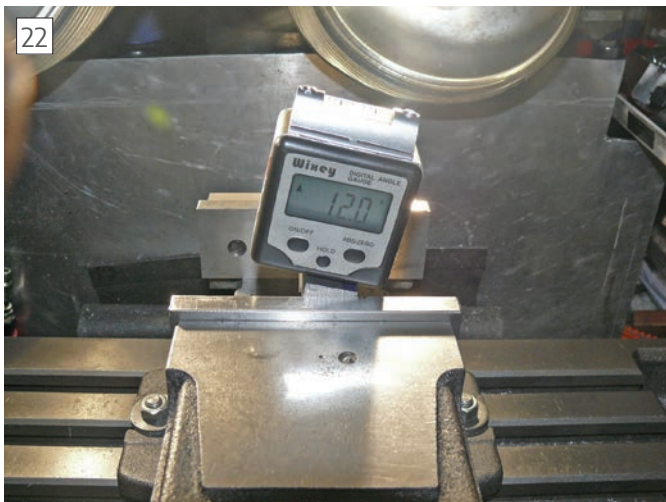
A piece of 12mm plate was machined to match the toolholder, two holes drilled and tapped m6 for the capscrews for the toolholder, and two

clearance holes to match the tappings in the 3 MT arbor. The complete set of parts awaiting assembly are shown in **photo 18**. It should be noted that two of the capscrews have had the head diameter reduced, to clear the toolholder when it is in position on the offsetting plate. This is shown more clearly in **photo 19**.

Because of the angle at which the



Milling toolbit slot in the grinding jig



Setting to mill the base of the jig



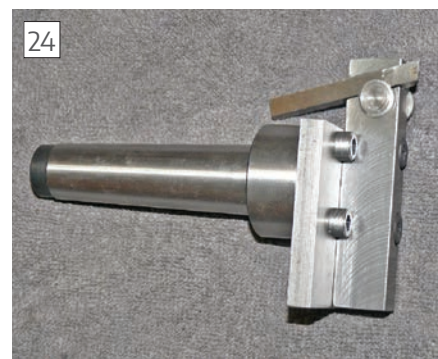
Sharpening jig

toolbit is set, the protrusion from the holder will affect the position of the cutting edge from the centreline if the arbor. To set the cutting edge of the toolbit close to the centreline of the arbor it was set by resting the toll on two more 3/4 inch toolbits, **photo 20**.

To enable the toolbit to be ground for sharpening a jig is required. This was produced in a similar way to the toolholder, but with the tool slot at 30 degrees, and with the clearance hole replaced by an M6 tapping placed

away from the slot, **photo 21**. The jig was then set wide face uppermost, with the slot underneath, in the vice at an angle of 12 degrees, for the base to be machined, **photo 22**.

The toolbit is clamped in the jig and the end of the toolbit ground. This will give angles suitable for use. The jig, ready for use, is shown in **photo 23**. The complete tangential flycutter is shown, ready for use in **photo 24**. ■



The completed tangential flycutter

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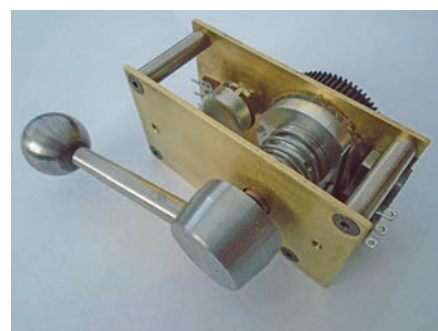
**Look out for your copy of MEW 317,
the July 2022 issue:**



Geoff Adams explains some useful Mini Lathe modifications.



Lawrence Pepper details a drip feed for lathe cutting fluid.



Derek Spedding makes a 'proper handle' for his Boxford AUD.

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A Shop-Made Quick Change Toolpost



Ted Hansen describes his approach to making one of the most useful of lathe accessories. This instalment includes all the remaining drawings. Part-2

Cutting the slot for closing the clamp is next. Drill the bottoming hole for the slot first. This will probably have to be done by marking out and drilling from each end because of the length of the piece. A slitting saw makes a neater job of cutting the slot, **photo 10**, although one cut with hacksaw functions every bit as well.

Finally, drill and tap the holes for the clamps and the height adjusting screw. Closing this slot with enough force to securely clamp the tool blade in place is asking a lot of a pair of M6 screws threaded into cast iron so, studs inserted to full depth and secured with Loctite or similar adhesive should be used instead.

In my case one job remained because I had not faced off the ends of the block at the outset. The tool holder was set vertical in the milling machine using a special, shop-built square (another George Thomas design, from Model Engineer in 1977, issue #3568, for this finishing cut, **photo 11**)

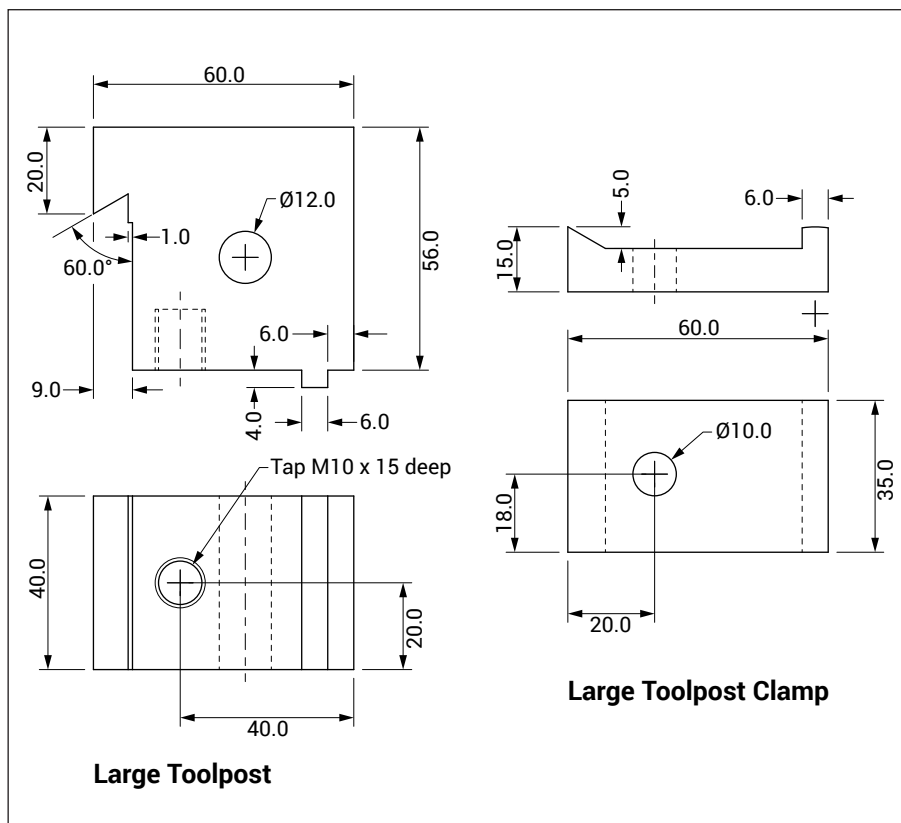
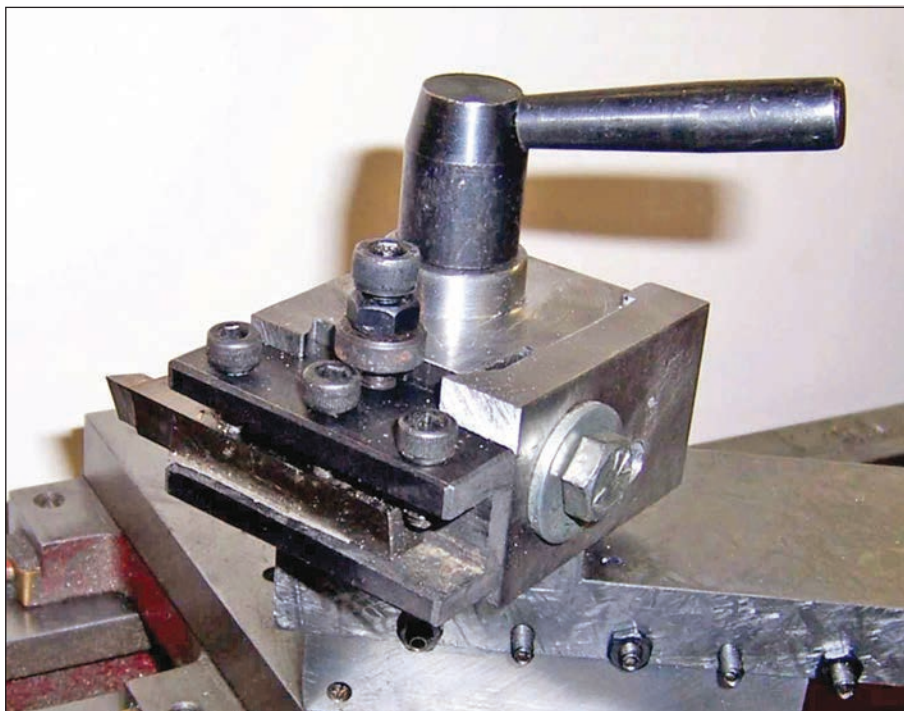
The final holder is shown in **photo 12**.

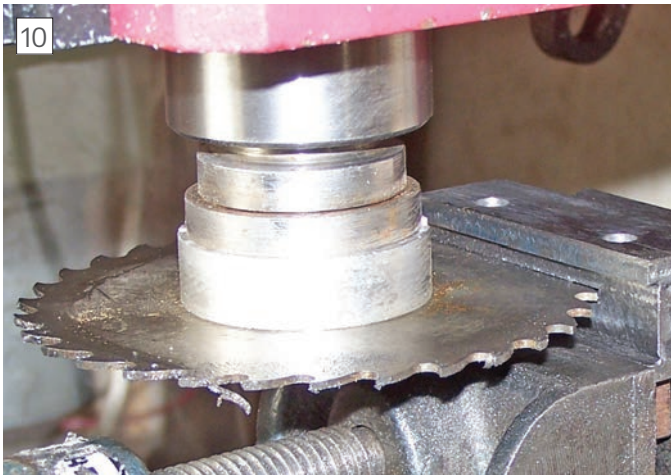
Height Adjusting Nuts:

Secure the height adjusting studs in place with Loctite or other thread locking adhesive.

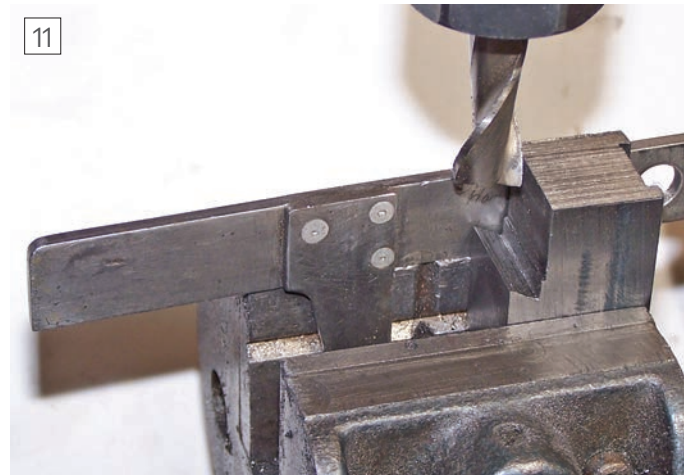
Make a series of height setting nuts all at once. Knurl a long length of material (brass or bronze preferred if you have it), then part the nuts off, drilling and tapping the holes as you go. Although the diameters are not critical, the actual adjusting nuts should be fairly large diameter to give a good seating against the tool post body.

Knurling does not cut the material like a lathe tool, rather, it deforms





Using a slitting saw to cut the slot for clamping the tool blade.



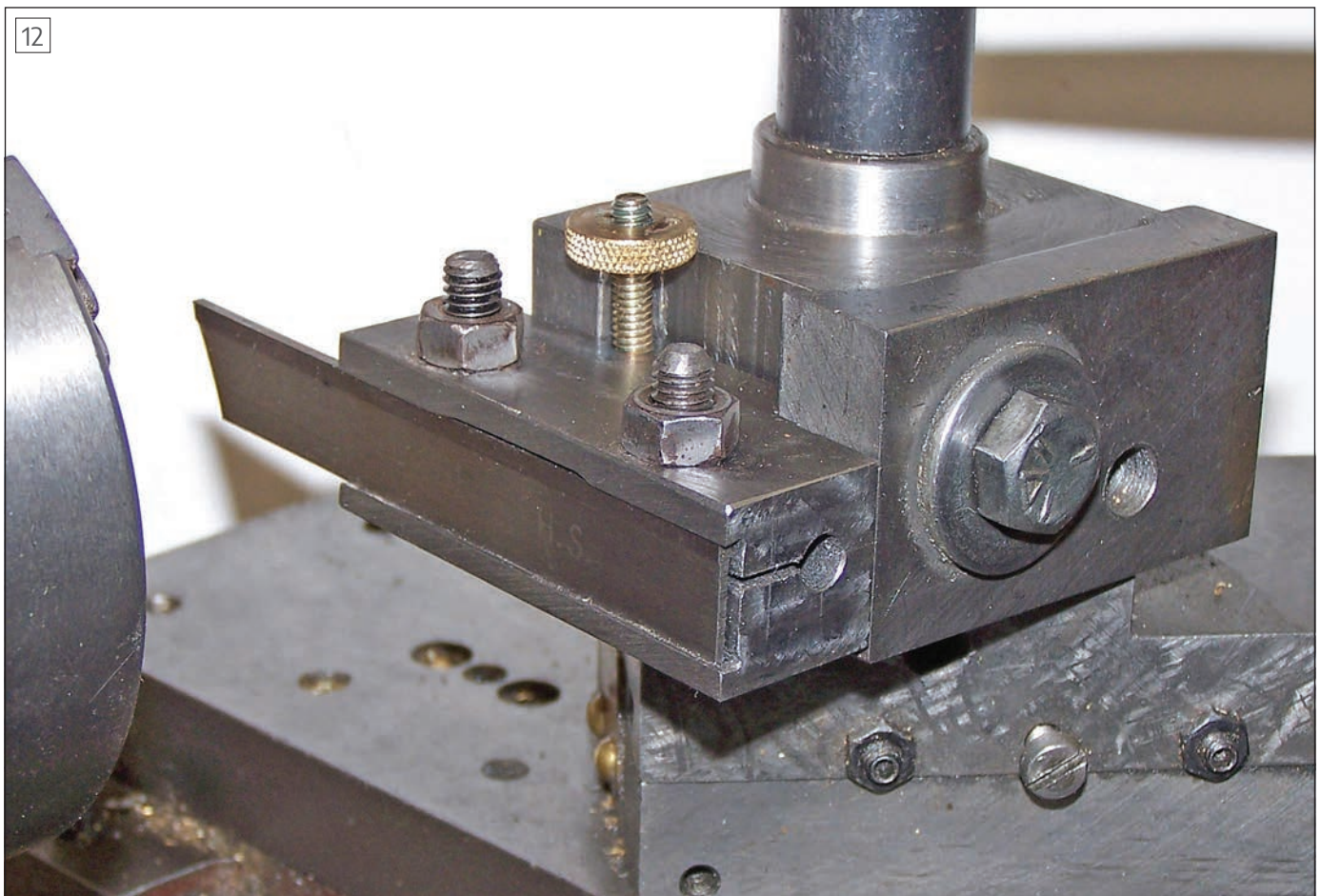
Setting up to mill the end of the tool holder. Note the small T square used to set the edge of the work vertical.

the metal and forces it into a series of raised pyramid shapes. This requires a large amount of force, much higher than the forces created by a cutting tool. Especially on a small lathe, a clamp type knurling tool is recommended so that this load is not passed on to the headstock bearings. These knurling tools are available from suppliers or can be made as a shop project with just the knurling wheels needing purchase, **photo 13**.

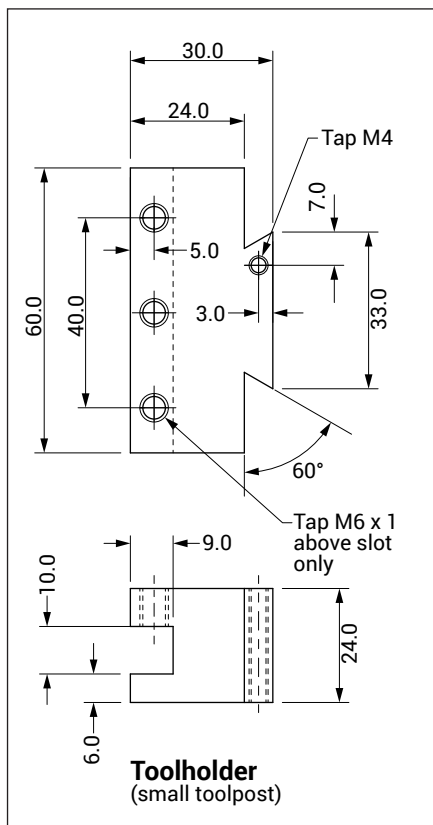
In use, the knurling tool is set at a slight angle to the lathe axis to concentrate the force on just a small edge of the knurling wheels, **photo 14**. The knurls are then tightened against the work, and the lathe run at a moderate speed using power feed. Several passes will probably be required to get a good pattern. Although it is not actually a cutting operation, knurling does create fine, almost powder-like, chips. These

should be washed away with a generous flow of light oil from an oil can to prevent them from clogging up the knurling tool.

Once knurling has been completed, chuck the stock in the lathe, face off the end, centre drill, then drill and tap the hole, and finally part off the individual nuts, **photo 15**. Generously chamfer the edges in conjunction with the parting off operation. The nuts should not need any further finishing.



The completed cutoff toolholder. Studs and nuts are used instead of cap screws for added strength.



There is really no need for lock nuts on the height adjust setting. Once the correct adjustment has been found, a drop of Loctite will hold the adjusting nut in position. The bond of the Loctite is not so strong as to make further adjustment difficult. If later adjustment is needed, the Loctite remaining in the thread will usually be enough to prevent the nut from working loose due to vibration.

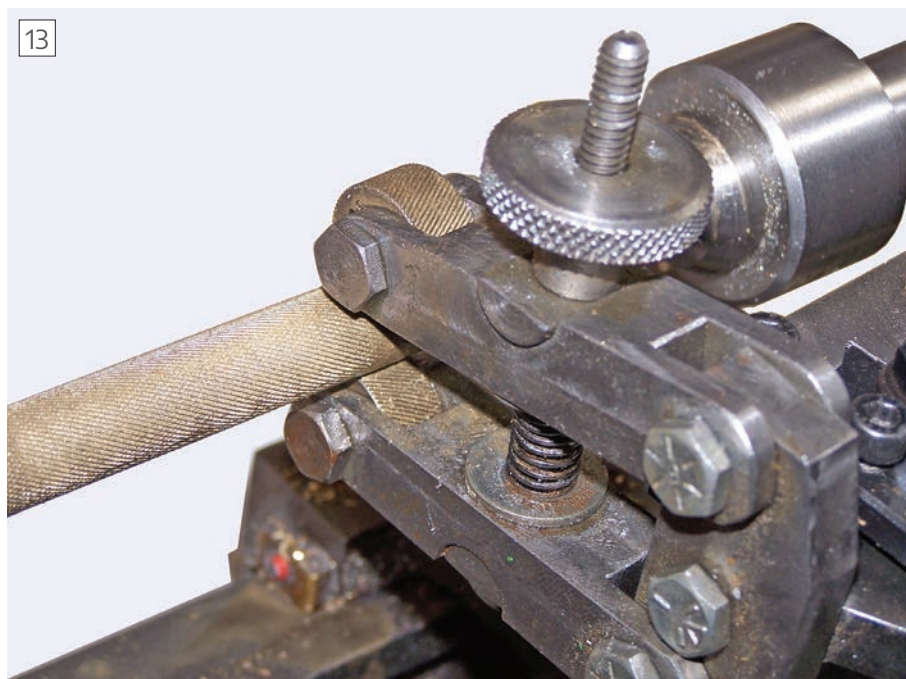
Conclusion:

Many years ago, I upgraded my vintage 9" South Bend with an adaption of George Thomas's four way tool turret (Model Engineer 1977, issues 3556 and 3557). That adaptation was, in fact, the subject of my first ever published article, (Model Engineer 1990, issues 3870 and 3872). and it was a huge improvement over the abominable pillar toolpost supplied with the lathe. At the time I thought it the ultimate tool setting device. This quick change toolpost is so much more convenient, however, that I sometimes wonder how I ever got by with "the old way"!

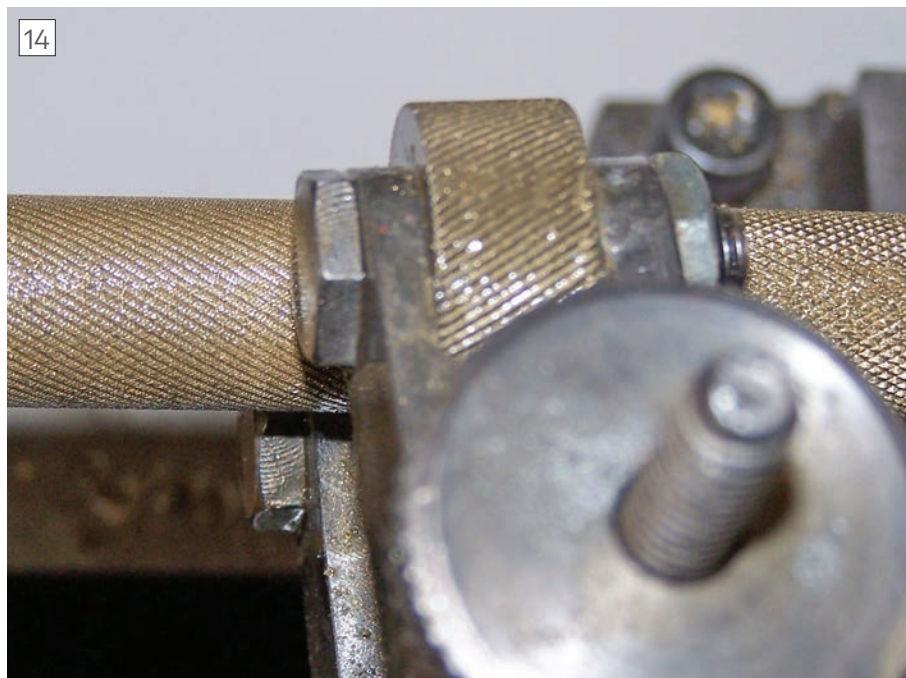
I hope you will find the same. ■

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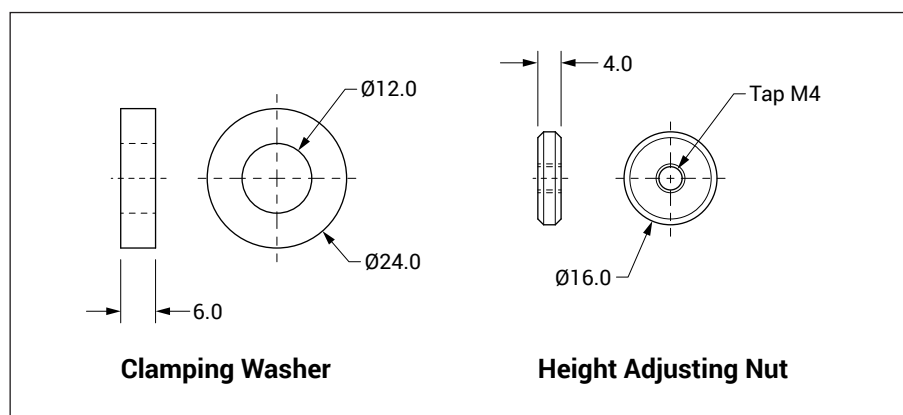
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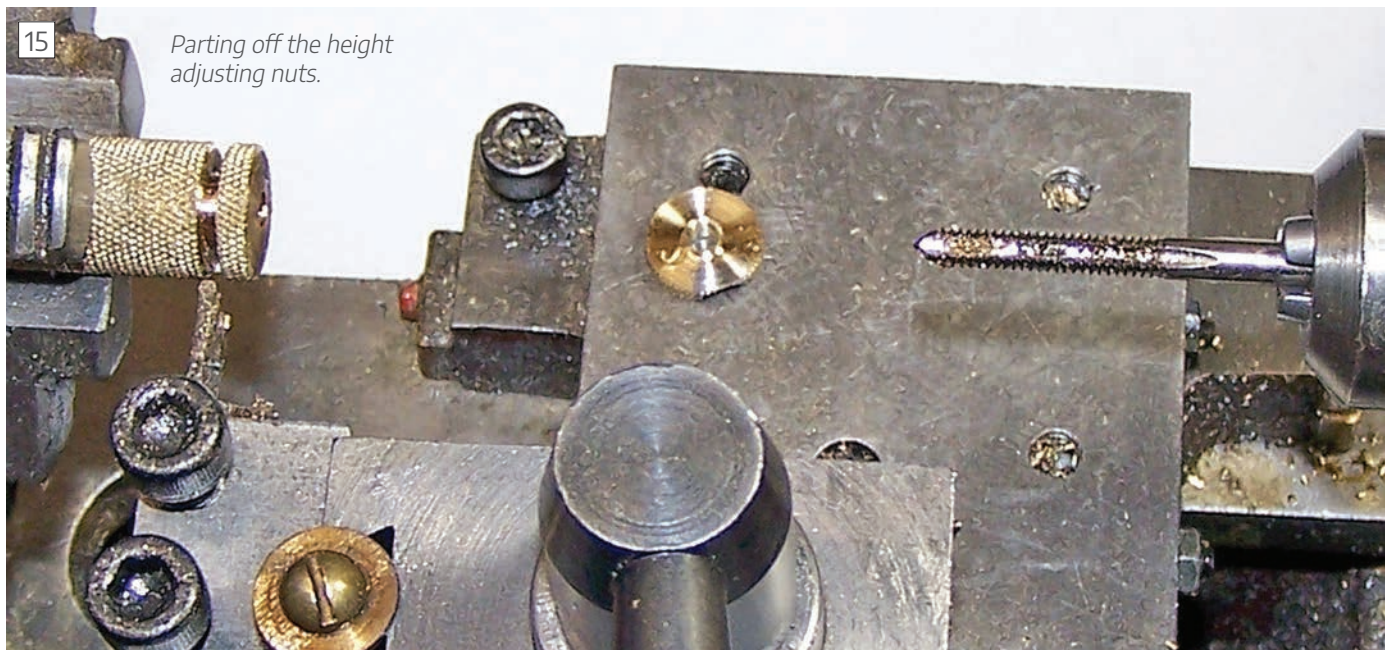
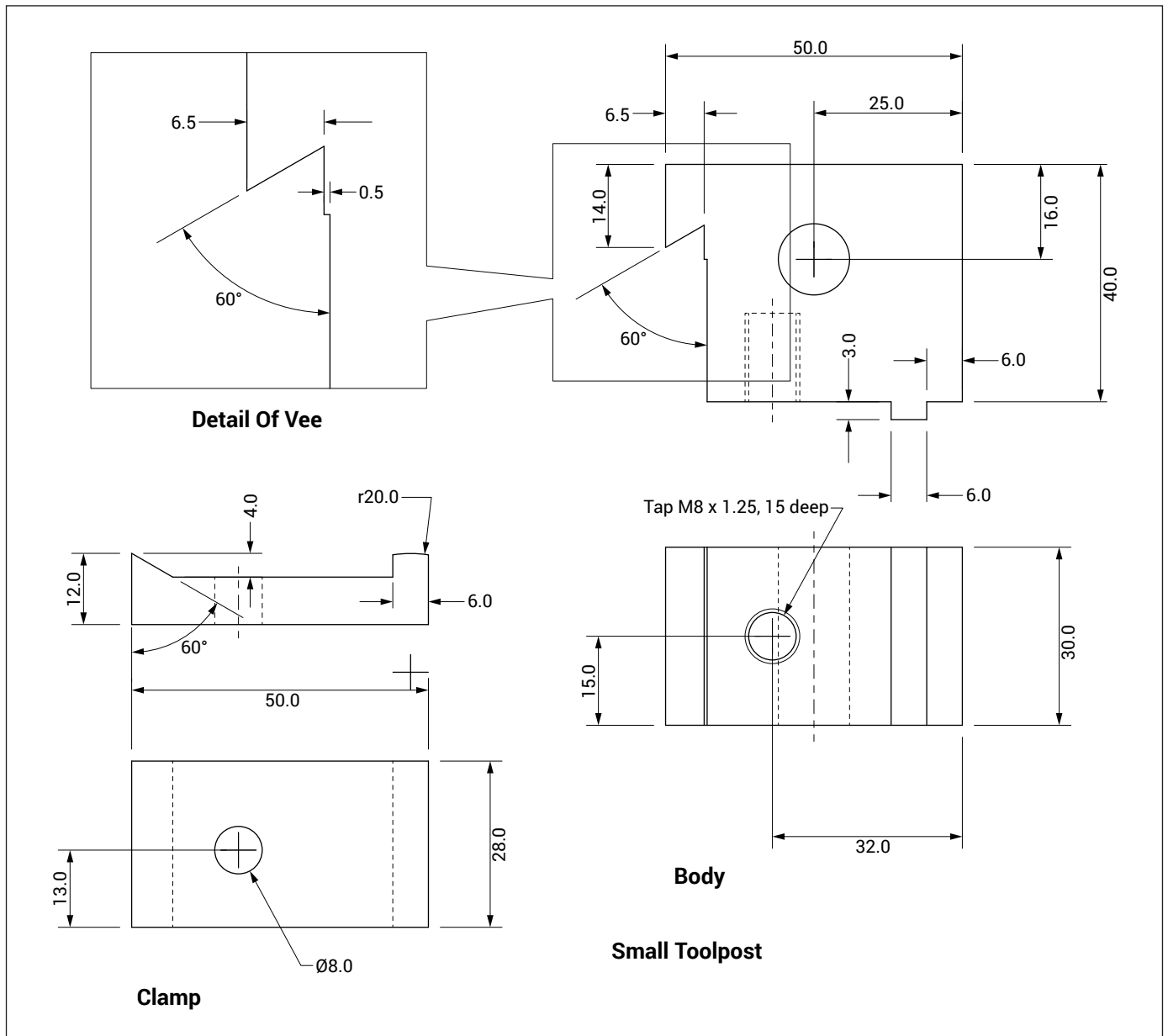


Knurling a length of brass stock using a shop made clamp type knurling tool.



A close up view of the knurling operation. Note the small angle of the knurling tool and the sharper pattern of the knurl on the right hand side after the second pass.





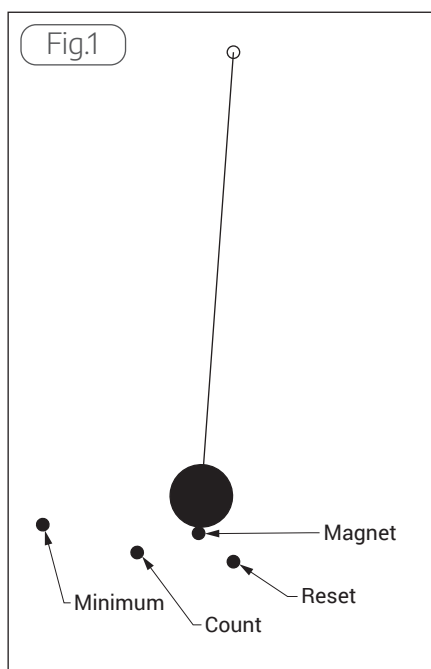
Building A Free Pendulum Clock



Tony Jeffree experiments with sensors and modules to make an efficient pendulum.

Around the beginning of the Millennium, I spent many satisfying hours constructing the $\frac{3}{4}$ Second Pendulum Clock as described in John Wilding's excellent series of constructional articles, serialised in *Model Engineer*. That clock is electrically impulsed, based on a Hipp Toggle mechanism that detects when the pendulum swing amplitude has decayed too much and causes a pair of contacts to close, energising an electromagnet to give the pendulum an impulse that will keep it swinging for another 80 swings or so. The pendulum experiences some mechanical interference in the form of the loads imposed by the Hipp toggle itself and the gathering pawl which drives a count wheel, which in turn drives the motion work of the clock, so it doesn't operate as a free pendulum, but the arc of swing is constrained within a range defined by the operation of the Hipp mechanism, which gives it some of the right ingredients for a decent timekeeper. My clock has been a great success, and it now hangs on the lounge wall in a brass and glass case of my own design (also documented in the pages of ME).

While building that clock, it struck me that it would not be too hard to harness some simple electromechanical/electronic techniques in place of the Hipp mechanism and the motion work to make the pendulum free in its operation for most of the time – the only interference would be an infrequent electromagnetic impulse, or some kind of direct mechanical impulse, such as a gravity arm, but as with the Hipp mechanism, still only impulsing the pendulum when its arc of swing had decayed. Having removed the mechanical loads imposed by the Hipp toggle and the gathering pawl, the interval between impulses could be considerably longer than with the $\frac{3}{4}$ Second clock. This idea lodged in the back of my brain for several years as other projects and life in general intervened, and it reappeared in the last



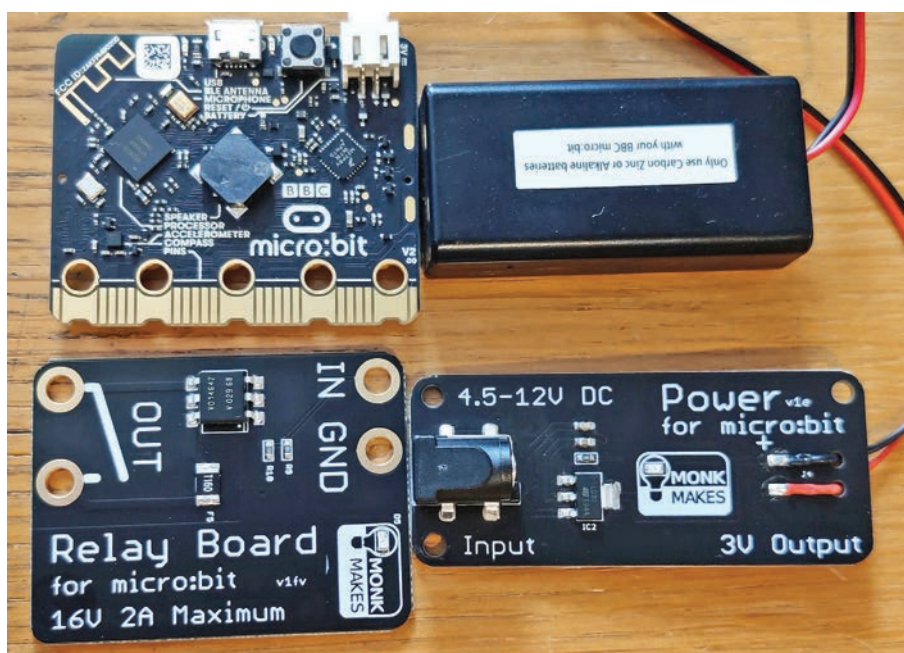
couple of years as retirement freed up more time to think about new projects.

What follows is very much a proof of concept, rather than a design for a clock

to adorn your lounge wall – some of the techniques and components I have used are unconventional and will no doubt cause the purist clockmakers in the room to shudder with mild revulsion, but some of the ideas seemed interesting enough to share with those that wish to experiment and perhaps build something more elaborate, aesthetically pleasing, and more in keeping with traditional horological techniques. This article concentrates on the business of making a pendulum and getting it to swing as freely as possible; as will be seen later, I took a short cut to providing motion work that could be driven from the pendulum's beat. My intention is to write a follow-up article showing how to build a Lavet stepper and use it to drive motion work for the clock, but more of that in the future.

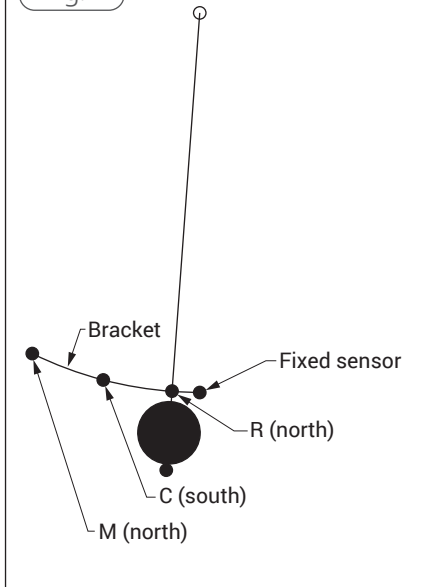
Detecting the swing

The first problem to think about was how to detect when the pendulum needs a kick, without the detection mechanism providing any mechanical interference. There are plenty of options



BBC Micro:bit and accessories.

Fig.2



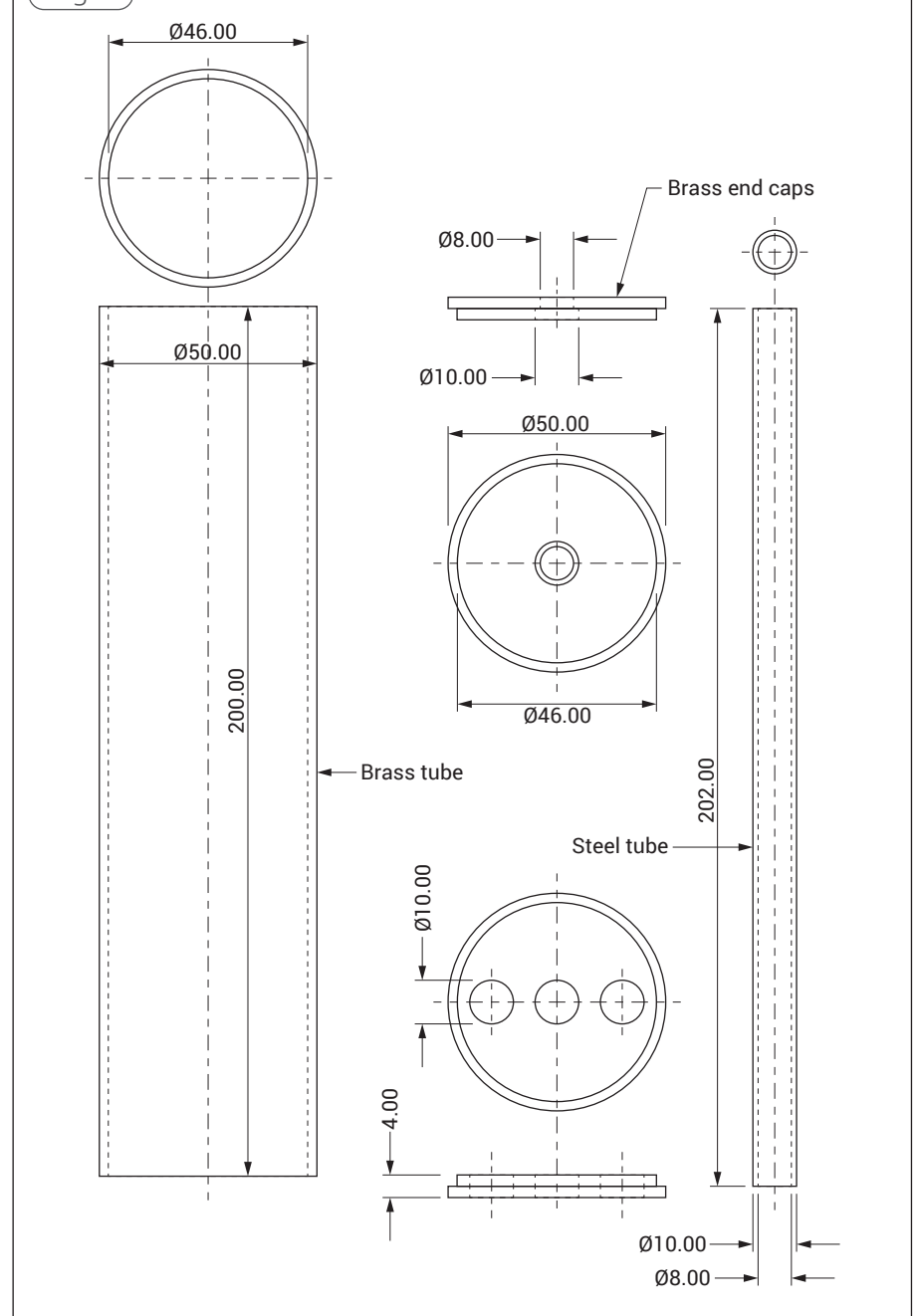
that could be pressed into service to detect the position of the pendulum and its angle of swing; obvious ones include photoelectric sensors, Hall-effect sensors that detect a magnetic field, inductive sensors, reed switches, even capacitive sensors (thanks Neill!) and the like. My initial thought was to use reed switches; these are glass-enclosed switches that close (or open) a pair of contacts when they come under the influence of a magnetic field. The field can be created by a simple bar magnet that could (for example) be attached to the pendulum, and a number of reed switches could be arranged along the arc of swing such that they detect the position of the pendulum at a given time and (if you have at least two detectors), the direction of swing also. That initial thought was primarily driven by simplicity – there isn't anything much simpler than a pair of electrical contacts. However, there are also potential downsides to reed switches – firstly, contact bounce, that can give false multiple indications and may need “de-bouncing” strategies to be employed either via circuitry or via software, and secondly, reed switches are mechanical devices that have a limited life in terms of number of operations. In practice, the latter may well be large enough for it not to matter; one spec sheet I looked at talked about billions of operations before failure, but even so, it led me to re-visit the other options.

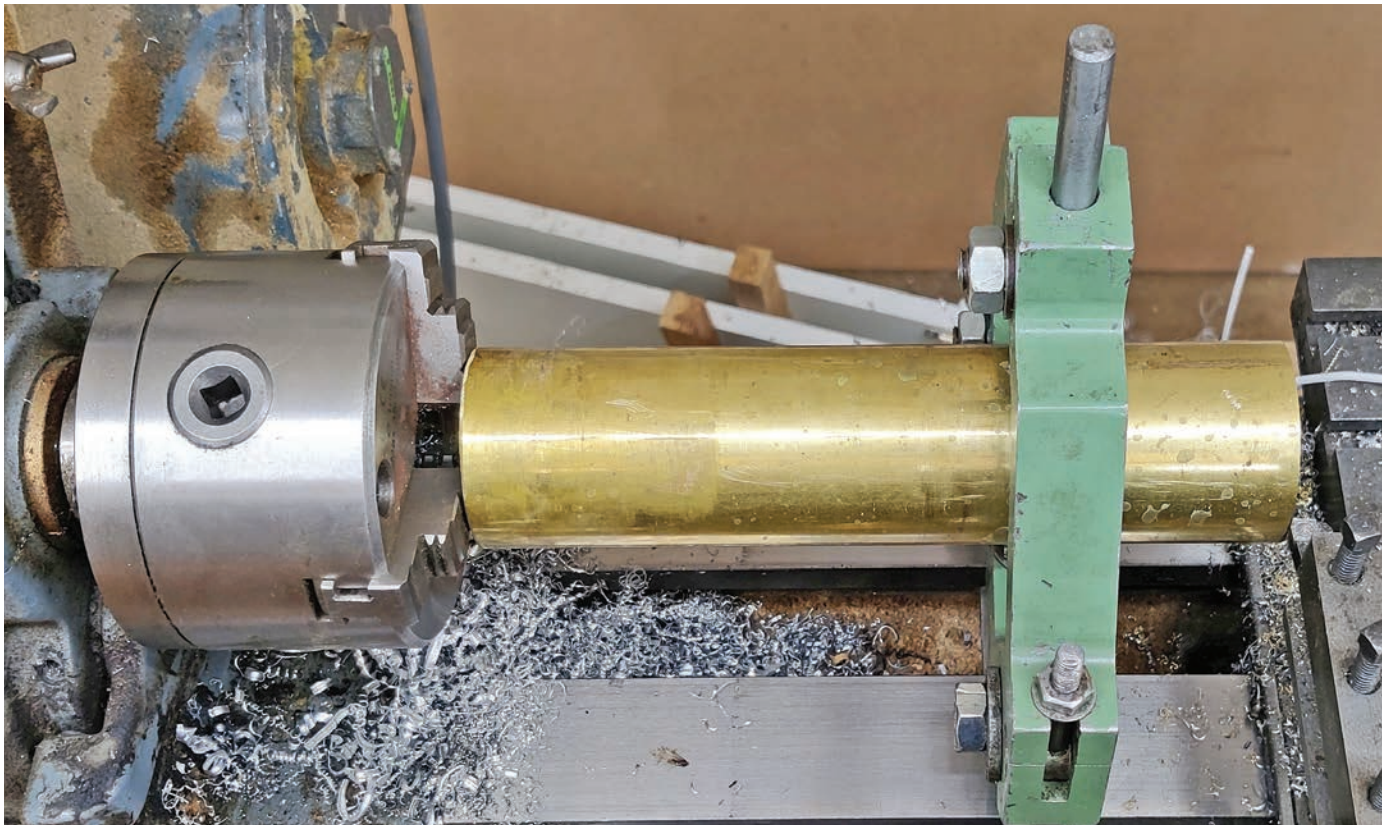
Optical detectors are certainly a possibility but are not terribly forgiving in terms of alignment and positioning, so my prejudice was to discard these in favour of Hall-effect devices, which

are pretty simple to use and fairly bullet proof – I recently re-assembled my CNC setup on my Myford lathe after the various bits had been languishing in boxes since our house move in 2014 and the Hall-effect device I use as a spindle sensor is still working perfectly. Hall-effect devices in their simplest form are 3-terminal devices, rather like a transistor; two terminals connect to the +Ve and 0V supply lines and the third terminal gives an output signal if the device detects a magnetic field. These devices are sensitive to the direction of the magnetic field; you need to point the correct pole of the magnet at the device for it to operate. Hall effect devices come

in a range of operating voltages, but the majority of them seem to need at least 3.6V as the supply voltage; I had planned to use a cheap single-board microcomputer to handle the “logic” side of the problem, and the particular one I had in mind (see later) is based around a 3.3V supply, so ideally, I needed to find a lower voltage Hall effect device. A search on the RS Components site revealed very few low voltage devices, but one, the Rohm BU52014HFV-TR has an operating range of 1.65-3.3V, which seemed to fit the bill very well. This is a 5-terminal device, of which only 4 are used; two for the supply voltage and 2 outputs, one that detects a N magnetic

Fig.3





Turning Pendulum.

pole and the other that detects a S pole. My first thought was that I could just use one of the outputs, but it turns out that there is a potential simplification to be had by using both, as will become apparent. The only real downside with this particular Hall effect device is that it is encapsulated for surface mount, which means wiring it up is a little trickier than with through-hole mount devices, but more of that later. I also found a more conventional 3-pin, single output device, a more recent version of the one on my Myford in fact – this is the Allegro A1104. While nominally requiring at least a 3.6V supply I figured that it was worth giving these a try as well.

How many detection points?

It took a spot of musing to figure out how many detection points I would need to (a) detect when the pendulum needs a kick, (b) when to start and end the kick, and (c) when to register a one-second “tick” via associated clock motion work. It turns out that all of the above can be achieved using three detection points, arranged as shown in **fig. 1**. The figure shows a pendulum with a magnet attached and three magnetic detectors, labelled Minimum, Count, and Reset, arranged along the arc of swing of the pendulum. For the sake of the description, each detector is activated at the instant the pendulum’s

magnet passes over the detector. The position of the Minimum detector (M) will determine the minimum arc of swing of the pendulum. The Count detector (C) is used to determine when the impulse should be applied and can also be used to signal 1-second intervals to drive the clock’s motion work. The Reset detector (R) is used to end the impulse. The way it operates can be described by a simple state machine, as follows:

Current stateE

InputM	Idle	Primed	Fire
Reset (R)	Idle	Idle	Idle
Minimum (M)	Idle	Idle	Idle
Count (C)	Primed	Fire	Idle

The columns represent the current state of the state machine (Idle, Primed, Fire) and the rows tell you what the next state will be for each current state if each of the detectors is activated. Referring to **fig. 1**, you can see that if the pendulum starts its swing from the right of the centre line and swings to the left, it will activate R, forcing the state to be **Idle** regardless of what it had been, then it will activate C, causing the state to change to **Primed**. If the arc of swing is great enough, then the pendulum will activate M (once if the swing only just reaches M, twice if it passes M and then returns on the backswing, activating M again), causing the state to revert

to **Idle**. As the swing proceeds to the right, C is activated, causing the state to change to **Primed** again, then R is activated, clearing the state back to **Idle** again. The above describes what happens most of the time – the angle of swing of the pendulum is large enough that M is always reached (or passed) on the swing to the left, so the state machine never reaches the **Fire** state. However, if the angle of swing is such that the pendulum passes C on the left swing but doesn’t reach M, and therefore stays in the **Primed** state on the return swing, then as the pendulum swings back past C, the state changes to **Fire** and as it passes R again will revert to **Idle** again. So, when the arc of swing has decayed sufficiently, the Fire state occurs for a time period determined by the positioning of and distance between the C and R detectors, and this can be used as the signal both to activate the impulse mechanism and (if necessary, depending on how the impulse is generated) to stop the impulse. The C detector can also be used directly as the signal to count seconds, as it is activated once for each stroke (left-to-right or right-to-left) of the pendulum. So, a detection mechanism based on this state machine scheme has the potential to do the job. Obviously, the position of the detectors can be varied to suit the impulse mechanism and the duration of

impulse that is desired. The arrangement shown would be appropriate for the impulse method used in the $\frac{3}{4}$ Second clock, where an electromagnet positioned directly below the rest position of the pendulum attracts an armature attached to the bottom end of the pendulum rod; for this, the impulse needs to start before the pendulum reaches the vertical and needs to end no later than when the pendulum is vertical. For other schemes it might be appropriate to move C and/or R further to the right, as long as R is positioned so that it is activated at a smaller angle of swing than M, otherwise the state machine as described won't work.

Those with beady eyes will notice that the first two rows of the state machine are identical, which indicates from a practical perspective that those two detection signals can be combined in parallel and the state machine reduced to two rows; however, you still need three distinct detection points to make the scheme work correctly. Also, strictly speaking, the C signal should never appear when the state machine is in the Fire state, so the cell in the bottom right-hand corner of the state table should never be needed but specifying that it is cleared down to Idle in this case is included for completeness. Another way to think about this state machine is that it is essentially a counting mechanism where Idle = 0, Primed = 1, and Fire = 2; the impulse occurs when the count reaches 2 and either M or R cause the impulse to end and the count to be cleared back down to 0.

The fact that the state machine effectively only has two rows, and the fact that the Hall effect device I had chosen has 2 outputs that discriminate

between N and S poles led me to a minor brainwave, that you could use a single Hall effect detector and use three magnets attached to the pendulum – arranged so that the outer pair of magnets present one pole (N, say) to the sensor and the middle one presents the other pole to the sensor. The two outputs of the sensor can then feed the inputs of the state machine – the output activated by the middle magnet provides the C input, the other output provides the combined M/R input. Figure 2 shows how such an arrangement could work; instead of having three stationary sensors and one magnet attached to the pendulum, you now have one stationary sensor and three magnets attached to a bracket on the pendulum. For clarity, I have shown the positions in **fig. 2** that are directly equivalent to fig. 1; in practice, for balance, one might choose to position the outer magnets, so they are equally spaced either side of the pendulum and shift the sensor to the right to create the necessary asymmetry, but the end result is the same either way.

Choice of “logic” and associated circuitry

Running even a simple counting mechanism like the one outlined here implies the use of some logic circuitry, to detect the inputs, register the changes of state, and output appropriate signals to drive the impulse mechanism and the clock motion work. Yes, you could wire it up using relays, or TTL logic gates, but the obvious choice these days is to go for a single-board microcomputer of some kind; there are now many such devices on the market, including various models of Raspberry Pi, Arduino,

and even fully fledged PCs that now come in single-board versions. For this application, I went for the BBC Micro:bit, partly because of its tiny size (4 X 5 cm), and partly because there appear to be plenty of programming tools and hardware add-ons available. Connecting up external circuitry seemed to be straightforward too as it has a handy edge connector with 4mm holes for the most frequently used connection points. One of the accessory devices for the Micro:bit is a solid state relay board capable of (silently) switching up to 2 amps at up to 16V, which has the potential to drive the impulse circuitry; there is also a convenient power supply regulator board capable of generating a smoothed 3V supply for the Micro:bit from anything up to 12V. I had already located a compact 12V solenoid that looked as if it might serve as an impulse actuator if I went down the mechanical impulse route, so these extra components looked perfect for the job; I could use a 12V “wall wart” or even a sealed lead acid accumulator, as the power supply and use that to drive the Micro:bit and power the rest of the circuitry. All in all, it looked like it was game on.

Photograph 1 shows the Micro:bit (top left), its standard AAA battery 3V power supply (top right), the 12V to 3V stabilised supply board (bottom right) and the relay board (bottom left).

● To be continued

The photos in this article are rather biased towards the end, we have had to move some forward to this instalment and hope this will not inconvenience readers.



Machining end cap.



Counterboring end cap.

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