No.249

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DECEMBER 2016

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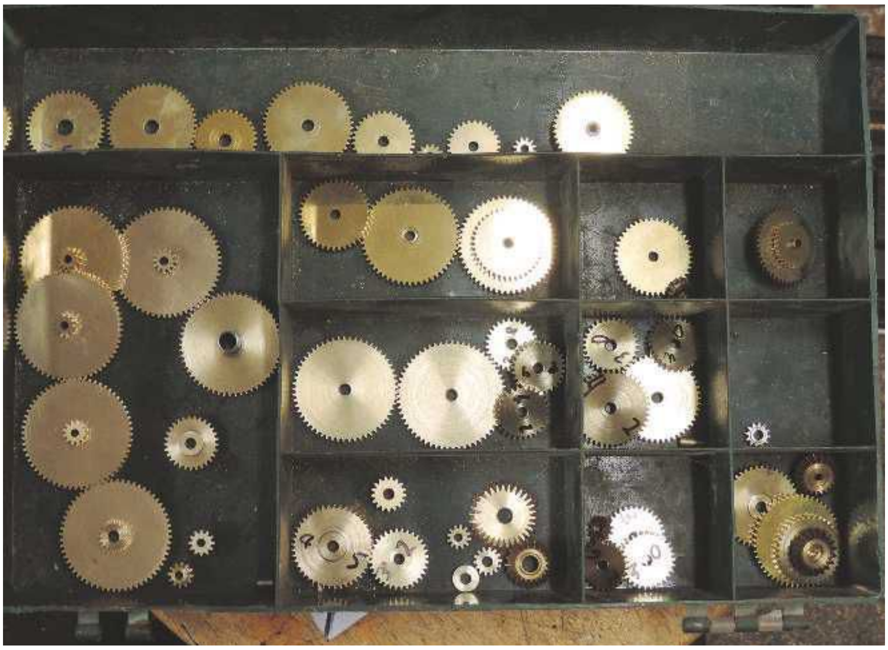
Model Engineers' Workshop, ISSN 0959-6909, is published monthly with an additional issue in August by MYTIMEMEDIA Ltd, Enterprise House, Enterprise Way, Edenbridge, Kent TN8 6HF, UK. The US annual subscription price is 52.95GBP (equivalent to approximately 88USD). Airfreight and mailing in the USA by agent named Air Business Ltd, c/o Worldnet Shipping Inc., 156-15, 146th Avenue, 2nd Floor, Jamaica, NY 11434, USA. Periodicals postage paid at Jamaica NY 11431. US Postmaster: Send address changes to Model Engineers' Workshop, Worldnet Shipping Inc., 156-15, 146th Avenue, 2nd Floor, Jamaica, NY 11434, USA. Subscription records are maintained at dsb.net 3 Queensbridge, The Lakes, Northampton, NN4 7BF. Air Business Ltd is acting as our mailing agent.

On the Editor's Bench



On My Bench

It's been time to return a power feed unit that I've been helping testing out for Arc Euro Trade. It's no secret that the device as currently produced leaves a few things to be desired; chiefly it's hard to set a really low speed and the high speed is perhaps a bit to high. In short the gearing is wrong, at least for the work I carry out on my mill.

That said, I am sorry to bid it farewell as I doubt whether I could have made any meaningful progress on the 'Jovilabe' I mentioned last time without it. I calculate there are over 2,500 teeth on all the gears, let alone the teeth on the baker's dozen or so that have gone into the scrap bin!

Being made of brass, a rather high feed rate came in handy with a high spindle speed. Each tooth-space was a back and forth pass with the mill so I think I would either have RSI or be quietly climbing the walls by now if it wasn't for the use of power feed. Readers may be interested in the cutter I made from silver steel, it has lasted well, only being touched up with a diamond slip two or three times during the process.

I have one last big challenge, and that's cutting a 344-tooth gear, at about 240mm diameter it's way to big for my mill, so it looks like my recently acquired Adept No. 2 shaper will come into its own. No easy way out there though, I have lots of lever pulling in store.

Gearcutter

This month we say farewell to gearcutter. I hope you have enjoyed the excellent drawings that accompanied this series, which we finish with a redrawing of Ivan Law and Dennis Chaddock's excellent Eureka device for backing off gear cutters, which originally appeared in Model Engineer in imperial form. I would like to thank Ivan who has generously given his blessing to the publication of this drawing.

Arduino Projects

This month we are featuring a couple of Arduino-based projects. While these may not be everyone's cup of tea, I think they show just how fruitful the results can be when a 'maker' approach using things like microcontroller modules meets hobby engineering.

Carl Wilson's stepper driven indexing head, is a fairly typical example of the sort of project many of us would find useful. One of these combined with power feed would have meant I could have virtually automated my gear making... and much reduced the input into the scrap bin!

The second project is a more esoteric one to create an electronic version of an engine indicator; I must admit I was taken aback by just how well this has worked. The use of this device has been discussed on the forum and if you decide to make your own, I would encourage you to share the results there.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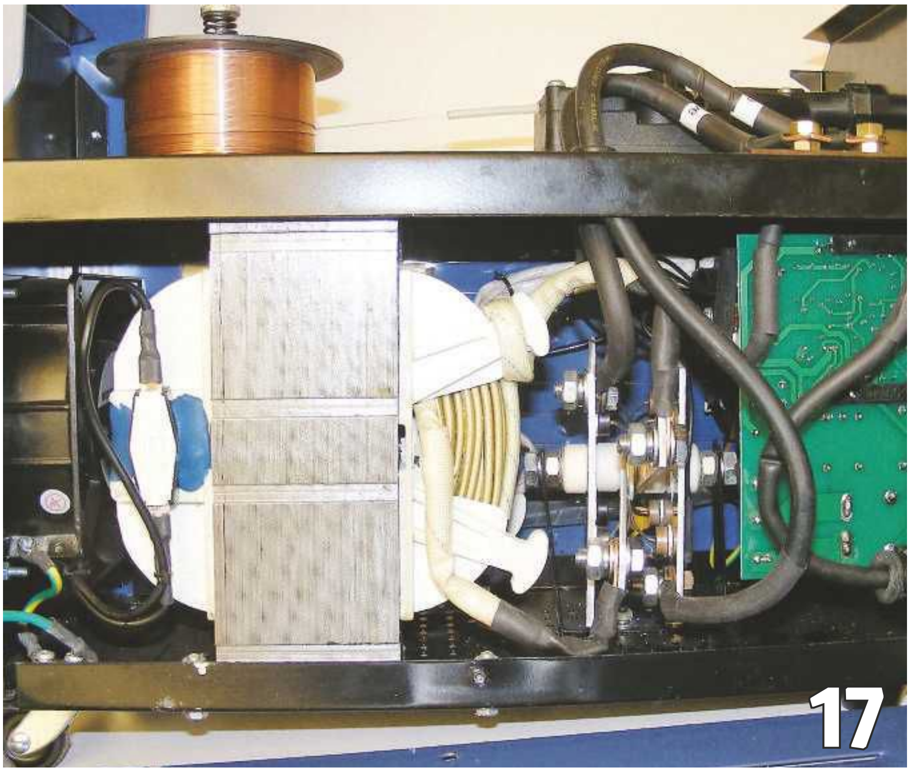


17

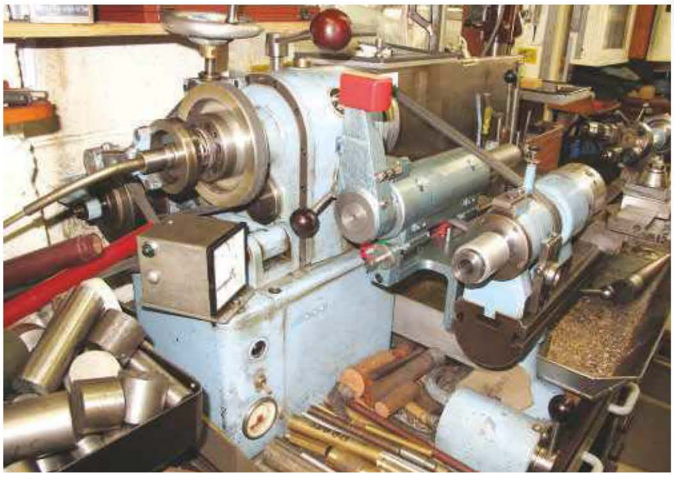
56

See page 26 for details.

Coming up...

in the January issue

Once you have enjoyed this issue, look out for the next, packed full of more tools and techniques!



Regulars

ON THE COVER »»

This month's cover features Carl Wilson's rotary table, one of our two special Arduino based projects.

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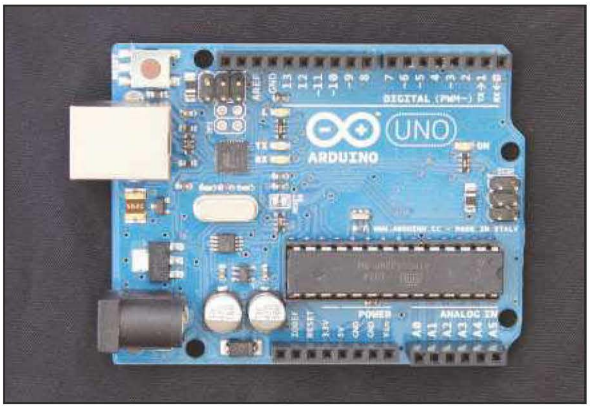

You can also visit our website for extra content and join in our online forum. This month's extra content: Download the files for Silly Old Duffer's Arduino Engine Indicator: www.model-engineer.co.uk/arduino-indicator

Hot topics this month:

■ **Old Face Mill**
Have you come across one of these older style face mills, and if so how did you sharpen it and set the blades?

■ **Alternatives to PC Based Controllers**
Looking at stand-alone CNC controllers.

■ **Apprentice Piece**
What makes a simple first exercise on the lathe, yet features plenty of different operations?

■ **LED Flourescent Tubes**
Have you tried these in your workshop? Find out how different people got on with this new technology?

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An Arduino in my toolbox

Silly Old Duffer **describes how a Jan Ridders Coffee-Cup Stirling engine was instrumented with an Arduino Uno Micro-controller programmed to be a Data Logging Triple Thermometer and Pressure Gauge.**

Like many Model Engineers I have several hobbies and interests. Photography, Amateur Radio, Electronics, Computer Programming, Microscopy and Reading all jostle for time that I'd like to spend with a Milling Machine and Lathe.

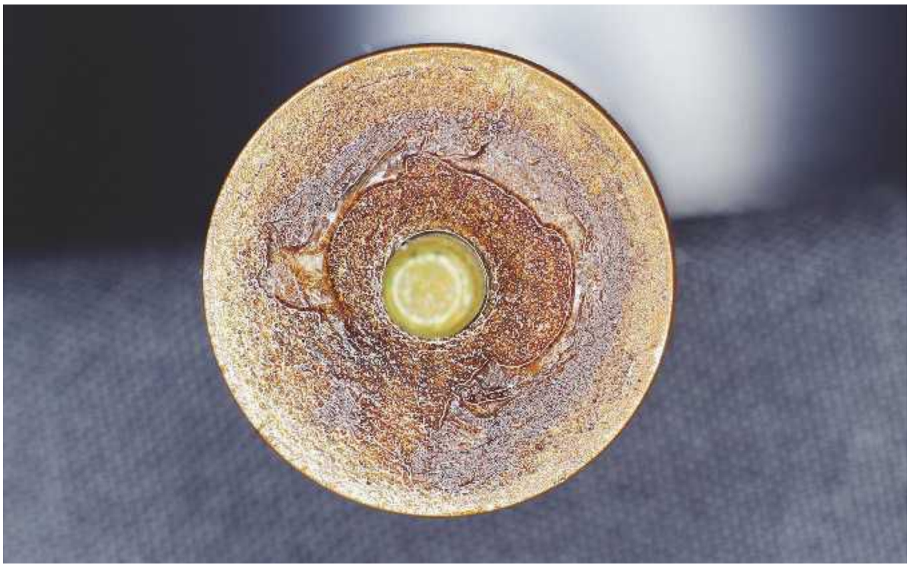
As time is short I'm always on the look-out for projects that allow me to combine two or more interests at the same time. This one is about adding an inexpensive microcontroller to my workshop's basic measuring equipment. Like most of us I have quite a collection: Dial Indicator; Steel Rules; DRO; Micrometer; Parallels; Feeler Gauge; Dividers; Thermometer; Stopwatch / Timer; Protractor; and Digital Calipers.

Recently I got interested in Heat Engines. Not building the shiny masterpieces proudly displayed at exhibitions, but studying their theory, history and how they work. Where possible this hobbyist likes to emulate the achievements of the pioneers, those geniuses of yesteryear on whose shoulders we stand.

Model Engineering Issue 4329 4th-17th July 2008 included plans and an article describing Jan Ridders Coffee-Cup Stirling Engine. The plans can also be obtained from Jan's website.

My Build of the Coffee-cup Stirling

Jan's Coffee-Cup Stirling is a Low Temperature Device. Heated by a mug of boiling water, the engine runs silently and is interesting to watch, **photo 1**.



Acid Damaged Piston

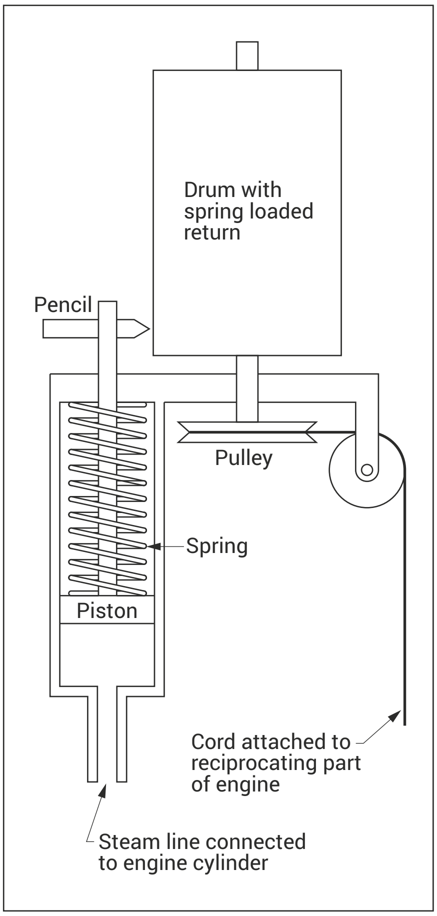
Whilst the engine is superficially simple I had a fair amount of trouble getting mine to work. The engine is not powerful and will fail unless friction and leaks are minimised. Thanks to a lot of help from the brothers on the www.model-engineer.co.uk forum, I eventually got it running.

I learned quite a few practical lessons whilst making the engine: of several sealants tried, RTV Instant Gasket was best but it emits aceticacid fumes until it is cured. And I found it's not good to run the engine before the sealant has fully cured, **photo 2**, because hot acetic acid fumes are very corrosive!

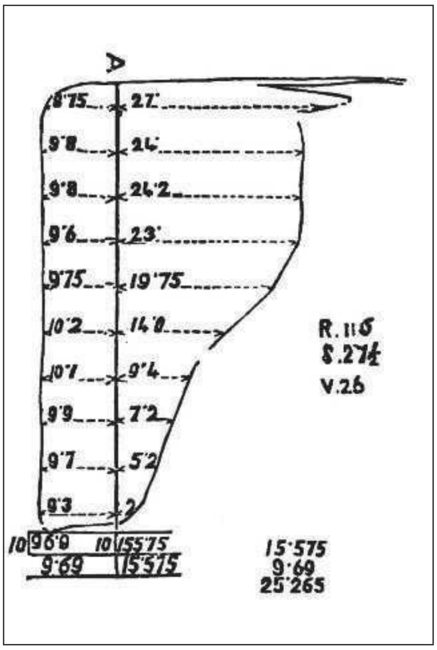
Cheap ball-bearings let me down. In the end I bought more a expensive equivalent made by SKF. Spinning the flywheel showed a significant reduction in friction after better bearings were installed.

I found that graphite made a more reliable piston than mild-steel even though machining carbon is hellish messy!

Failure of the engine to run led me to think hard about how it worked, and I realised that I didn't really understand it. Ignorance may be bliss but it makes it hard



Engine Indicator



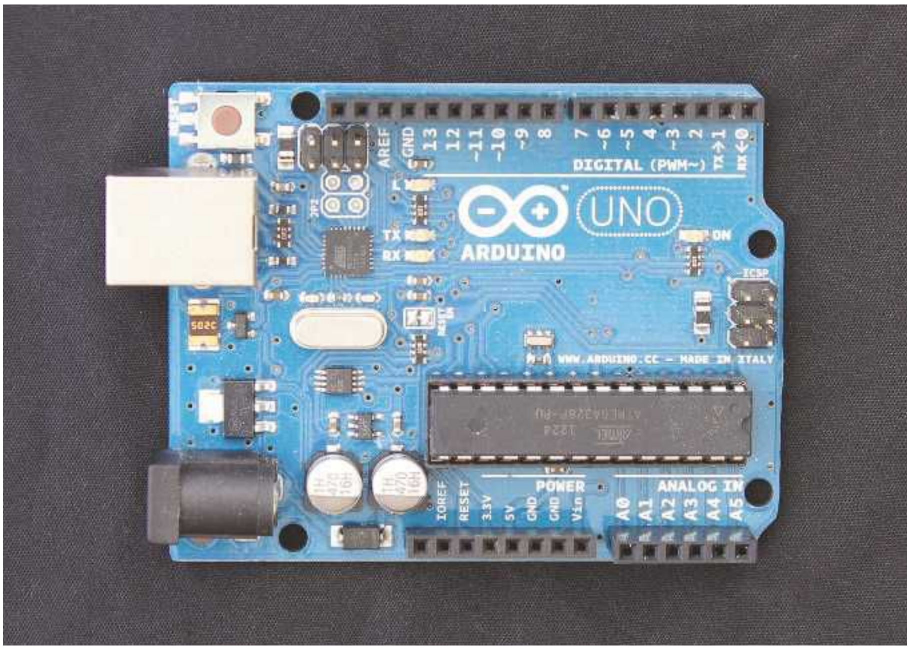
Example Engine Indicator Diagram

to diagnose faults and make improvements.

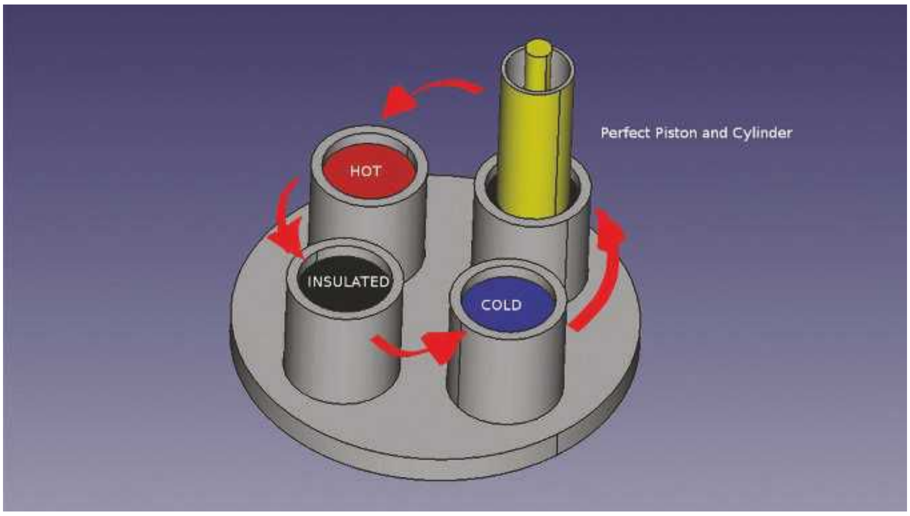
Research on the web and in various text-books revealed that the pioneers also had trouble understanding how and why their engines worked. Many false leads were followed in the past. It took three hundred years of clever development and scientific investigation to get us where we are today. Part of that story is the development of tools that allow engineering quantities to be measured.

Scientific assisted engineering reduces the cost of finding practical solutions to real problems. For example, there's a customer requirement for a cargo ship required to carry 5000 tons of steam coal from Cardiff to Aden. The ship is to steam at 10 knots. Before attempting to build such a ship it helps to know what the total displacement of the likely design will be, how powerful the engine needs to be, and how much bunker coal will have to be carried to make the voyage. Most important of all, how much will it cost to build a ship to this specification and is there any profit in selling one? As engineer-novelist Neville Shute said, "an engineer is man who can do for ten shillings what any fool can do for a pound".

James Watt was well aware of the need for measurement and understanding. Watt made at least ten major contributions to heat engine technology and science. Wanting to know more about what was going on inside the cylinder of his engines, one of those major contributions was a measuring device that recorded as a graph the pressure inside the cylinder as the engine rotated through a single cycle. This device, **photo 3** attracted my attention.



Early Model Arduino Uno with Dual-In Line ATMega328P

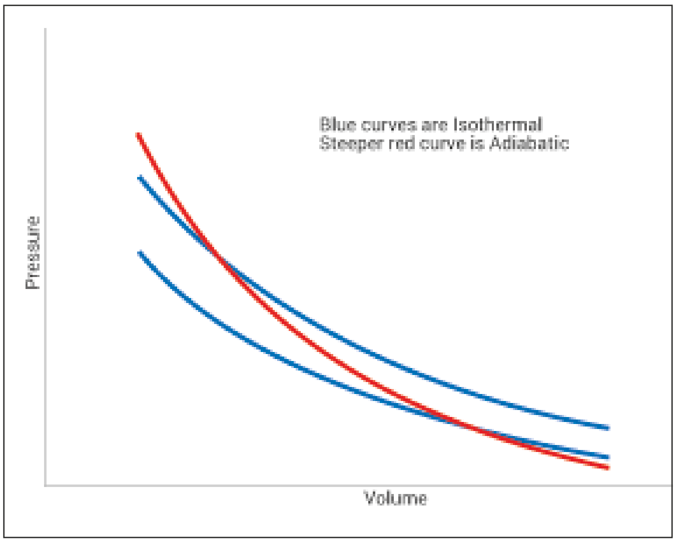


The Carnot Cycle

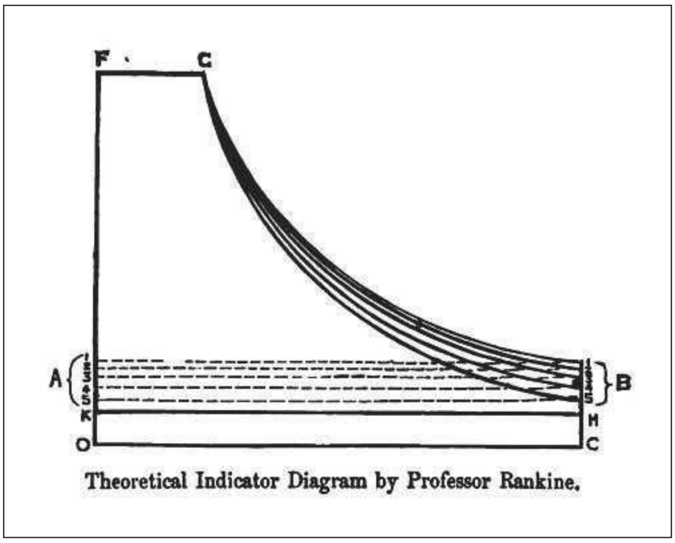
Watt's "Engine Indicator" was a trade secret for many years. It enabled Watt to make his engines work more efficiently than those of his rivals, many of whom were nipping competitively at his heels. Even when the much-improved Engine Indicator was in the public domain it seems that many practical engineers still "didn't get it". For that reason in 1869 N P Burgh wrote "The Indicator Diagram Practically Considered", which is just the book I needed!

Burgh explains the benefits of looking at steam engine indicator diagrams in his introduction:

"I acquired thus a correct knowledge of the positions of all the details that regulated the steam at the points of admission, cut-off, expansion, exhaustion, compression, and lead, in relation to the



Adiabatic and Isothermal Curves



The Rankine Cycle (Reciprocating Steam Engines)

positions of the piston and crank pin at the same scale as the diagram ; and by laying it on the crank-pin's circle I saw at once how it was formed in relation to time and speed, and the cause of the defects, if any existed ; indeed, being the only method of gaining that information truthfully."

"The Indicator Diagram Practically Considered" has been digitised by Google and is available as a free download from the Web.

An "engine indicator" draws a form of Work Diagram called an indicator diagram, or in modern parlance a "pressure/volume diagram" or "PV Loop". PV-loops are useful for analysing the working of other machines such as pumps, including the human heart.

Used on a piston engine the area covered by the PV Loop gives the net power available inside the cylinder, **fig 2**. The shape of the loop reveals how that power is being developed and provides information that might allow the engine to be improved. Misshapen PV Loops reveal defects such as leaks. The curves reveal what type of thermodynamic expansion is occurring. Several types of working fluid expansion are potentially useful in a heat engine: adiabatic; isothermal; isobaric; isometric; and poly-tropic.

Engine indicator diagrams are valuable in that they can be used to determine the mean cylinder pressure during a cycle. Knowing this, engine power developed inside a cylinder of known size can be determined from the formula

$P = M \times A \times (2 \times S \times R)$

Where:

- P is in watts
- M is mean pressure in pascals
- A is the area of the piston in square metres
- S is the piston stroke in metres
- R is the rotational speed of the engine in rotations per second.

Just the background I wanted for my Coffee-cup engine project!

Theoretical and practical cycles

In 1824 Nicolas Carnot developed the thermodynamic cycle for which he is famous. Carnot postulated an ideal engine consisting of a weightless frictionless piston moving in a perfectly insulated cylinder filled with an ideal gas as the working fluid. The cylinder has a perfectly conducting base. Weights were mentally added to the top of piston and Carnot calculated what would happen if his perfect engine was moved from a hot stand to a perfectly insulated stand, then to a cold stand and back again, **fig 3**.

Carnot's highly original thinking built on Boyle's Law (1662), Charles's Law (1801 and Guy Lussac's Law (actually Amonton, about 1702) The gas laws determine what happens inside a piston engine.

Boyle's Law is:

$PV = k$

Charles's Law is:

$V/T = k$

Guy Lussac's Law is:

$P/T = k$

The three laws can be combined

$PV/T = k$

Where P is Pressure, V is Volume and k is a constant

When heat is first applied to Carnot's ideal engine, the gas inside the cylinder expands by absorbing heat whilst the temperature remains constant. This is called an isothermal expansion.

After removing the heat input by moving the engine onto the insulating stand, an adiabatic expansion occurs. In an adiabatic expansion, the volume of gas increases whilst the internal energy of the gas is reduced by doing work that causes the temperature to drop. No new heat enters or leaves the ideal gas during an adiabatic change.

In the third stage, the environment outside the engine does work on the gas. Heat flows out of the engine into the cold stand.

Finally, the engine is placed back on the insulated stand. Air presses on the piston causing the temperature of the gas to rise until it returns to the original starting temperature. The cycle can be repeated to do more work, **fig 4**.

Carnot's cycle is valuable because it defines the absolute limits of efficiency that can be achieved by a heat engine. It is impossible to do better than Carnot's theoretically frictionless, perfectly insulated engine.

How sad that Carnot's engine doesn't actually exist! A great deal of time was wasted in the 19th century when inventors tried to implement Carnot's perfect cycle with a real engine. Unfortunately, it's not practical. Nonetheless, the idea of designing engines that pay due cognizance to the laws of thermodynamics is a good one, and that approach gave us the refined engines we have today. Modern engines do not follow idealised formula, rather their operation has been optimised by carefully balancing theory, experiment and the experience of practical men.

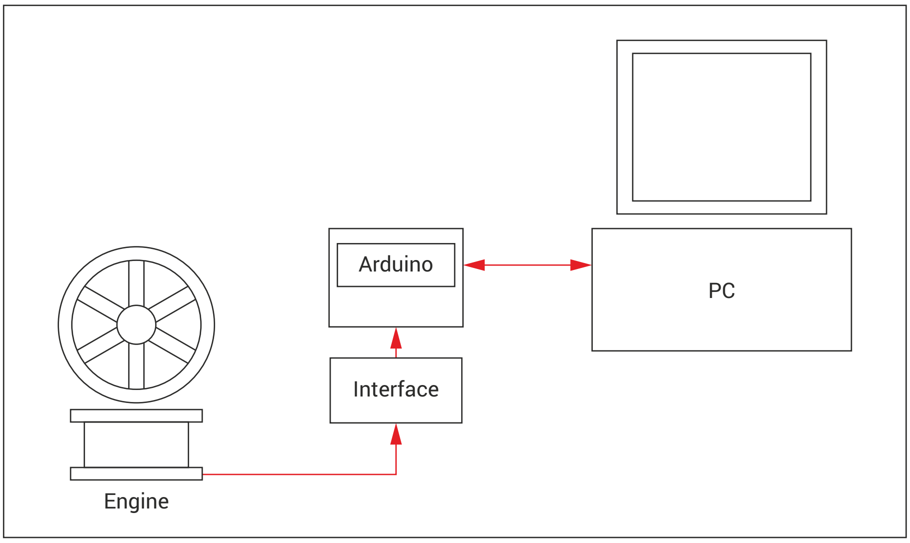
A second important consequence of Carnot's work is the understanding that his cycle is reversible. As this makes possible the heat-pump and refrigeration I shall celebrate Carnot next time I enjoy a cold beer! And I would like to know if my unheated Coffee-cup Stirling driven in reverse cools down.

Like James Watt, William John Macquorn Rankine was another brilliant Scot. In 1859 his "A Manual of the Steam Engine and Other Prime Movers", described the ideal cycle for reciprocating steam engines, **fig 5**.

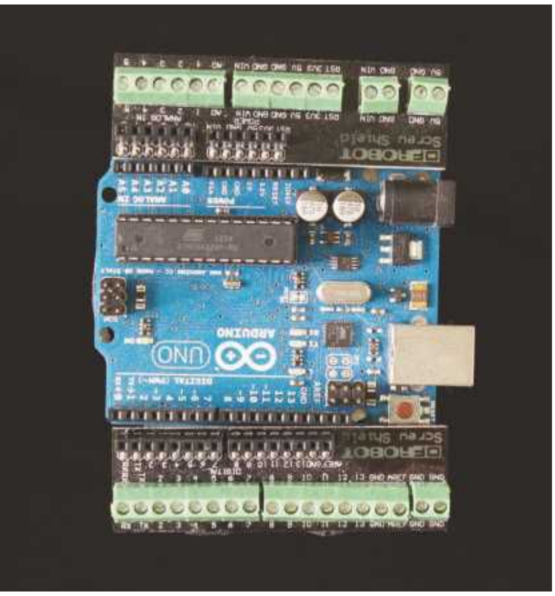
Rankine's theoretical limit of efficiency for a real engine with steam as the working fluid was closely approached about 1930, for example by the triple expansion steam engine fitted to World War 2 Liberty Ships. Higher efficiencies cannot be achieved which is why the reciprocating steam engine was supplanted by internal combustion engines and steam turbines.

My Engine

Knowing some theory and history tickled my interest in monitoring the innards of my Jan Ridders Coffee-cup Engine. Could it be done?



General Arrangement



Uno With a Terminal Shield

Making a mechanical engine indicator sensitive enough to record meaningful data whilst not disturbing the operation of my Coffee-cup Stirling Engine is too great a challenge for my very moderate workshop skills. But modern electronics, **photo 3**, and the availability of computers with free software tools makes the whole project "do-able".

At the outset, I said that I didn't really understand how the hot-air engine works. I do know that it depends on pressure fluctuations caused by moving a displacer out-of-phase with the power piston, but what causes the pressure to fluctuate? The displacer, which is driven by the power piston from a shared crankshaft, moves air from the hot end to the cold end of the displacer cylinder. Alternating heating and cooling of air inside the closed engine causes pressure changes acting on the power piston. There's a cycle similar to that described by Carnot. Graphs might help me understand this better.

I decided that it would be informative to measure the temperatures of the hot and cold ends of the engine as well as pressure variations inside the cylinder as it turns through a cycle. Recording the data would allow me to analyse and graph with software tools what was happening inside the engine.

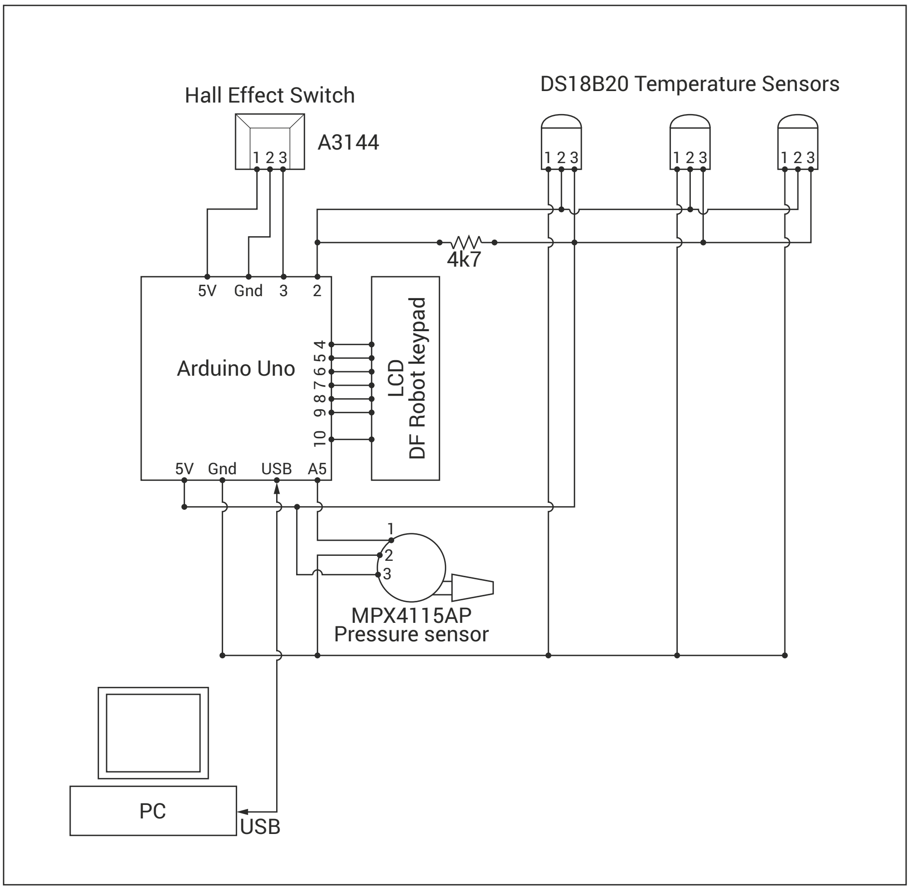
Computers are first class when it comes to data analysis. Once measurements are recorded in a file many different tools and techniques can be applied to extract information and knowledge from raw data. Maxima and minima can be identified as can the circumstances in which they occur. Formula can be applied, for example to calculate power, averages, trends and other useful statistics. Results can be merged, sorted, tabulated, graphed, cross-referenced and filtered. It is possible to return later, perhaps years later, to check new ideas against data stored before all the possibilities were understood. Best of all, many of the software tools needed to do this work are free. All you have to do is learn how to use them.

The Coffee-cup Stirling is particularly suitable for investigation because the temperatures and pressures involved are moderate. All the work can safely be done on a dining table.

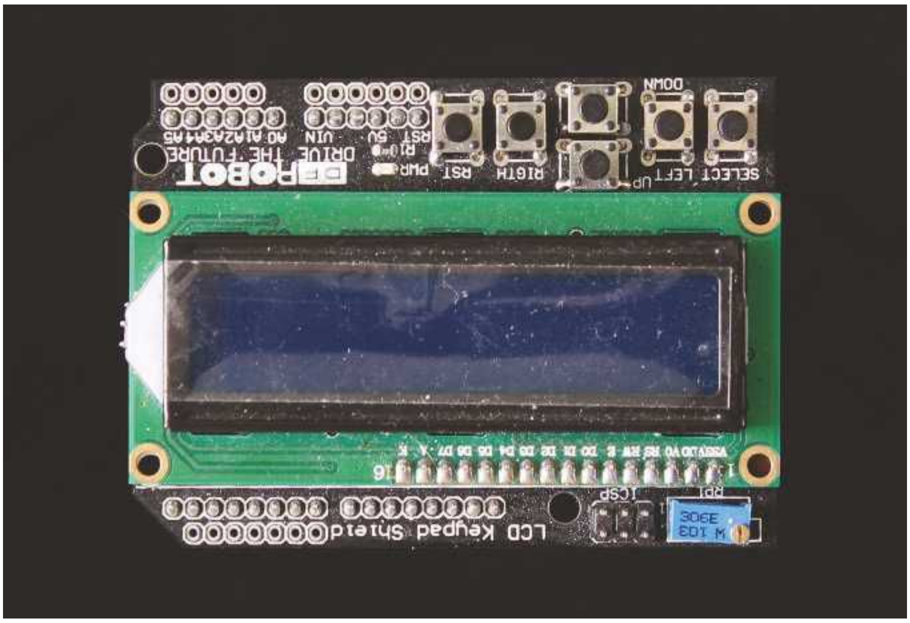
Manipulating the engine's pressure data on a PC would allow me to calculate the engine's indicated power and also to draw PV-Loops from a large amount of engine data. I thought about what data I needed to capture.

Three temperatures are of interest: ambient room temperature, the temperature of the lower or "hot" plate and the temperature of the upper or "cold" plate. As the engine depends on air to cool the "cold" plate, the heat loss will be proportional to the temperature difference between cold plate and ambient. In other words the engine should run better on a cool day.

We also need to record current atmospheric pressure and cylinder pressures as they vary inside the cylinder whilst the engine is running. Atmospheric pressure can be got by temporarily removing the power piston and taking a measurement whilst the sensor inside



The Interface Circuit



The DF-Robot Liquid Crystal Display Shield

the engine is open to atmosphere. After replacing the piston the sensor will measure cylinder pressures.

Each cycle does work and work done per second gives power. To calculate power, we need to know how fast the engine is rotating.

So the requirement is this: take and record three temperatures, and pressure, and rotational speed. As a future development it would be useful data measurements whilst maintaining the hot plate at a constant high temperature and the cold plate at a constant lower temperature.

For setting up and for taking ad-hoc measurements it is convenient to display current RPM, and temperatures and pressure.

Fortunately, this is not too difficult with a micro-controller, programming skills and some basic electronics, **fig. 6**.

Choosing a Computer

Interfacing a Personal Computer directly to sensors is surprisingly awkward. PCs are just not designed for this kind of work. On the other hand PCs are excellent at connecting to other computers, and they easily run the software needed to analyse and graph data.

By adding an Analogue to Digital Converter to the electronics something like a Raspberry Pi could do the whole job in one box. I chose not to go that way partly because of cost but mainly because the Raspberry Pi's GPIO (General Purpose Input Output) connections are intolerant of mistakes. Squirting too many volts into an input or output will permanently damage the machine.

Microcontrollers are intended for this kind of work. There are many different types of micro-controller on the market. Each has fans and critics and their opinions about which microcontroller is best can get heated!

I chose to use an Arduino Uno because it's designed to make life easy for the user. The Uno board includes everything needed to support the AVR micro-controller on which it is based and it is electrically robust.

The Integrated Development Environment (IDE) needed to write and install Arduino programs is free and well supported. It comes with a rich variety of example programs that can be cannibalised and studied.

The Arduino does not have an operating system. It exists only to run whatever program you load into it. You write and debug the program using the IDE installed on your PC, and then burn the compiled program image on to the Arduino. As soon as the upload has completed, the Arduino reboots and runs your program. Thereafter the program is permanently installed and will run every time the Arduino is switched on. You can reprogram the Arduino simply by uploading another program from the IDE.

The Uno is an 8-bit computer with six 10-bit resolution analogue input-outputs, and ten digital input-out ports. Two of the digital ports may be used to trigger external interrupts. The computer has three internal timers. This basic machine is sufficient for this project. There are other Arduino boards with greater capability if the project expands.

Much fuller explanations, references, tutorials, examples and troubleshooting advice are available on the Arduino website.

On the hardware side there are many different types of "Shield" and other electronic components available for the Arduino, **photo 4**. These reduce the difficulty and time taken to develop the electronic interface with the engine sensors. They are widely available.

Being an open design, the Arduino Uno is made by many different suppliers. So far as I know all makes work equally well but it's good etiquette to support future open source projects by buying the Genuino version, a.k.a. Arduino in the USA.

Display

The DF Robot Keypad Shield is a suitable liquid crystal display plus control buttons, **photo 5**. It plugs into the Arduino. The LCD is supported by the Arduino LiquidCrystal library. As updating the display is somewhat compute time expensive, it is only done periodically in this project, actually once every 2.5 seconds.

Contrast may need to be adjusted if the LCD lights up but no characters are seen. Contrast is adjusted by turning the screw on top of the blue box located on the top left side of the LCD board.

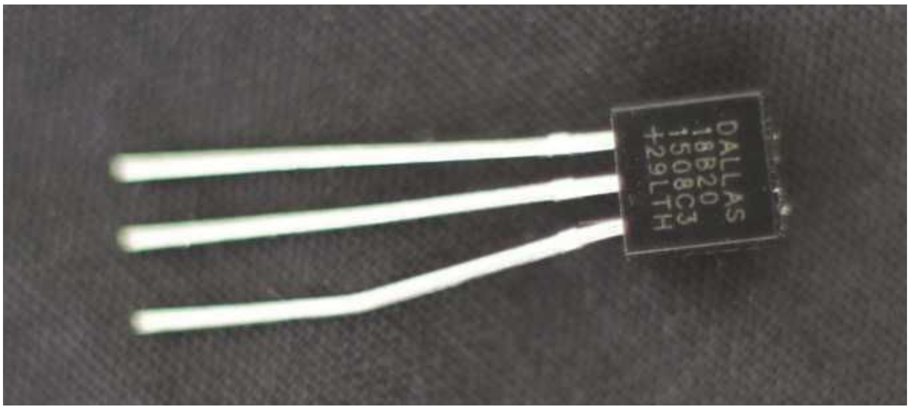
Connections

I used a strip terminal shield between the Arduino and DF Robot shield, **fig 7**. This shield provides convenient screw terminal connections to each of the Arduino's I/O pins.

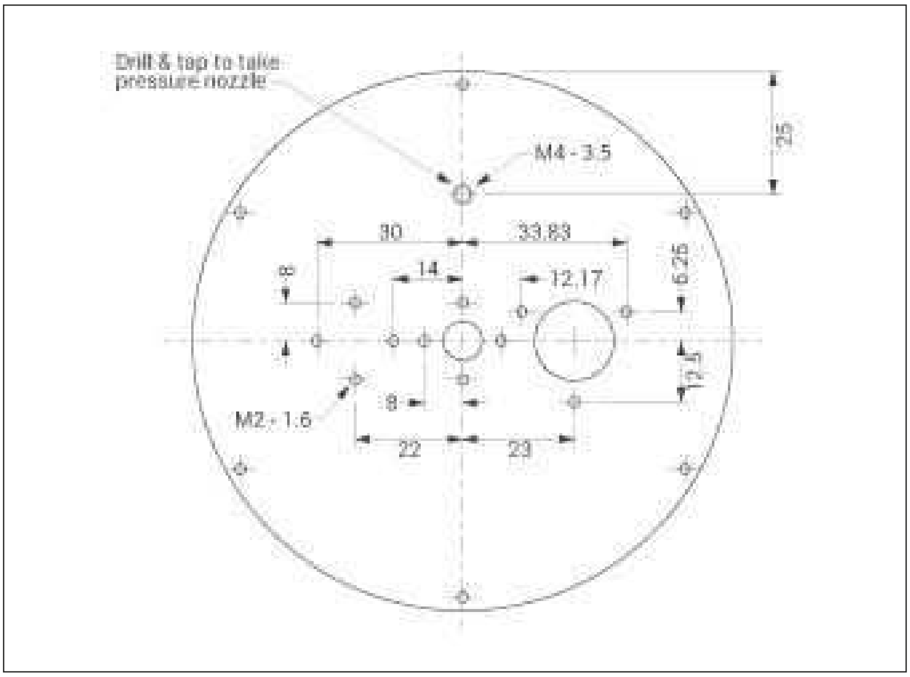
Some points about the circuit may be of interest.

Although they look like simple transistors, **photo 6**, the three DS18B20 temperature sensors are brainy digital devices that can be connected in parallel on a bus: although they share the same one wire bus, they can be uniquely identified by the Arduino. Three wires and a 4.7k ohm resistor are all that is needed to link several of them to an Arduino. The sensors measure temperature in the range -55C to +125C: this limits the maximum temperature that could be applied experimentally to the Hot Plate, but the engine normally runs below 100 Celsius.

After being initialised by the Arduino the temperature sensors can each be asked independently to return a temperature. This



Dallas Temperature Sensor



Upper Plate Plan

they do by signalling a number in degrees Celsius. An Arduino software library does the heavy lifting.

In this project a disadvantage of the bus approach is that the digital sensors take a relatively long time (in computer terms) to take a temperature. For that reason the Arduino shouldn't ask too often for readings: we need the program to prioritise pressure measurements. As once every 2.5 seconds is a suitable compromise, temperature taking and thermostatic control is handled by the same subroutine that manages the display. I further reduced delays by coding the program to not wait for the temperature sensors to respond. Instead, a timer is set to call an interrupt function that will take the readings after a suitable delay. In the meantime the taking of pressure readings continues.

A further time consideration is that the precision of temperature readings can be set by the calling computer. The downside of higher precision is that measurements take longer to take. This project uses the lowest precision available (0.5C) because that takes the least time. The precision is "good enough" for this project.

The Arduino becomes a tachometer by using a hall effect switch, type A3144, to detect the passing of a small magnet stuck top dead centre on the flywheel. It would be straightforward to substitute an optical sensor. The hall effect switch generates an interrupt that causes the Arduino to log the current time in milliseconds. RPM is calculated from the time taken between flywheel generated interrupts and smoothed as a running average. Each magnet triggered interrupt also signals the start of a new cycle so that pressure readings can be linked to the cycle in which they occurred.

The A3144 is specified to operate between -40C and at least +85C. In this application it is used at room temperature.

In an engine, pressure is the fastest changing measurement. Therefore it pays to take as many pressure readings as possible during each revolution. The MPX4115AP pressure sensor is an analogue device producing an output voltage between 0.2 and 4.8V. The output voltage is proportional to the working range of the device, which is 15kPa to 115kPa. The maximum pressure allowed before damage is 400kPa. The device is intended to operate between -40C and 125C; therefore it is advantageous for the sensor be somewhat remote from the hot parts of the engine. The accuracy of pressure readings is normally +/- 1.5kPa but this may not be achieved here because of temperature variations inside the cylinder.

Raw pressure voltage values are converted to kilo-pascals using the formula:

kPa = (raw_volts / 1023.0 + 0.095) / 0.009

Be careful to wire the pressure sensor correctly. A mistake may destroy the sensor and they cost about £15 each. Pin 1 is the Output and, for the avoidance of doubt, it is marked with a small notch. Pin 2 is ground and Pin 3 the +5V power input. Pins 4, 5 and 6 must be left disconnected.

Of concern to any project powered from a computer's USB port is the total load. Not all USB ports are equally good at providing power!

In this project the Arduino, LCD Keypad Shield and Sensors, photo 7, draw about 60mA. If the optional thermostat capability is used the power relay module (SRD-05VDC-SL-C) I used pulls another 60mA whenever the coil is energised. Therefore the total load is unlikely to exceed 120mA. Nonetheless it is best to avoid supply problems by connecting the Arduino to a powered USB hub rather than directly to your PC.

MS-Windows, OS/X, and Linux machines can all run the software used at the PC end of the link.

Modifying the Engine

Modifications to the Coffee-cup Engine are simple.

It is convenient to replace two of the six nuts that hold the upper plate to the pillars with studs. The studs can be used to attach a plastic strip that tightly presses the upper temperature sensor against the Cold plate. Alternatively wooden clothes pegs can be used to clip sensors to the plate edges. However the sensors are mounted it is important to make sure that all the leads are insulated from each other and from the aluminium engine.

To accommodate the pressure nozzle, first drill the top plate as shown in **fig. 8** with a 3.5mm drill and thread the hole with an M4 tap. It is possible to do this without dismantling the engine but it is safer to remove the pillar and crankshaft assembly. Don't ask how I know!

Then make a brass nozzle to take the short length of silicone hose used to link the engine to the pressure sensor, **fig. 9**.

Plug the pressure sensor and engine nozzle together using a short length of silicone hose. I used the thick-walled type used for food processing but thin walled aquarium air tubing worked just as well. Check for leaks again!

Programming the Arduino

First download and install the Arduino IDE from https://www.arduino.cc/ Whilst donations are welcome the software is free. The website also has an online shop selling the Arduino Uno, or you can buy one from a Maplins Store or any of several internet suppliers.

The IDE provides everything needed to program the range of Arduino boards.

The computer language used is a dialect of C and, just to keep you on your toes, an Arduino program is called a Sketch. There is much information on the web and several books on Arduino programming to get learners started.

Connect the Uno to your PC with a Type A USB cable and start the IDE. Use the Tools menu to set the board to "Genuino/Arduino Uno", or whatever board you have. Then use the Tools menu to select the port to which the Arduino is connected.

The simplest example, a sketch called "blink" requires nothing more than an Arduino. The sketch can be loaded from File->Example->01.Basics This very simple sketch flashes a light emitting diode (LED) that's fitted as standard to all Arduino boards.

After successfully getting "blink" to work, import my sketch into the IDE, Verify it and then Upload it into the Arduino.

The sketch developed to measure the Coffee-cup Engine is available from a zip archive hosted on the Model Engineer Website at http://www.model-engineer.co.uk/news/article/silly-old-duffer's-arduino-indicator/24290. The zip archive contains all the code used in this project.

Capturing the Data

The Arduino IDE includes a serial monitor that will display data sent from the Arduino to the PC. It is useful for checking and confirming that the Arduino and PC are talking. They won't communicate unless the baud rate is set identically on both ends of the link: I used 115200 baud.

Though the operation is rather clumsy it is possible to capture Arduino data with the IDE's serial monitor and then copy and paste it into a file. It is better to use a PC terminal program that can do data logging. I used putty, which can be configured to automatically create time-stamped log files.

Once the data captured by the Arduino has been logged, a PC based scripting language and graph plotting package are used to analyse it.

Python3 is a powerful modern computer language. In this application it: reads the log file created by putty and removes any damaged lines; reads data and, while calculating the mean cylinder pressure, identifies the maximum and minimum cylinder pressures encountered; produces a data file for each cycle containing the data needed to draw PV_Loops and calculate the indicated power of the cycle; finally produces a report summarising the analysis. The Python script does not draw graphs, it only processes data so that it may be graphed by another tool.

Two tab separated files are output per cycle:

To draw PV-Loops per cycle, the script(called enganal.py) outputs files prefixed "ind" suffixed "Cycle_number" in a sub-folder called "indicators". Each line is organised into fields:

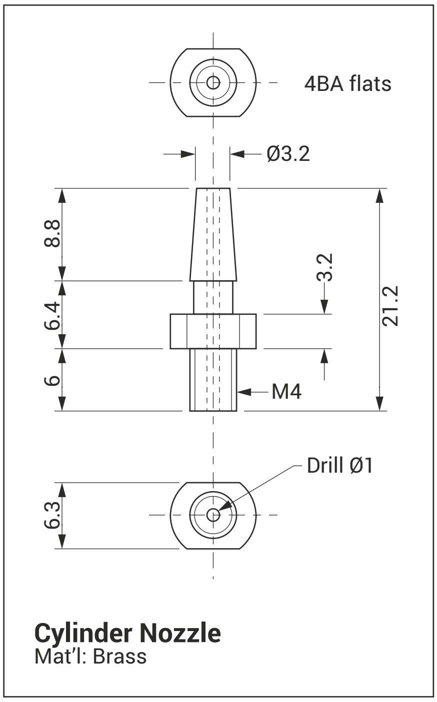
1 - Forward Stroke Pressure in kPA
2 - Backstroke Pressure in kPA
3 - Cylinder Volume at time of sample (not used)
4 - Time data (not used)
5 - Time data (not used)
6 - Time data (not used)
7 – Heater Flag (not used)
7 - Atmospheric Pressure in kPA

To graph Power vs RPM per Cycle, the script outputs date-stamped files prefixed "ip", with the fields:

1 – Cycle Number
2 – RPM
3 – Indicated Power this Cycle

A cleaned up copy of data read from the input putty log is placed in a tab separated file called "e_temps.dta".

One feature of the Serial connection to an Arduino may be confusing. Opening a serial link to an Arduino from a UNIX system (Linux or OS/X) causes the Arduino to reset and ask if the IDE is about to upload a new program image. Putty will get some apparent garbage before the Arduino connects normally to the user program. The garbage will appeat at the beginning of the log file. It's removed automatically by "enganal.py" or it can be deleted manually with a text editor. Windows is unlikely to trigger this behaviour. The bootloader exchange can be fixed by breaking a link on the Arduino Board, but that inconveniently stops new programs from being loaded from the IDE. Nothing is ever easy!



Nozzle Plan

Plotting the graphs

At first I tried using a Spreadsheet to graph the data. Tab separated files are easy to import. Spreadsheets have many virtues, but they don't cope well with big data. Measuring engine parameters with an Arduino produces lots of data: a 40 minute run creates a 26Mb log file. Imported into a spreadsheet the file makes a sheet sized 8 columns by 800,000 rows. Although the manipulations necessary to calculate results and draw the graphs is possible, sheer weight of data slows the software to a crawl.

Instead I used a Python3 script to check and clean up the data, perform the numeric calculations needed and to translate the data into formats suitable for a command-line graphing package.

Summaries of RPM, run time, mean pressures, temperatures and indicated power are produced by the Python script. A typical report looks like:

Enter raw atmospheric pressure: 820
Using /home/dave/putty20160603130112.log
Analysis of /home/dave/putty20160603130112.log
Samples = 1123892
Bad data lines rejected = 5
Bad rpm rejected = 4282
Good data lines accepted = 1115319
Indicator Diagram Files Output = 4453
Power per Cycle Log is /home/dave/Desktop/stirling/indicators/ip201606071506.dta
Area of piston face 132.71 sq mm
Stroke 10 mm

Pressures
Max Avg Min Atm
kPa 100.922 0.620 98.206 99.618
Max Avg
RPM 118 78.72
RPS 1.967 : 1.312
Run-time: 51.89 minutes (3113.51 seconds)
Average Plate Temperatures
Lower 42.67C Upper 25.19C Difference 17.49C

Calculated Power
SI: Mean Pressure 0.62 kPa @ 78.7 avg rpm -> 0.00216 W

A separate file containing the pressure data needed to draw PV-loop graphs is produced for each engine cycle, as is another file containing each cycles Indicated Power .

Gnuplot is a comprehensive Open Source Graphing Package popular in Universities for Mathematical, Engineering and Scientific work. Gnuplot is scripted: it does not have a true Graphics User Interface, though the Windows version initially looks as if does. At first scripting gnuplot is intimidating, but that passes with experience. Fortunately there are plenty of good examples and several tutorials on the web. Compared with a spreadsheet gnuplot is blazingly fast. It is also very flexible and full-featured to the point of confusion!

The following example of a gnuplot script draws a PV-loop for all the engine cycles between cycle 28 and cycle 35 (s=28 and n=35 in the code). All the loops are overlaid on the same graph which makes it easy to see if the engine is performing consistently. By default the output is sent to the computer screen: this script sends it to a jpg image file called "all.jpg"

```
set title "Coffee-Cup Engine\nIndicator Diagram"
set autoscale xy
f="indicators/ind"
s=28
n=35
set terminal jpeg
set output "all.jpg"
set ylabel "kPa"
set xlabel "Stroke mm"
set grid
plot for [i=s:n] f.i.".dta" using 3:1 with lines smooth sbezier linetype rgb "red" title "",\
 for [i=s:n] f.i.".dta" using 3:2 with lines smooth sbezier lt rgb "red" t "",\
 for [i=s:n] f.i.".dta" using 3:7 with lines smooth sbezier lt rgb "red" t ""
```

The gnuplot script expects each line of input data to contain 8 tab separated columns. The columns contain:

1 – Cycle Number
2 – RPM
3 - Raw Pressures
4 – Ambient Temperature
5 – Cold Plate Temperature
6 – Hot Plate Temperature
7 - Heater Flag (Not used)
8 – Time since start of run in milliseconds

To be continued...

Converting a gasless MIG welder

Mike Cox undertakes a useful upgrade

I have had an old Topweld 140 AC arc welder since the late 1970's. This I had used for a number of projects. Whilst it worked well my welded joints were never pretty. AC arc welders were very much all that was available to the amateur at the time of purchase. Over the years MIG (metal inert gas) welding has tended to displace the arc welder. One of the main reasons for this is that MIG can be used to weld relatively thin material such as used for car bodies. Arc welding is still used for welding thick sections such as structural steelwork.

A while back I was in ALDI and they were selling off some gasless MIG welders, **photo 1**. Presumably they had over ordered and supply had exceeded demand. I bought one of these and played around making practice welds. I could certainly make better looking welds but with the gasless wire it was still necessary to chip of the slag before making a second run. I started to wonder whether it would be possible to convert the welder from gasless operation to "proper" MIG using a shielding gas.

Dismantling the torch showed that the innards were exactly the same as for a MIG with gas torch. There was a gas valve incorporated in the torch. The only thing different was that the gas tube was not present. Further investigation showed that there was plenty of room in the large sleeve, that covers the welding cable, wire feed liner and switch wire that connects the torch to the welder, to run a gas tube.

The other difference between gasless and with gas operation is that the polarity of the torch is different. For gasless operation the work piece is connected to the DC +ve and the torch is DC-ve. For with gas operation the work is -ve and the torch is +ve. Taking off the side panels of the welder it was easy to see how the torch and ground clamp could be connected to a small terminal block in the wire feed compartment at the top of the welder. Flying cables could then be connected to the + ve and -ve plates of the rectifier and these passed up into the wire feed to connect to the terminal block to give whatever polarity was required.

The cost of this conversion looked to be very inexpensive. All that would be needed would be some 4 mm nylon tube for the gas supply and some 16 mm welding cable for the flying leads. These were available on ebay and I ordered 5 metres of 4 mm nylon tube at a cost of £4 and 1 metre of 16 mm welding cable at £3. The other bits and pieces like brass screws for the terminal block, phenolic laminate sheet for insulation, rubber grommets etc. were are readily available items that were lying around the workshop.

On top of this I would need a gas bottle (600 g CO2 disposable bottle12.99 delivered from Halfords), a regulator (£9 on ebay), some MIG welding wire (0.7 kg of 0.6 mm wire £5.99 from Machine Mart). I already had some 0.6 mm MIG tips for the torch because I use them as gas nozzles in my propane burner for my aluminium melting furnace. All these latter items I would have had to buy if I had purchased a with gas welder in the first place.

The welder as purchased

The gas line.

The gas line must run from the torch through the sleeve enclosing all the torch connections (welding cable, switch cable,

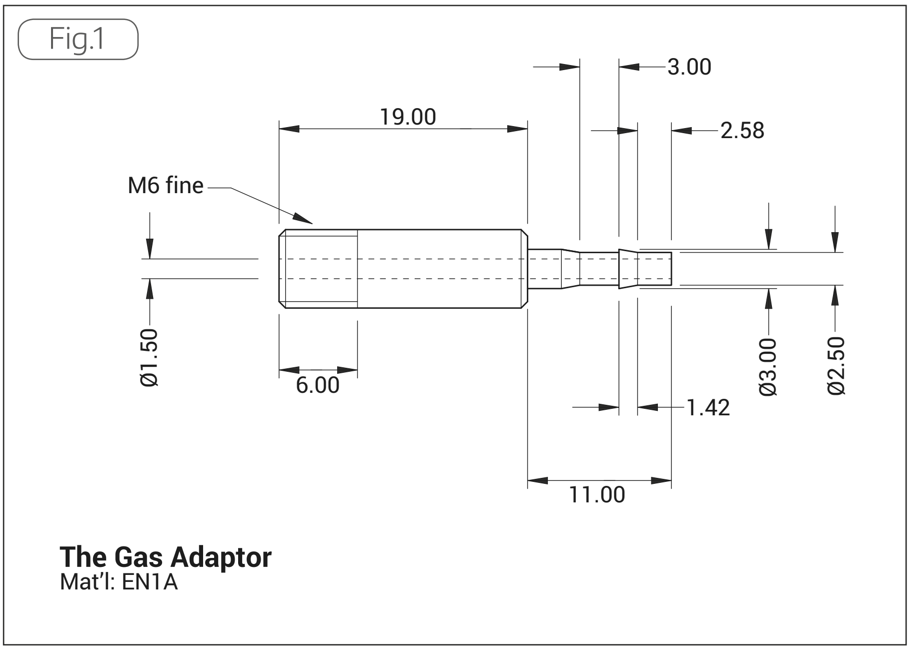
The wire feed unit.

Feeding the gas tube into the sleeve.

wire liner etc.) and then into the welder box. The gas line must exit the welder box at the back of the box to then connect to the gas bottle regulator.

All the connections to the torch arrive at the welder box through the sleeve and this enters the wire feed unit, **photo 2**. Undoing the screws on the left-hand side of the wire feed unit allows access to where sleeve ends. The new 4 mm gas tube was fed into the sleeve and with the torch sleeve laid out straight it was possible to push the tube all the way through to the torch, **photo 3**.

The inside of the welder torch is shown in **photo 4**. On the right is the swan neck. This screws into the brass block. The brass block connects electrically to the thick welding cable on the left. Below the cable is the wire sleeve through which the MIG welding wire runs. The brass block also incorporates the gas valve which is operated by the brass plunger that can be seen at the bottom of the block. This is operated by the trigger on the torch. The same trigger also presses



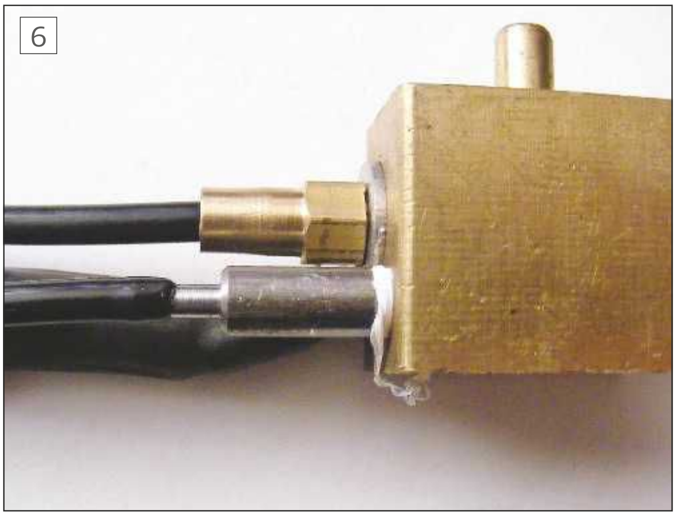
The torch

The adaptor for the gas port.

the spring at the bottom of the torch to the small brass block just above it in the photo. When contact is made between the two then the wire feed motor operates to feed wire to the swan neck. The new gas line can be seen at the top of the torch and this connects to the gas port on the brass block. Thus when the trigger is squeezed the wire feed starts and the gas valve opens feeding gas to the swan neck.

The gas port on the brass block was threaded with an M6 metric fine thread with a pitch of 0.75 mm. It was necessary

6

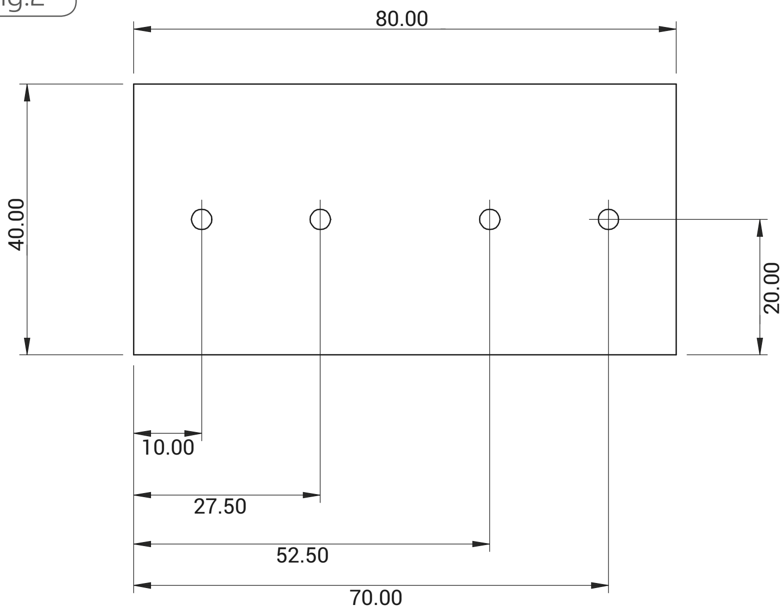


The adaptor screwed to the gas port and the gas line attached.

7

The gas tube emerges from a grommetted hole at the rear of the welder.

Fig.2



Terminal Block Insulators
Mat'l: 2mm phenolic laminate

8

The support for the gas cylinder.

to make up a small adaptor to connect the pipe to the block, see **photo 5** and **fig. 1**. This was turned from 6 mm EN1A and single point threaded. It was installed in the brass block with a generous layer of PTFE tape around the thread and tightened down using long nose pliers. The end of the nylon gas tube just is a tight fit over the adaptor, **photo 6**. Once all the torch modifications were made the sleeve was clamped around all the connections with a cable tie and the trigger and cover replaced. The torch can now be tested by plugging in the welder and turning it on. The gas cylinder was connected to the gas tube and on squeezing the trigger there was the sound of gas escaping from the swan neck and the wire feed motor supplied wire to the torch. To leak test the gas line it was pressurised at maximum

9

The polystyrene ring to support the bottom end of the cylinder.

The plastic top of the support.

pressure from the gas regulator and then the regulator was closed. This leaves the gas line filled with gas at high pressure. It was left pressurised for 30 minutes and at the end of this time when the torch trigger was actuated a substantial puff of gas was released indicating little or no leakage had occurred from either the gas valve or the gas line.

At the welder end a cable tie was used to clamp the sleeve around all the connections. The end of the gas line was passed down through the hole in the top plate of the welder, following the welding cable, to the inside of the welder box. It was then routed down the side of the transformer and out through a grommetted hole in the back panel, **photo 7**.

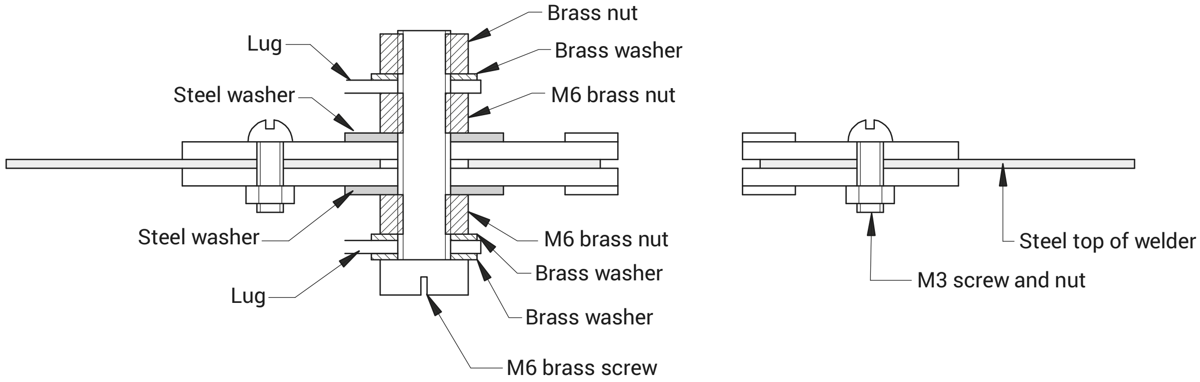
The gas line then connects to the gas bottle via the regulator. To support the cylinder and regulator I found a stainless steel container that had been discarded. I had once been part of a toilet brush holder. This was cleaned up and bolted to the back of the welder using some long 12 mm diameter stand offs, **photo 8**. Two of the screw holes that secure the turbo fan in the welder were utilised for the long screws. A ring of polystyrene, **photo 9**, and a plastic top, **photo 10** were made to stop the cylinder rattling in the stainless steel container. The finished support is shown in **photo 11**.

Electrical modifications.

The electrical modifications were very straight forward. A terminal block, **photo 12**, was constructed and fixed to the top plate of the welder. To make this two pieces of phenolic laminate were cut to size as shown in **fig. 2** and one piece was marked out for the holes. The four holes were then drilled out 3 mm. The two plates were clamped together and the holes drilled through the second piece. One of the plates was held against the top plate of the welder and one of the outside holes was spotted through and drilled through 3 mm. The plate was then attached to the top using an M3 screw and nut. The other out side hole was drilled through 3 mm and the plate secured with a second M3 screw and nut. Using the plate as a template the two middle holes were drilled out 3 mm through the steel top of the welder. The screws were undone and the second plate then placed under the top of the welder and the screws used to secure everything in position. The middle holes were then drilled out to 6 mm through all the layers. The two phenolic plates were then removed and the centre two holes enlarged to 10 mm using a step drill. The edges of the holes in the steel plate were carefully deburred and the top and bottom phenolic plates were reinstalled using the M3 screws. This sequence of

The finished support.

Fig.3



Section Through Assembled Terminal Block
Only one stud shown for clarity

drilling operation was used to ensure that the large holes in the top of the welder were concentric with the smaller holes in the phenolic pieces. This then provides an insulating gap in the steel around each of the terminal bolts. The way the connections are made is shown in **fig. 3**.

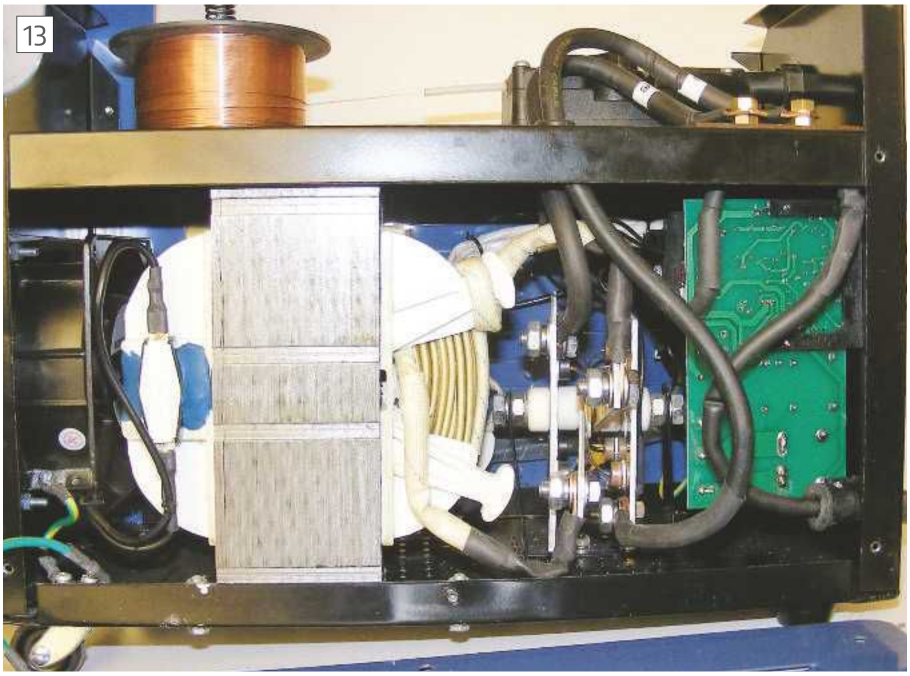
Photo 13 shows the inside of the modified welder. On the right hand side can be seen the terminal block. One terminal connects to the wire that leads to the earth clamp (emerging from the weld at the bottom right) and the other connects to the wire that goes to the torch. It was necessary to undo the cable leadthrough clamp on the earth wire in order to pull a little more of the earth wire through so that it would reach the terminal.

The vertical metal plates, between the transformer and the green circuit board in photo 13, are the cooling fins for the rectifier

12

The terminal block

13



The inside of the welder after conversion.

14

Terminal lug.

diodes. They are also the connection points. One wire was connected to the bottom of the right-hand plate. This is the positive plate and the earth clamp was previously connected here. The wire used was 16 mm welding cable. Another similar wire was connected to the top of the left-hand plate. This is the negative plate and it was previously connected to the torch. The connections were made using crimped copper lugs, **photo 14**. These can be bought but I had some 3/8" copper pipe and they were easy to fabricate from this. Before crimping the lugs on heat shrink tubing was put on the wire and after crimping the lugs it was shrunk down with a hot air gun.

The two cables were passed though grommetted holes in the top of the welder, and were terminated with more crimped on lugs, **photo 15**.

The flying leads were labelled with the polarity and the terminal block labelled with torch and clamp.

Photograph 16 shows the connections set up for welding with shielding gas.

15

The flying leads.

Initial trials.

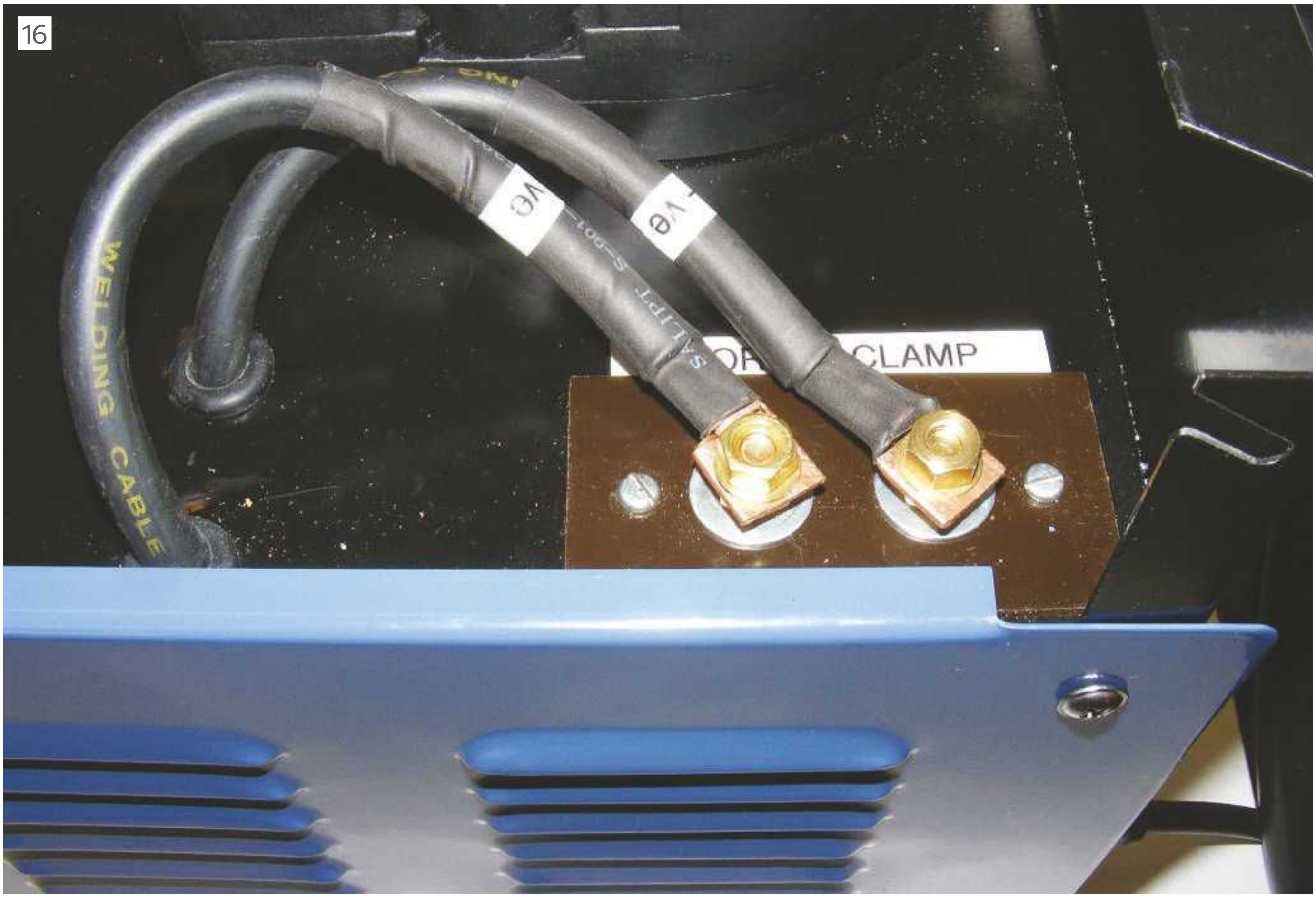
After completing all the modifications I connected the gas cylinder and put a reel of 0.6 mm wire on the welder. The drive wheel on the wire feed was marked for 0.6 mm on one side and 0.8/0.9 mm on the other. I fixed it with the narrow groove to drive the wire. I set the polarity so that the torch was positive and the earth clamp negative as is normal for with gas MIG welding.

With the gas turned on I first checked the wire feed and the gas flow (by listening to it) and all seemed to be ok. I made a few test beads onto a 2 mm mild steel plate and after playing around with the power and wire feed I soon had a good "frying bacon" sizzle and some half decent weld beads.

To revert to gasless welding is straight forward. It is only necessary to reverse the polarity on the terminal block and adjust the wire feed for the appropriate size wire.

After a bit more practice I shall think about making some welded metal fabrications. ■

16



Connections made for with gas welding.

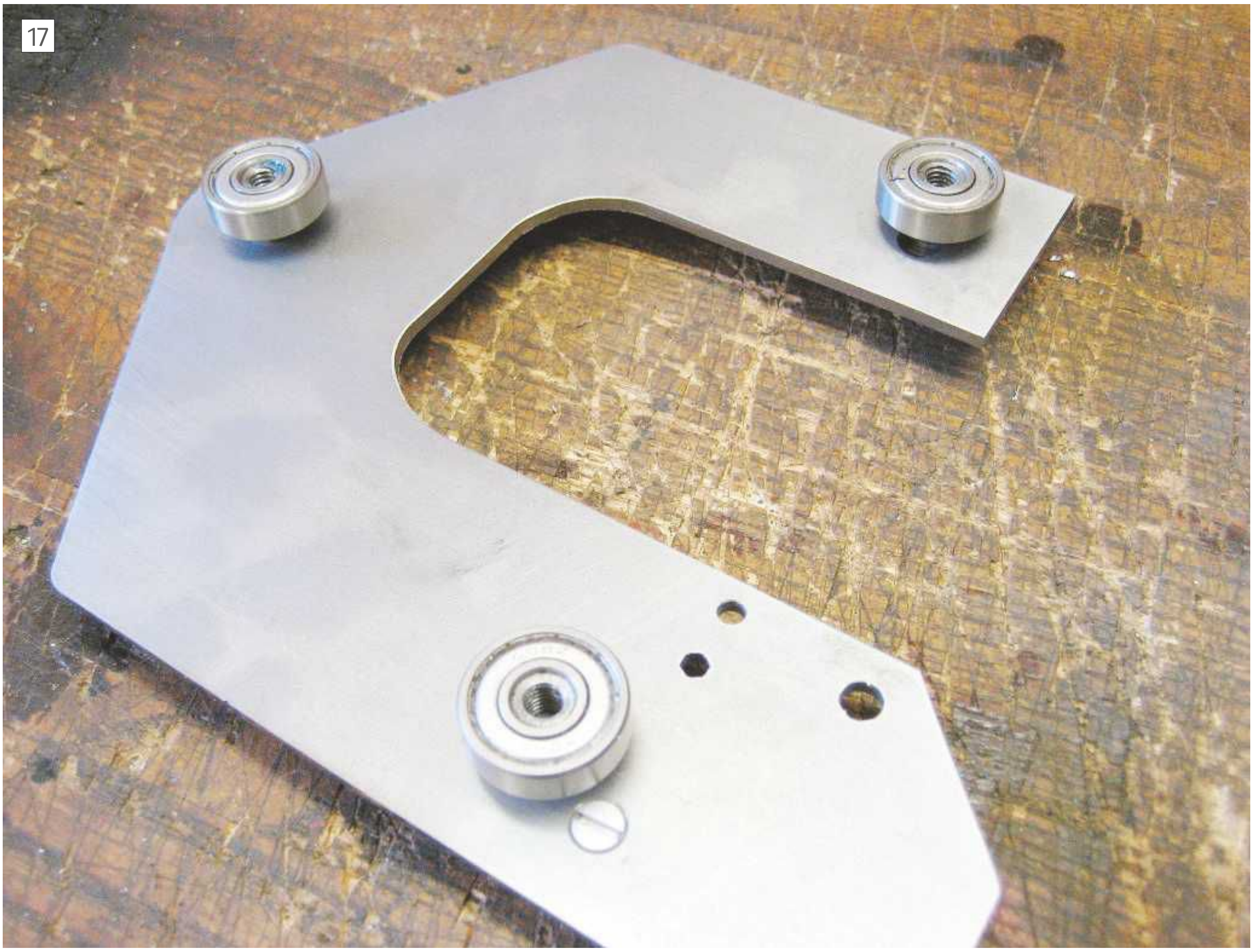
A Miniature Belt Sander for your Lathe

This step-by-step guide from Mogens Kilde explains this a useful addition for any workshop.

16

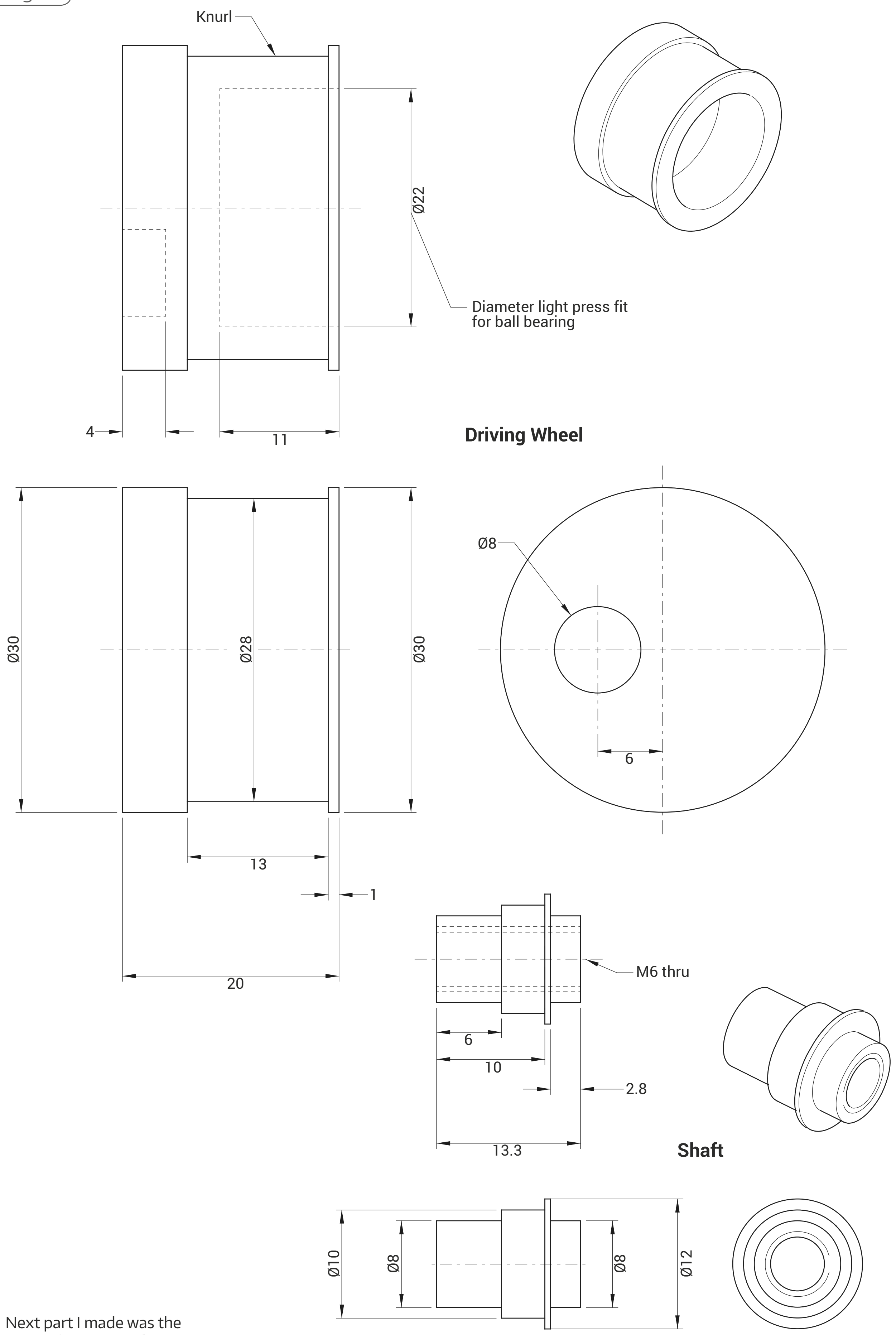
The three shafts were pressed into the ball bearings (must admit one of them had to be locked onto the bearing using Loctite 641), **photo 16**.

17



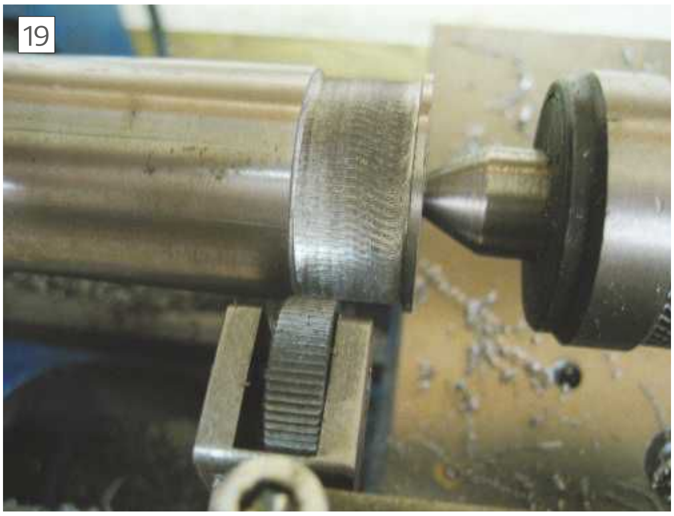
To finish off this part of the project the shafts with pressed on ball bearings, were mounted on the main tool frame, **photo 17**.

Fig.5

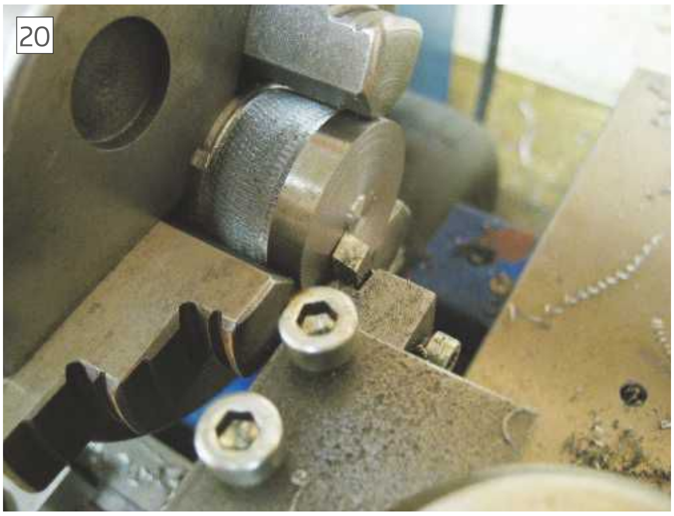


Next part I made was the driving belt wheel, **fig. 5**.

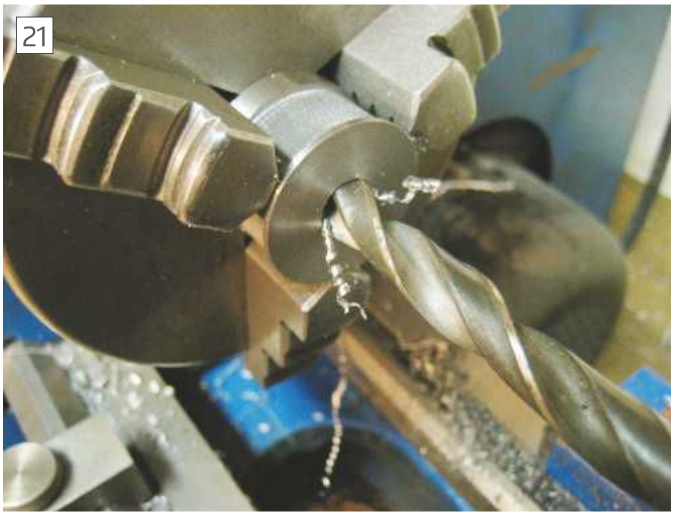
This wheel was made from 30mm free machining steel. First job was to face off the steel bar, make a centre hole, and changed to a special narrow grinded toolbit, so I could turn the 28mm section, **photo 18**.



Next the surface was knurled; this was done to obtain a better grip on the sanding belt, **photo 19**.

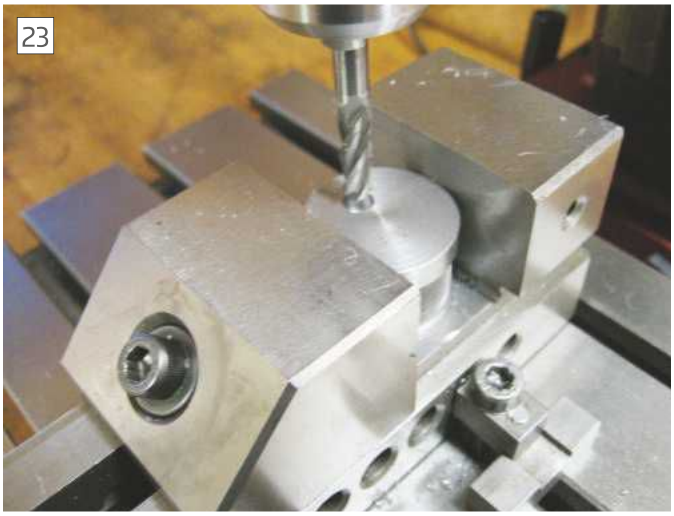


Next the work piece was cut off a little over size, turned over in the chuck and faced off, **photo 20**.



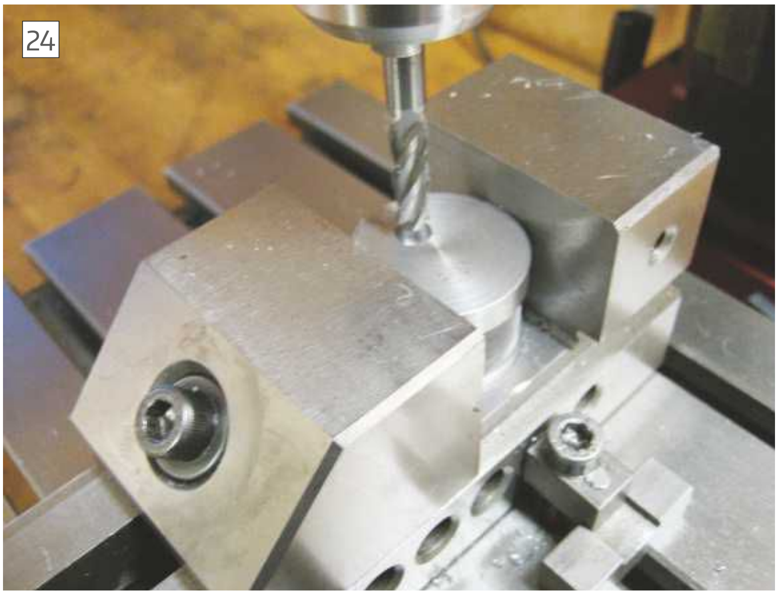
Now the inner boring was made, starting with a large twisted drill, **photo 21**.

Then the ring was bored to final inner diameter and depth using a boring bar in the lathe. Again I aimed for a diameter 0.02mm under nominal measure to obtain a light press fit with the ball bearing, **photo 22**.



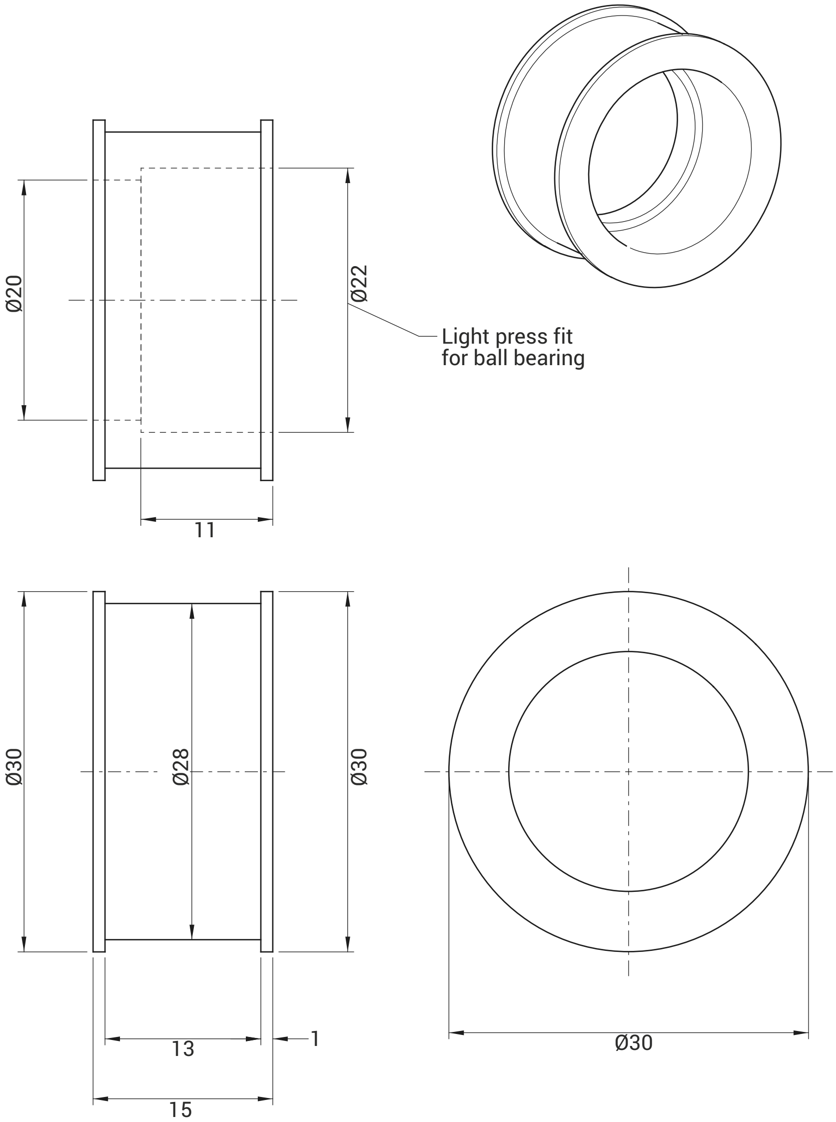
Next the part was placed onto the bed of my bench mill, and the 8mm hole was drilled with an end mill, **photo 23**.

24



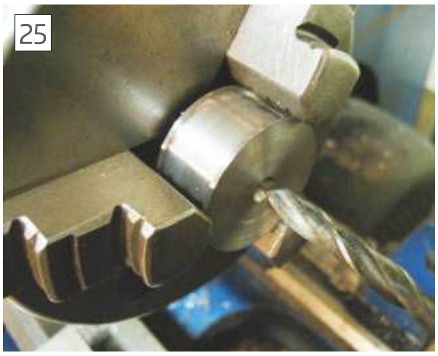
Finally, the driving belt wheel was pressed unto the lower ball bearing / shaft and mounted onto the main tool frame, **photo 24**.

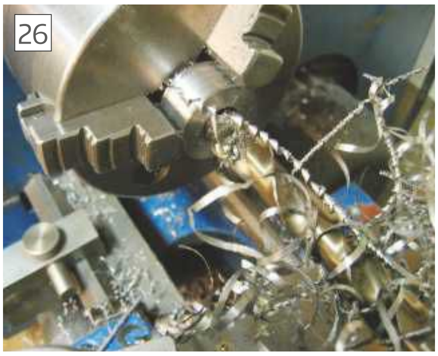
Fig.6



Belt Wheel

The next set of parts I made was the 2 pcs. of belt guiding wheels. These where also made from a 30mm free machining steel bar, **fig 6**.

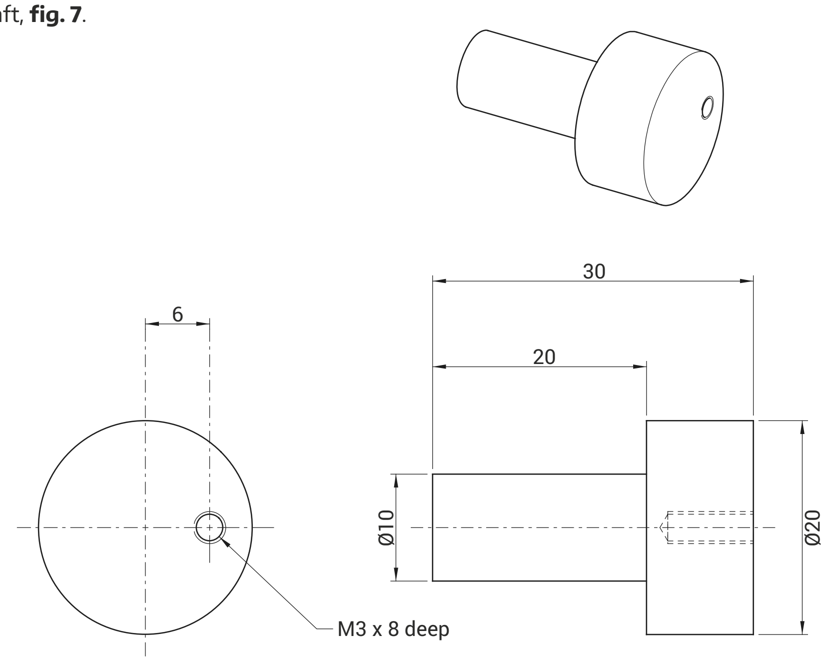




The work process was very much the same as for the driving belt wheel, **photos 25,26,& 27**. Both wheels where pressed onto respective ball bearings and mounted to the tool frame.

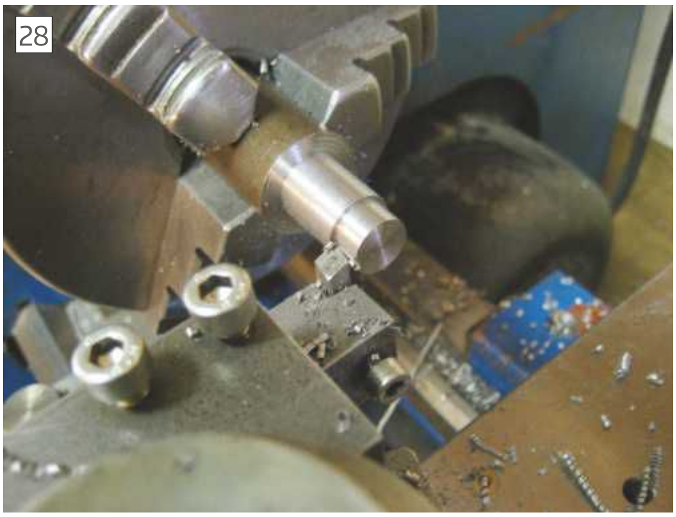
Now I was ready to go on to the next part, the driving shaft, **fig. 7**.

Fig.7



Drive Shaft

I decided to make a clutch solution for the drive, so any misalignment between the lathe chuck and the belt sander driving wheel, would be taken up by this clutch arrangement.



This part was made from 20mm diameter free machining steel. First job was to turn the outer profile as per the drawing, **photo 28**.

The work piece was cut off at appropriate length, **photo 29**.

To be continued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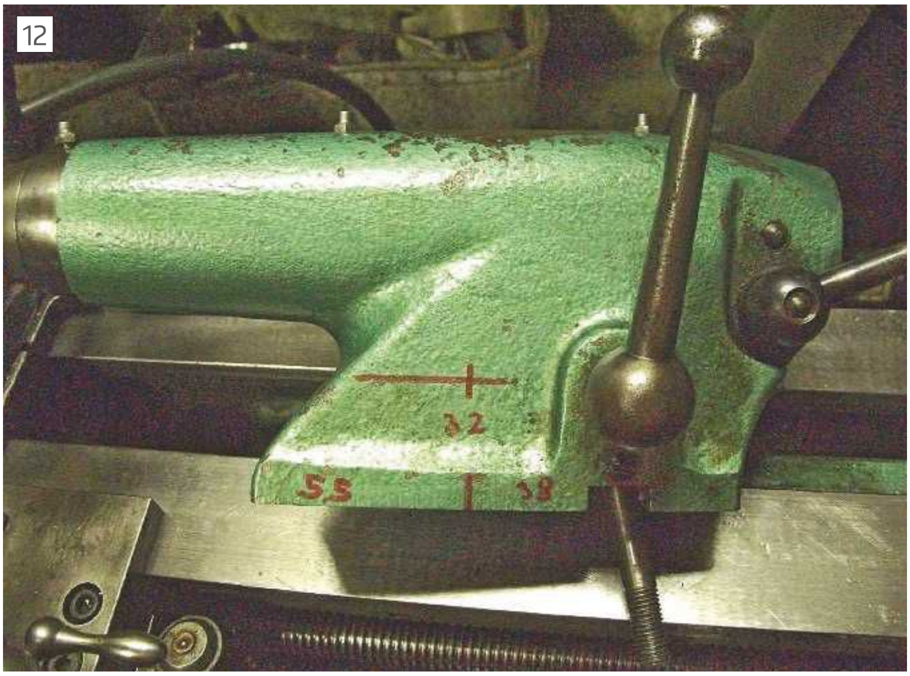
Modifications to a Myford 7 Series Lathe

Continuing this short series, Inchanga, in South Africa, describes further work carried out on the tailstock of his lathe.

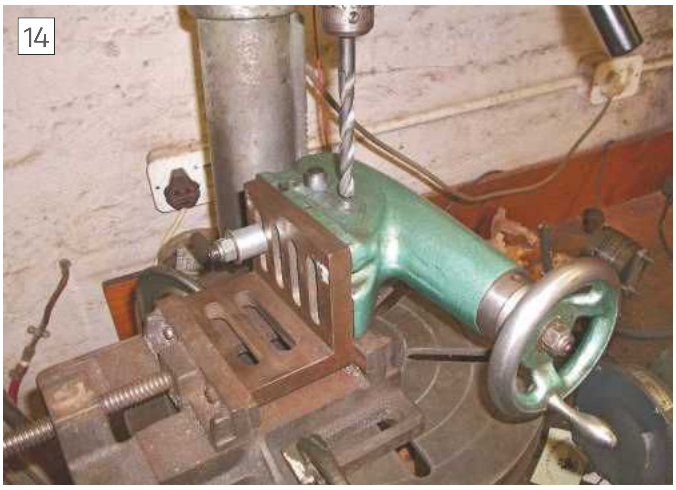
The second tailstock modification deals with the positive retention of the top portion to the bottom portion so that it cannot rise and give a false height and allow swarf to become trapped between the two parts. This modification took quite a bit of thinking about before the writer began drilling holes in the various parts! What is required is a clamping bolt that pulls the two parts together but does not interfere with the normal working. If photo 4 is revisited we can see that the internal part of the top portion is a large empty space with only the bed clamping mechanism taking up any significant volume. After much measuring and doodling on paper it occurred to the writer that if the new clamping mechanism is placed behind the eccentric shaft it would have sufficient clearance to avoid the other working parts. The eccentric shaft is situated 1 ¼ inch (32mm) above the joint line between the two major parts. The alignment pusher screws are directly below the eccentric shaft. If the new clamping mechanism used a similar cross shaft and it is placed on the same level as the eccentric shaft it can pass across the same void in the top casting. If a line is drawn on the top casting at the 1 ¼ inch level and extended backwards



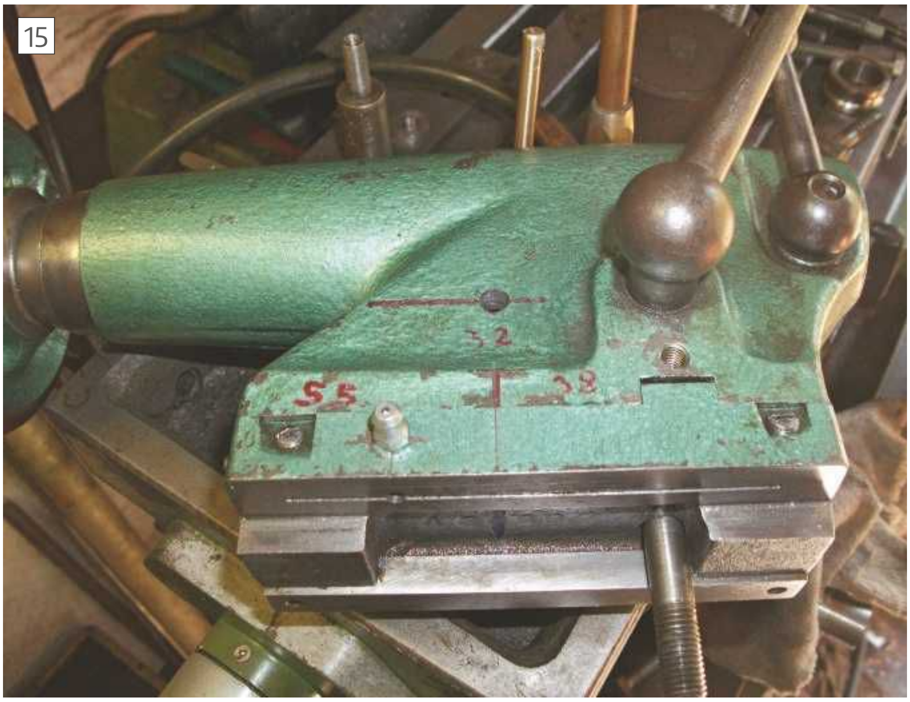
Top casting marked for clamping mechanism

by 1 ½ inch (38mm) it would be in a convenient place. From here a line drawn vertically downwards would pass through the base plate to take a clamping bolt, a 6mm metric or 0BA would be adequate. This bolt will be far enough back to clear the bed locking plate and accessible from below the bed through the gap. The

Opposite side of casting



Drilling the clamping rod hole in the tailstock casting



Transferring the hole position to the base plate casting

Clamping bolt hole location

marked out top portion of the tailstock is shown in **photo 12. Photograph 13** shows the opposite side marked for drilling.

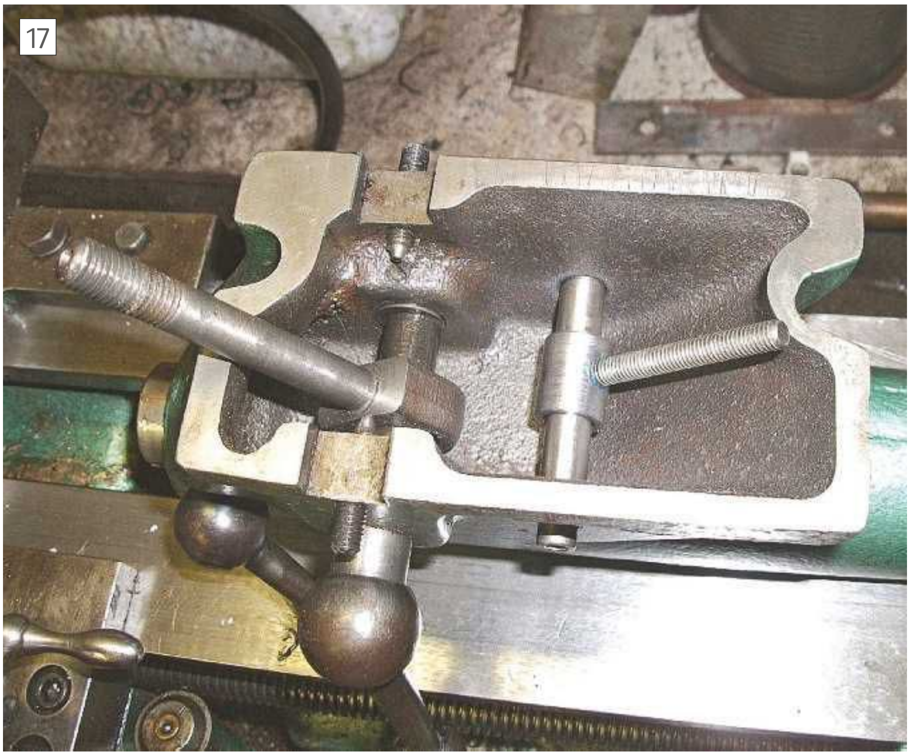
The external width of the casting where the new hole is required is about 60mm and a rod of 3/8 inch (10mm) diameter round steel bar should suffice. This shaft passes through the casting sides. The effort to bend a 3/8 inch diameter steel rod with an effective length of 30mm is quite high. In fact, if the new owners of Myford care to make a minor modification to the tailstock casting a pillar could be cast into the top portion with very little effort only requiring drilling and tapping to fit a suitable stud. The same applies to the base plate modification for positive lubrication!

Drilling the top casting is a bit of a challenge as the sides and ends are curved, the only flat surface is the base. The writer contrived a Heath-Robinson set up using an angle plate and the clamping bolt to secure it to the angle plate. This is then held in a large drilling vice and the angles adjusted by eye to get everything squared up correctly. For this the writer wished they had two pairs of hands! The eccentric locking handle grub screw was removed so the eccentric shaft could be moved across the casting so that it didn't interfere with the drilling machine table. **Photograph 14** shows the set up. Although this looks flimsy by not being too fierce with the drill feed handle it worked! Begin by putting a 5mm drill through from one side. Unless you have a long series 5mm drill it will be too short to break through on the opposite face of the casting.

Open out the hole is increments to 10mm. Without disturbing the set up now spot through with a 7mm drill (which is just long enough to go right through) to break out the opposite side. The pin that goes through the casting is 10mm diameter and reduced to 7mm at one end for 3mm in length. The 7mm-diameter end is drilled and tapped to take a 2BA or M5 cap screw to secure the rod in place. The 10mm diameter end should protrude from the casting by about 2mm, so make the rod a little over length to start with as the castings may vary in exact width.

The base plate needs a corresponding hole for the additional clamping bolt. If the normal clamping bolthole is examined, it is very close to the gib strip. The bottom of the base plate casting is anything but flat but a suitable place is in the middle of the roughcast portion. To find the exact place where the hole is required we transfer off the top casting marking out onto the base plate and then using a T square mark out the position in relation to the long dimension. **Photograph 15** shows the marking out and **photo 16** shows the final hole location. By a sheer fluke it end up being in the middle of the number zero in the casting identification number A2099.

This hole was drilled 7mm to allow a M6 or 0BA bolt to pass though. This bolt is a smaller version of the eccentric clamping bolt and a nut and washer pulls the top



Modified internal clamping mechanism

Fully assembled tailstock base plate

Machining tailstock alignment screws

portion firmly onto the base plate. The new clamping bolt can swing and move sideways on its shaft just like the normal bed clamping bolt to take up the correct alignment. When the two parts are assembled the two bolts hang down and pass through their respective holes. The final part of this is a sleeve of round rod about 20mm in length and 20mm in diameter. A hole is drilled through the sleeve to be a loose fit on the rod, so a 10.5mm hole is required. The sleeve is drilled and tapped for a piece of studding of M6 or 0BA that is screwed in with some Loctite retaining adhesive. A Nyloc nut and a flat washer complete the assembly. **Photographs 17** and **18** show the final assembly.

Turning now to the front clamping mechanism. The two pusher screws for setting over the tailstock (Myford part A2146) need to be modified by turning a 60° point on the end. The corresponding place on the cast iron block they push against is drilled with a small centre drill to make a locating hole. This is simple to do with a 4.7mm drill in a hand-drill put through each screw hole and a witness mark made in the two sides of the square lump. **Photographs 19** and **20** shows this process.

Incidentally a possible replacement for the setting over screws already exists and is used on the carriage for the front gib strip location. This is Myford part A7424/1 and is a similar length screw with a little pin on the end to engage in the locating hole in the carriage gib strip.

Centre drilling pusher screws position

If Myford wants to incorporate this modification then it would be advisable to beef up the thickness of the square stub sticking up that the clamp bolt passes through. The thickness is at present a little too thin for comfort if drilling holes into it. A minor change to the base plate casting could incorporate this and the cast in oil grooves for very little effort.

The net result of these simple modifications gives much more positive location of the top portion to the bottom base plate. The front adjuster screws are now pulling the front of the two parts tightly together due to the action of the tapers, so no swarf can get between them. The rear-clamping bolt adds extra security. To adjust the tailstock alignment means that the rear clamping bolt needs to be slacked off before adjusting and when the correct alignment is obtained both the front pusher screws and the rear clamp nut should be tightened.

Whilst on the subject of things that could be changed I would like to mention the continued use of BA and imperial fasteners. Although they work they are today regarded as old fashioned, I know that the Myford lathe design is itself old fashioned and that is one of its attractions, but surely by now we could have embraced more usage of metric fasteners. It is not as if they are not suitable, the 2BA screws could be replaced with M5 and 4BA with M4 which are almost identical, and the ¼-inch screws with M6 etc. I suppose the final call has to be made by Myford, as only they know the prices of bought in fasteners to their requirements.

For screws and studs in cast iron castings neither the metric or BSF threads are a good choice as the pitch and root depth are a little too fine to get a good hold on the cast material. It is even worse for aluminium and the use of BSW or UNC would be a far better option. BSW is, like BA and BSF, regarded as old fashioned, so my personal choice would be UNC, which are readily available. ■

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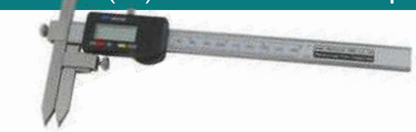
- Easy to read display.
- Large internal jaw capacity.
- Storage case.

Part no	Range	Price
ME-CAL-LO-500	0-500mm(20”)	£95.32
ME-CAL-LO-600	0-600mm(24”)	£105.14

150mm (6”) Centre Pitch Caliper



- Adjustable precision ground points.
- Metric/imperial conversion.
- High quality hardened stainless steel.
- Storage case.

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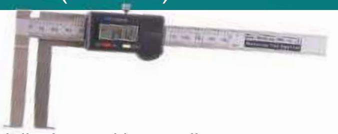
ME-CAL-CL-150	0-150mm(6”)	£43.26

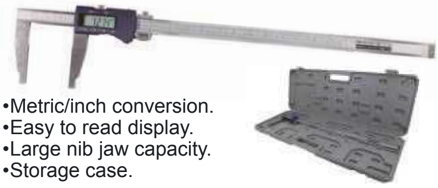
150mm (3/4”-6”) Internal Caliper



- Specialist Internal bore caliper.
- Raised contact points making it easier to measure stepped bores, groove etc.
- Storage case.

Part no	Range	Price
ME-CAL-INT-150	19-150mm(3/4”-6”)	£44.90

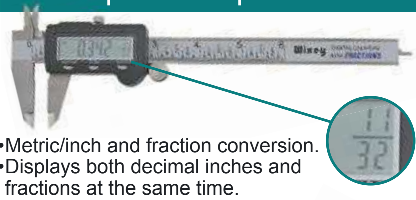
Digital Caliper with Nib Jaws



- Metric/inch conversion.
- Easy to read display.
- Large nib jaw capacity.
- Storage case.

Part no	Range	Price
ME-CAL-LO-500-NB	0-500mm(20”)	£84.22
ME-CAL-LO-600-NB	0-600mm(24”)	£97.97

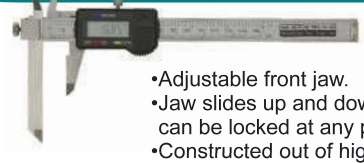
6 Inch Imperial Calipers Fractions



- Metric/inch and fraction conversion.
- Displays both decimal inches and fractions at the same time.
- Precision ground measuring faces.

Part no	Range	Price
WR100	0-150mm(6”)	£27.50

150mm (6”) Offset Calipers



- Adjustable front jaw.
- Jaw slides up and down and can be locked at any point.
- Constructed out of high quality hardened stainless steel.
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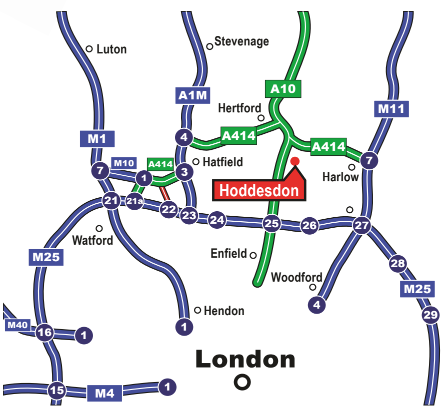
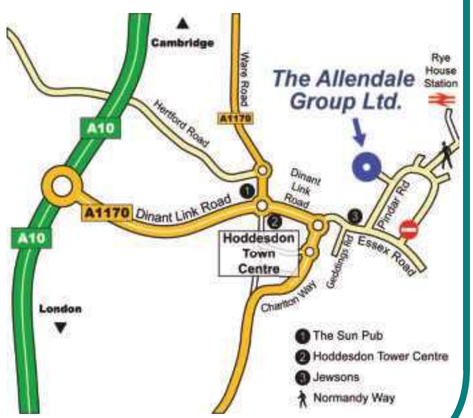




On the Wire Christmas NEWS from the World of Hobby Engineering

Have you been Naughty or Nice in 2016? This month we take a suitably festive look at some suggestions for Christmas presents. Not all for the workshop, some of them could be just the right sort of present to entertain a youngster and fan the spark of an interest in engineering in the same way that I'm sure Meccano did for many readers (and editors!)

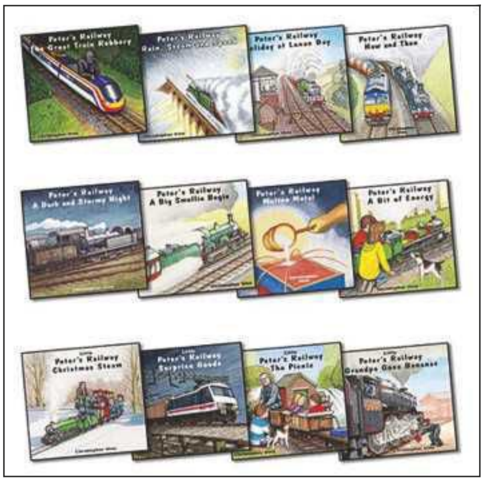
Peter's Railway

Once again it's that time of year,
When Chris Vine writes a poem, I fear:

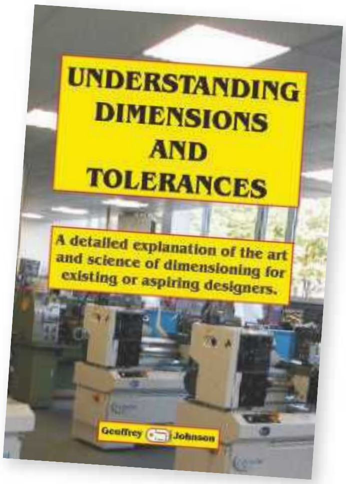
Stories, Real Engineering, History and Adventures!

It's It's Christmas Time, but what to do?
What to get from you-know-who?
Perhaps your kids like engineering,
(Science and reduction gearing)?
Or maybe they are hooked on trains,
Well - here's some books to feed their brains!!
We've paperbacks and hardbacks too,
and sets and special offers;
to help you choose but not deplete
your hard-won Christmas coffers, w
So now's the chance to buy a set,
a chance you should quick seize on.
To make up for this ghastly verse,
it won't - but here's a coupon !

Use voucher code PRWEB on **PetersRailway.com** to get a 10% discount on all orders.



Understanding Dimensions and Tolerances



In 2014 Geoffrey Johnson wrote to the Model Engineer magazine complaining about the poor standard of dimensioning on the drawings supplied to engineers from various sources, both amateur and professional, including Workshop Drawing books, and how such technical ignorance can lead to a waste of time and materials.

His letter was published, and shortly afterwards he was invited to give a lecture on the subject by the Society of Model and Experimental Engineers. Afterwards he had to answer many questions from the members, most of which were whether there was a book available about it. I replied I knew of no such book.

Geoffrey's resulting book 'Understanding Dimensions and Tolerances' with 140 illustrations, is now available from the Amazon Bookshop. It will be available in paperback from Amazon by 14th November 2016, and from any bookshop from mid January 2017. There are a lot of exercises to do, and the book is preferable as some of the exercises are better done with the book rather than on the screen of a tablet. Geoffrey would be prepared to present the SMEE lecture to any organisation if requested, via the editor.

Chester Bench Grinder

Chester think that one of the handiest things for family members to buy a model engineer is something that everyone needs, but may not have in the workshop, and where size and shape isn't so important, unlike cutters, vices etc. when you have to have the correct ones!

For this reason they suggest a great Christmas gift item would be their 6" Bench Grinder, which is £64.50 including Vat and Parcel Service delivery. The grinder is lovely compact unit, with two grades of wheel supplied and fitted. Unlike many grinders it also features a wheel dresser, light, coolant tray and eye shields.

16mm Loco Figures

Many builders of engineering models will agree that, especially to those unfamiliar with the full size machines, it can be very difficult to judge their size without anything familiar to give them a 'scale'. Equally, machines that, in life, would have had a driver or attendant just don't look right on their own. A new solution to this is to use a 3D printer to create lifelike figure, but unfortunately not all of us have one, or the ability to create the required computer model. If you go searching on the internet, you are more likely to find C3PO or Batman than suitable figures. ARD Digital have come to the rescue, at least for 16mm railway enthusiasts, with a range of excellent quality 3D printed figures, all made from scans of real people. They have sent me two samples of their 16mm figure, an engine driver and another male figure from their extensive range. Both are of excellent quality. I understand they are heat tolerant enough for footplate work, as long as they aren't too close to the firehole!

The price of these figures is just £5.00 and for £30 you can even get yourself scanned so you can drive your own loco in miniature! Visit their website at **designscanprint3d.bigcartel.com** to see the range and just how good the figure looks when painted.

Warco Belt and Disc Sander

A useful addition to any workshop is a robust belt and disc sander. Many people think of these as woodworking tools, but fitted with 'red emery' belts and discs they can remove metal, including steel, at an astounding rate leaving a 'brushed' finish that resembles a ground surface. This quality machine from WARCO features a horizontal or vertical sanding table, with fence and a calibrated table with mitre gauge for the sanding disc. With a cast iron body it has a 240V 440w induction motor that runs at 2850 rpm.

The belt and disc sander is to be found at **www.warco.co.uk** and costs £115 including VAT.

Moore and Wright Hotlist

Machine DRO are offering up to 50% reductions on selected Moore and Wright products on their latest hotlist, so if you fancy some quality measuring equipment this Christmas head on over to **www.machine-dro.co.uk**. Examples include a Moore and Wright 150mm (6") Digital Caliper Absolute for £72 or an M&W Digital Protractor for just £32.40. They have also got rid of their minimum order for online orders, so even if you just want some stocking fillers they have plenty to offer.

Sam's Curious Cars

This would be an entertaining present for a youngster who is interested in computers and is looking to explore ways to relate them to the real world. Well presented in a colourful box Sam's Curious Cars like all the other sets in their range includes a number of modules, rather like those found in many electrical or mechanical construction sets. The Cars set has two geared motors, an RGB LED, a switch, tilt sensor and a potentiometer, as well as various bits such as card vehicle bodies, a plastic chassis and controller base that can hold the modules, which have soft silicon covers. The difference is that these contain self-contained lithium batteries and a Bluetooth module, so instead of wiring them together, you just charge them up from a USB socket and then link them together in an app on your computer (Bluetooth dongle included), tablet or smartphone. Using a simple and appealing graphic interface it's possible to link them up in various ways and change things like motor speed and rotation. For more sophisticated control, you can add chunks of Javascript. Despite a few teething problems caused by a conflict between Sam's dongle and my own(!) I was soon able to get Sam's pickup truck chasing the dogs around the landing.

It's also worth thinking about whether or not the modules could be used in any workshop projects. For example, the motors could be used to turn small model stationary steam engines under remote control, for example – imagine being at an exhibition and starting a model in motion using your phone!

The package includes instructions for 20+ starter projects, some of which include practical construction challenges as well as programming ones. At £149 it isn't a casual purchase but it could be a great start in robotics for a bright kid. Be warned there are a host of other modules and kits, which all work together, that they will want next!

To find out more or order a Sam's set at **https://www.samlabs.com/**

Index

for issues 237 to 248 of MEW

SUBJECT INDEX

This index is arranged by Subject, listing Articles, Quick tips and letters to Scribe a Line.
Column five: C = Construction, P = Process, M = Miscellaneous, Columns three and four, e.g. 228 60 refer to the particular issue and page number. Column six: A=Article, T = Trade, L = Letter, Q = Quick tip, S = Subject.

3D PRINTING	DAVIES	238	25	M	A	3D PRINTING FOR ME PRINTED	EXAMPLES
ADHESIVES	DAVIES	246	42	M	A	PERSPEX BONDER	BONDING PERSPEX
ADHESIVES	DAVIES	248	54	MW	L	PERSPEX BONDING AGENT	BONDING PERSPEX
ADHESIVES	LITSON	248	54	M	L	PERSPEX BONDING AGENT	BONDING PERSPEX
BENDING	DOGGET	237	22	P	A	HEAVY DUTY ROLLERS 2	BENDING ROLLS
BENDING	WALKER	237	27	S	A	PIPE BENDING OPTIONS	THEORY & METHODS
BENDING	BARKER	237	31	C	A	A TUBE BENDING TOOL	PIPE BENDING DESIGN
BORING	GEORGINEER	242	20	M	P	BUTTON BORING	BUTTON BORING
BROACHING	COX	241	24	C	A	ROTARY BROACHING	SIMPLIFIED METHOD
CHUCKS	CHAMBERLAIN	241	9	C	A	FITTING A 4-JAW CHUCK	CHUCK INSTALLATION
CHUCKS	MURDOCH	245	42	P	L	2ND CHUCK KEY FOR A MYFORD	LONGER CHUCK KEY
CHUCKS	HOWETT	248	30	P	A	USES FOR OLD DRILL CHUCKS	POWER DRILL CHUCK
CHUCKS	HINCKLEY	248	52	M	A	CHUCK FIXINGS	EASIER CHANGING
CLAMPING	HANSEN	248	41	C	A	LARGE WORK MILLING CLAMPS	LARGE WORK CLAMPS
CLEANING	WYATT	246	52	M	A	ULTRASONIC CLEANING	ALLENDALE TANKS
CLEANING	MATTHEWS	248	55	M	L	U/SONIC CLEANING TANK TIP	SMALLER ITEMS
CNC	BOWMAN	237	57	P	A	CNC IN THE WORKSHOP 19	M/CYCLE FORK FRAME
CNC	BOWMAN	238	33	P	A	CNC IN THE WORKSHOP 20	TACKLING 3D PARTS
CNC	REEVE	238	64	P	A	LOFTED SOLID TO CYLINDER HEAD 3	PART MODIFIED
CNC	RODGERSON	240	62	M	A	18 MONTHS WITH A TORMACH 1	18 MONTHS EXPERIENCE
CNC	RODGERSON	241	28	M	A	18 MONTHS WITH A TORMACH 2	18 MONTHS EXPERIENCE
CNC	BUNT	242	62	P	A	CNC WITHOUT NUMBERS	GENERATING G CODE
CNC	BOWMAN	245	9	P	A	CNC IN THE WORKSHOP 21	ODD SHAPED ITEMS
DIVIDING	HILLS	242	30	P	A	DIGITAL DIVIDING IN THE LATHE	DIGITAL DIVIDING DEVICE
DIVIDING	MANDREL	244	58	P	C	A SMALL DIVIDING HEAD	EDGAR WESTBURY DESIGN
DIVIDING	FIRTH	247	37	P	A	MAKING DIVISION PLATES	CUSTOM PLATES
ELECTRICAL	BROWN	242	60	S	A	SINGLE TO 3 PHASE CONVERTER	THREE PHASE CONVERTER
ELECTRICAL	FLETCHER	244	17	S	A	SINGLE PHASE MOTORS	REVERSING MOTORS
ELECTRONIC	GABEL	240	52	P	A	AN ELECTRONIC LEAD SCREW	ELECTRONIC METHOD
ELECTRONICS	EDWARDS	239	20	M	A	PLAYING A PICCOLO	ARDUINO PROJECTS
ETCHING	HAGON	242	14	M	P	PHOTO ETCHING 1	PHOTO ETCHING 1
ETCHING	HAGON	243	68	M	P	PHOTO ETCHING 2	PHOTO ETCHING 2
EXHIBITION	WYATT	240	18	M	A	MANCHESTER SHOW 2016	MANCHESTER EXHIBITION
EXHIBITION	WYATT	243	29	M	A	DONCASTER 2016	NMEX IN IT'S NEW HOME
EXHIBITION	WYATT	247	59	M	A	MODEL EXHIBITION 2016	BROOKLANDS 2016
FILING	MANDREL	237	55	P	A	FILING BUTTONS	EASY BUTTON FORMING
FILING	BAILEY	242	61	C	A	LATHE MOUNTED FILING REST	TWO HOLE FILING REST
FORMING	BOWMAN	241	67	C	A	EXHAUST CONES	EXHAUST CONES
FORMING	SLINGGERLAND	248	54	M	L	EXHAUST CONE DIMENSION	REVISED CALCULATION
GEARS	ALDRIDGE	244	35	C	A	GEAR CUTTER 1	FRAME CONSTRUCTION
GEARS	ALDRIDGE	245	53	C	A	GEAR CUTTER 2	ROTARY TABLE
GEARS	ALDRIDGE	246	55	C	A	GEAR CUTTER 3	ASSEMBLY & USE
GEARS	ALDRIDGE	247	46	C	A	GEAR CUTTER 3	CUTTER HEAD DRIVE
GEARS	ALDRIDGE	248	46	M	A	GEAR CUTTER 4	PULLEY & TOOLING
GRINDING	NOEL	242	52	P	A	VERSATILE GRINDER FROM SCRAP	GRINDER FROM SCRAP
GRINDING	COX	247	17	C	A	DIAMOND DISC GRINDER	CARBIDE TOOOLING
HOROLOGY	HICKS	237	69	C	A	THREE JAW CHUCK MOUNT	NON-STANDARD CHUCK
HOROLOGY	HICKS	239	30	C	A	A SPRING LET DOWN TOOL	MAINSPRING UNWIND TOOL
HOROLOGY	BUNT	240	20	C	A	CLOCK PILLAR HOLDING DEVICE	HOLDING LONG SLIM WORK
INDEX	CHAMBERLAIN	238	37	M	A	INDEX FOR ISSUES 225 TO 236	INDEX FOR ISSUES 225 TO 236
INST/SERV	SALTER	238	9	P	A	IMPROVED MYFORD SUPER 7	VARIOUS IMPROVEMENTS
INST/SERV	HILLS	238	14	P	A	SOUTH BEND LATHE DRO FIT	SOUTH BEND DRO MOD
INST/SERV	WAIN	238	57	C	A	BENCH DRILL ADAPTED TO MILLING	FINE FEED MODIFICATION
INST/SERV	HALL	239	34	M	A	MILL SLIDE AND TABLE PROTECTION	SLIDE PROTECTORS
INST/SERV	MOIGNARD	239	55	M	L	CURING LATHE VIBRATION	WORN BELT REPLACED
INST/SERV	GARNISH	239	55	M	L	TOOL HEIGHT ADJUSTMENT	TOPSLIDE MILLED
INST/SERV	WAIN	240	24	C	A	HOBBYMAT MD65 ACCESSORY BASE	ACCESSORY BASE UPDATE
INST/SERV	BISHOP	240	27	P	A	SUPER SEVEN STAND	SUPER SEVEN STAND SET UP
INST/SERV	DARVENIZA	240	34	C	A	A SIMPLE CHUCK BACK STOP	REPEAT JOB SETTING
INST/SERV	INCHAGA	240	60	P	A	RF-25 MILL MODIFICATIONS	ADJUSTABLE INDEX DIAL
INST/SERV	LEONARD	241	46	P	A	MODS TO A DRILL PRESS	REDUCUNG QUILL PLAY
INST/SERV	STEVENSON	241	64	P	A	TALES FOM BODGER'S LODGE	LATHE BED WIPERS
INST/SERV	SHRIMPTON	242	44	C	A	MARLOW MILL PWR FEED 1	POWER FEED UPDATE 1
INST/SERV	SHAW	243	12	P	A	EXTENDING A BENCH DRILL	INCREASING CAPACITY
INST/SERV	SHRIMPTON	243	16	C	A	MARLOW MILL PWR FEED 2	POWER FEED UPDATE 2
INST/SERV	WINWOOD	243	22	P	A	THE SEIG X2P HI-TORQUE MILL	UPRATING SEIG X2P MILL
INST/SERV	COX	244	45	C	A	FIXED COLUMN FOR AN X1 MILL	INCREASED HEADROOM
INST/SERV	REID	244	53	M	A	ONE MAN AND HIS LATHE	SOUTHBEND & BOXFORD

INST/SERV	LEWIS	244	65	P	A	FIXING A FIXED STEADY	REMEDIAL WORK
INST/SERV	THOMAS	244	66	C	A	IMPROVED WORDEN GUARD	DUST REDUCTION COVER
INST/SERV	HEARSUM	245	45	C	A	DRUMMOND M LATHE EXTENSION	LATHE BED EXTENSION
INST/SERV	BUNT	246	28	C	A	ROTARY TABLE PLATE	SHERLINE ROTARY TABLE
INST/SERV	SINCLAIR	247	9	C	A	FINE LEAD SCREW CONTROL	PRECISE ADJUSTMENT
INST/SERV	INCHAGA	247	22	P	A	MYFORD 7 LATHE MODS 1	TAILSTOCK MODS
INST/SERV	WOOD	247	28	P	A	BANDSAW OVERHAUL	BANDSAW MODS
INST/SERV	INCHAGA	248	13	P	A	MYFORD 7 LATHE MODS 2	SURFACE/BED WEAR
INST/SERV	SHAW	248	32	P	A	POWERED SADDLE CRASH	BENT FLANGE
M/C REVIEW	WYATT	245	24	M	A	MACHINE MART - CLARKE DRILLS	CLARKE DRILLS
MARKING	KILDE	244	25	C	A	TWIST AND PUNCH	OPTICAL CENTRE PUNCH
MEASURING	FRAMPTON	237	52	P	A	AN ENGINEER'S TEE-SQUARE	WORKSHOP AID
MEASURING	CLARK	238	42	M	L	DETERMINING PCD	FINDING PCDS QUICKLY
MEASURING	WORDEN	246	36	S	A	SCREWMEZ	MEASURE THREADS
MEASURING	WYATT	248	24	S	A	DIGITAL CALIPER REVIEW	COMPARISONS
MILLING	ADAMSON	237	9	C	A	SACRIFICIAL ROTARY WORK TABLE	HOLDING LARGER WORK
MILLING	AYRES	238	44	P	A	FLAT BELT FRANKENSTEIN	CUSTOM MILL/DRILL
MILLING	MILLER	239	24	P	A	ROTARY TABLE STOPS	ROTARY TABLE ACCURACY
MILLING	STRATTON	239	27	P	A	MILLING MACHINE PWR DRAWBAR	REMOTE DRAWBAR SYSTEM
MILLING	PIDDINGTON	240	42	P	A	MILLING IDENTICAL LENGTHS	NOVICE MILL USER TIPS
MILLING	PACE	241	56	C	A	LATHE MILLED LEADSCREWS 1	MILLING SPINDLE 1
MILLING	PACE	242	34	C	A	LATHE MILLED LEADSCREWS 2	MILLING SPINDLE 2
MILLING	GREEN	243	9	P	A	CASTINGS FROM SOLID	SIMULATED CASTINGS
MILLING	PACE	243	52	C	A	LATHE MILLED LEADSCREWS 3	MILLING SPINDLE 3
MILLING	SMITH	244	23	P	A	MACHINING SQUARES	USING AN ANGLE GAUGE
MILLING	GABEL	246	35	P	A	MILLING TABLE ALIGNMENT	ALIGNMENT BLOCKS
MISC	CHUCK	237	46	M	A	KEEPING WARM IN THE WORKSHOP	LIGHT ENTERTAINMENT
MISC	GORDON	237	48	P	A	MAKING PARALLELS	HANDY ACCESSORIES
MISC	JENNING	238	46	M	A	SMART PHONE IN THE W/SHOP	EXPLORING APPLICATIONS
MISC	JOLLIFFE	240	40	M	L	CENTERING CASTINGS IN THE LATHE	TURNING CASTINGS
MISC	JOHNSON	241	13	P	A	CAMERA FOR A DISABLED USE	ONE HANDED OPERATION
MISC	JOLLIFFE	243	42	P	A	SOME PRACTICAL HINTS	DRILL DEPTH STOP
MISC	MURDOCH	243	51	M	L	SET BUTTONS ON PCD	ALIGNMENT TIP
MISC	JENNINGS	244	12	P	A	SWING OUT MAGNIFIER	MAGNIFIER ARM
MISC	JENKINS	245	28	C	A	A LAMMAS HARDNESS TESTER	HARDNESS TESTER
MISC	BROMILOW	245	59	C	A	OUT OF THE FRYING PAN	FRYING PAN REPAIR
MISC	BESTER	246	38	M	A	NO LIMITS: GEORG SCHLESINGER	PROD ENG PIONEER
MISC	MILLER	247	35	M	L	LAMMAS HARDNESS TESTER	PRACTICAL EXPERIENCE
MISC	WAIN	247	68	C	A	HOBBY LATHE LIGHT	BETTER LIGHTING
MISC	SMITH	248	9	P	A	REPLICATED GWR NAMEPLATE	DIY NAMEPLATES
MISC	CROASDALE	248	56	M	L	CAMERA MOD	TRIPOD MOUNT
MISC	KING	242	24	M	A	GUIDE TO DIGITAL READOUTS	A BEGINNER'S GUIDE
PLANS	WYATT	239	37	C	A	FREE PLAN: A BORING HEAD	FULL DRWING SET
PLANS	WYATT	239	46	C	A	A MICROMETER BORING HEAD	COMPLETE INSTRUCTIONS
POWER TRAN	WRAIGHT	237	14	C	A	MYFORD POWER CROSS SLIDE 2	MOTORISED OPTION
POWER TRAN	WRAIGHT	238	50	C	A	MYFORD POWER CROSS SLIDE 3	WIRING INSTALLATION
POWER TRAN	HAUGHTON	246	12	C	A	POLY-V BELTS AND PULLEYS	CONSTRUCTING PULLEYS
POWER TRAN	GABEL	246	45	P	A	LATHE CROSS SLIDE DRIVE	STEPPER DRIVE
POWER TRAN	CRAMMOND	246	69	P	A	CHESTER CHAMPION DOWNFEED	PWR DOWNFEED ADDED
PRESSES	ASTBURY	238	42	P	L	PUNCHING HOLES IN ALUMINIUM	FORCE & HOLE SIZE
PRESSES	McKEOWN	239	64	S	A	USING AN ARBOR PRESS	PRESS SET UP
READERS' TIPS	GARNISH	237	25	M	Q	TAPPING WITH TAILSTOCK FEED	MAINTAINING TENSION
READERS' TIPS	BURNS	237	25	M	Q	TOOLPOST LOCKING TORQUE	USE OF THRUST WASHER
READERS' TIPS	SHAW	238	32	M	Q	HUMIDIFIER OVERFLOW PIPE	DRAINING OVERFLOW
READERS' TIPS	HILTON	239	12	M	Q	ENGINEER'S BLUE V MARKER PEN	MARKING OUT OPTION
READERS' TIPS	MANNERS	239	12	M	Q	TIDIER WORKSHOP TIPS	STORAGE SOLUTIONS
READERS' TIPS	VARLEY	240	12	M	Q	ROUND COLUMN MILL ALIGNMENT	LASER ALIGNMENT DEVICE
READERS' TIPS	HOWELLS	240	12	M	Q	RAPID MILL VICE SETTING	VICE SETTING AID
READERS' TIPS	DAWES	241	26	M	Q	SIMPLE SCREW SHORTENING	USING A PIERCING SAW
READERS' TIPS	FLETCHER	241	26	M	Q	TAPS AND DIE STORAGE	TAP & DRILL HOLDER
READERS' TIPS	ALLEN	242	28	M	Q	PRECISION VICE CLAMPING	PRECISION CLAMPING
READERS' TIPS	MATTHEWS	242	28	M	Q	CLEAN UP	CLEANSING TIPS
READERS' TIPS	BARCZI	243	60	M	Q	NOVEL PARALLELS	USING TOOL STEEL BAR
READERS' TIPS	YEOMAN	243	60	M	Q	THREAD GAUGE	INEXPENSIVE GAUGE
READERS' TIPS	ROBINSON	244	62	M	Q	EASIER MILL VICE OPERATION	USING SMALL HANDLE
READERS' TIPS	NYE	245	35	M	Q	SIMPLE DIVIDING	EASY DIVIDING METHOD
READERS' TIPS	SPEDDING	246	32	M	Q	SWARF GUARD FRICTION HINGE	MAKING A SWARF GUARD
READERS' TIPS	WOOD	246	32	M	Q	SPEEDY FORM TOOL	CORNER ROUNDING TOOL
READERS' TIPS	GORDON	247	45	M	Q	EASY HEX MAKING	CUSTOM BOLT HEADS
READERS' TIPS	CHAMBERLAIN	247	45	M	Q	SADDLE CLAMP SCREW	KNUCKLE SAVER
READERS' TIPS	THEASBY	248	28	M	Q	UNUSUAL ALUMINIUM SOURCE	ALUMINIUM BAR
READERS' TIPS	MIDDLEYARD	248	28	M	Q	SLACK QUILL CURE	OPTION TO SHIMMING
REVIEW M/C	WHITE	241	35	M	A	AMADEAL AMAT25LV MILL	AN IN DEPTH REVIEW
SANDING	KILDE	248	65	C	A	LATHE MINIATURE BELT SANDER	LATHE BELT SANDER
SAWING	MANDREL	238	20	P	A	BANDSAW IMPROVEMENTS	WORKHOLDING MODS
SAWING	NOEL	239	61	P	A	CARVERSAW CONVERSION	HANDY POWER SAW
SAWING	CHECKLEY	241	18	C	A	A SLITTING SAW ARBOR	USEFUL SLITTING TOOL
SHARPENING	MAUREL	245	17	S	A	DRILL SHARPENING 1	CUTTING FACES
SHARPENING	ASHTON	245	36	C	A	ACUTE SHARPENER 1	ASSEMBLING THE KIT
SHARPENING	LEONARD	245	65	C	A	WORDEN MODIFICATIONS	WORDEN IMPROVEMENTS
SHARPENING	ASHTON	246	19	C	A	ACUTE SHARPENER 2	USEFUL ASSEMBLY JIGS
SHARPENING	MAUREL	246	64	C	A	DRILL SHARPENING 2	SHARPENING JIGS
SHARPENING	DINIZ	247	52	M	A	SHARPENING TECHNIQUES	SHARPENING CHISELS

INDEX BY AUTHOR, SUBJECT, ISSUE AND PAGE NUMBER

Credits

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A Simple Tailstock Depth Readout

Paul Tiney takes a wry look at making a useful gadget.

Problem: I was unable to tell how deep I had drilled when using the tailstock.
Cause: Tailstock quill does not have any graduation marks on it.
Solution: Make something!

Materials

- Bit of scrap metal strip. "Now young Paul, a "bit" is a thing that goes in a horse's mouth. You mean a piece". (Ah, how the voice of my old apprentice supervisor echoes down the years.)
- Terrys spring tool clip. Other makes may be available but to me all things "springy" are made by Terrys, anything to do with holes is by Dormer, and all lathe chucks are called Bernard (sic)
- One pop rivet (two if you make a mistake)

Tools

- Rivet pliers.
- Drill bit. (smug look appears on young Paul's face)
- Scriber.
- Steel Ruler. "A ruler is monarch, you mean a rule". (smug look fades)

The tools and materials

Method

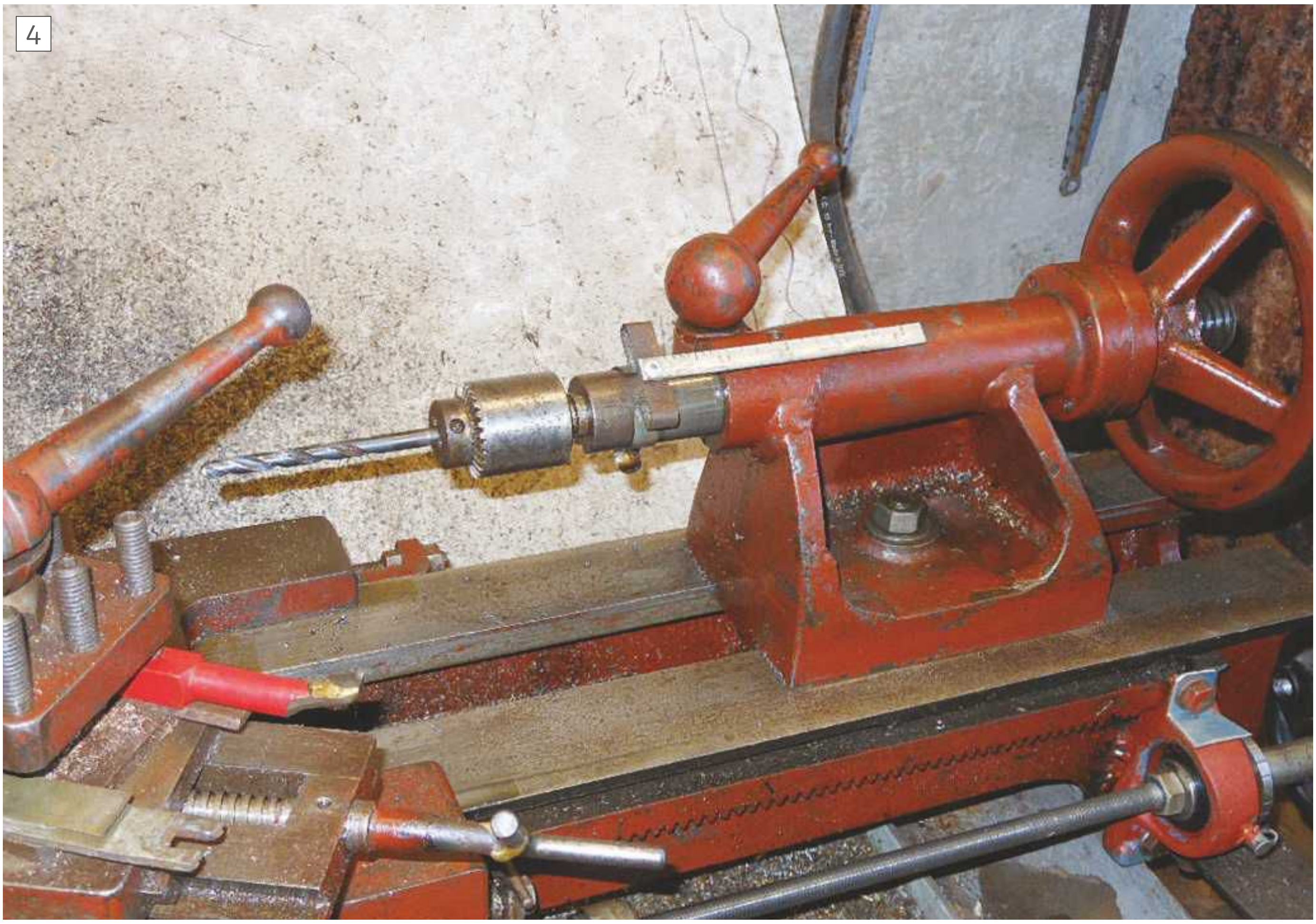
Make sure the tool clip is a nice fit on the tailstock quill. When satisfied that it is, neatly drill a hole through the end of the metal strip using the handy screw hole in the tool clip as a guide. Now rivet the clip and metal strip together. Butt the zero end of the steel rule against the edge of the clip and transfer the graduations to the metal strip using a scriber. Having done that you can now make the transferred scribed lines more distinct and even number them. With thoughts of grandmothers and eggs I know you will have your own methods.

How it is used.

Clip the "instrument" in place. Whizz the tailstock along the bed and clamp it. Extend the tailstock quill until the drill is just touching the work. Slide the clip up the quill until it hard against the body of the tailstock. This is the "zero" position. Now as

Ready for graduations

How to set the zero point for graduating



4

Finished scale attached to the lathe

the drill goes progressively deeper into the work the clip remains on, and moves with, the quill. The edge of the tailstock body indicates against the graduation marks on the metal strip how deep the drill has gone. Simple and yes, crude.

Comments

It isn't very accurate - correct, it is only as accurate as the judgement of your eye, but you should have the instruments for more accurate means of measurement if you need them anyway. However, and here is the starting point for a discussion, you only need to be as accurate as the job requires. By this I mean that to always work to "two tenths of a thou" when the job does not require it may demonstrate skill but not necessarily full comprehension. To the professional, money, and to the amateur, time may be wasted when there is no need. Horses for courses and gents galloping by on horseback come to mind, but am I really being too cavalier in my attitudes? (You have now exceeded your pun quota – Ed.) ■

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Content may be subject to change.

ON SALE 9 DECEMBER 2016

Gear Cutter

Alan James Aldridge describes a flexible machine for the production of gears in the home workshop – part four

Form cutters

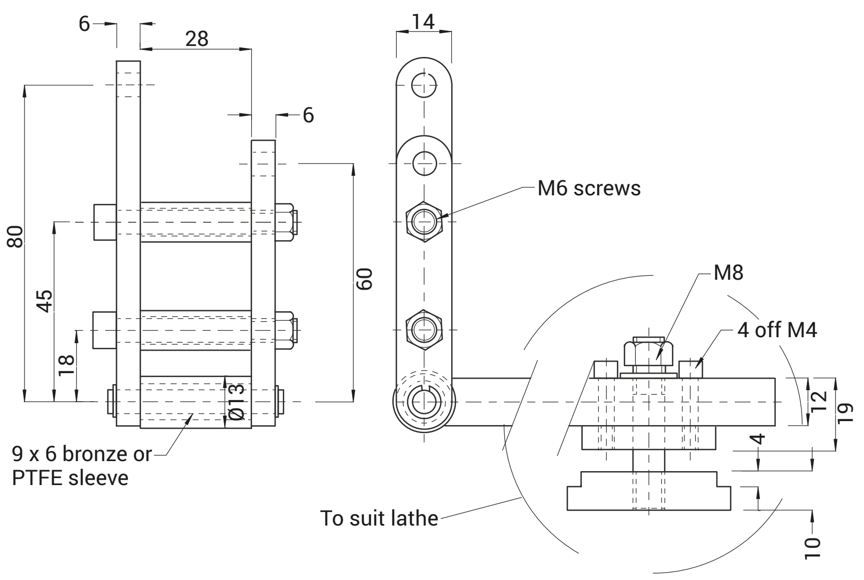
The next requirement is a shank for the form tool for shaping the teeth. This is merely a length of plain steel bar cut to a length then sawn down the middle about 25 to 30 mm long and with a sloping end. A pinch screw spans the slot, **photo 27**.

The pin holes have to be gauged from the actual 'pin heads' which are the cutters of the form tool and this information comes from the table introduced earlier. Though it might appear to be a formidable and off-putting task, it is not so. It involves selection starting with the choice of DP or module and the size of the wheel to be cut, which comes from the number of teeth required. This puts the wheel in one of the ranges of cutter size and then one can calculate the pin sizing which is purely arithmetic using basic sums. As an example, the following shows the way.

For a wheel with 36 teeth and 20 DP the table gives the cutter number as 3. The form tool diameter is given as 304.0 mm but that applies to a DP of 1.0; our wheel is 20 DP. Therefore divide
304.0/20 = 15.2 for the pin diameter;
The same applies to the other dimensions:
321.0/20 = 16.05 for pin spacing;
78.68/20 = 3.934 for the depth
101.6/20 = 5 for cutter width

With a 15 mm pin diameter there will be trouble with the pin interfering when used with the backing off tool, so it will require cutting back on the backing off tool side just ahead of the depth measurement point or the smaller pin retaining extension which fits the holes in the underlying bar. There is no need to use a pin extension approaching 15 mm, just 6 mm will do. The cut off at the front of the cutting edge has to be greater than the depth of cut figure and a general rule is to cut back the pin to give a flat edge on the diameter for a small distance on both sides of the gap then to run out at an angle and cut just clear of the retaining pin, as is shown in **photograph 27**. For smaller cutters the material is silver steel bar turned to the sizes required to make the stepped cutter pins. These are heat treated while silver soldering the pins to the shank, as there is sufficient heat that one can get small pins to red heat ready to be dipped in water. Tempering follows the same sort of route to bring the temperature up to give a yellow colouring before dipping. I make larger stepped, cutting pins in 476 alloy steel or gauge plate, both of which are hardenable. Very large pins are in plain steel with a silver steel insert as described earlier. The pins need flat tops and sharp edges. I have both a linisher and a diamond file which allows the button to be re-sharpened from time to time and leaving the cutting edges of both buttons in line. In previous articles on gear cutting two differing types of pin cutter have been shown. One of these had coned cutters sitting in drilled holes on a flat bar. I do not see how this works as re-grinding of the cones would alter the gap between the cutter pins, whereas the plain cylindrical pin set at an angle would still have the same gap after sharpening and just requires resetting for centre height in the toolpost.

Fig.17



Gear Cutter Duplex Tooling 2 Linkages

The pins have to be spaced as closely as possible to the dimension given in the table. Drilling the holes exactly on the measurements given is an unlikely event on the smaller gears and larger DPs, so the spacing is controlled by the split shank and the cross shank screw. As this screw only works in one way, the error when drilling the holes has to be on the wide side, say 0.25 mm too wide. Setting the gap is achieved using feeler gauges.

Of the four dimensions needed for making cutters, the depth of cut may appear somewhat difficult to achieve as there is no immediate and obvious datum point from which to measure off. The round cutter blank has to be to width with the leading edge square to the sides. The pin cutter is sat in the toolpost on centre height and brought to the blank so the pins touch both sides of the leading edge of the blank, then one can go back to the table for the depth of cut and proceed to shape the blank. For the lighter and thinner cutters the same processes apply, as long as the end is thinned as previously suggested. Rough checks can be made, but these require a mating gearwheel of the same DP or module, and this almost certainly needs to be the bigger of the two wheels. It is not necessary to retract the tool, just offer up the bigger wheel to the cutter and see how close the fit is. Another check is to carefully measure the width of the tip of a tooth on the cutter and compare that to another wheel.

There are other dimensions which can be found in books on gearing, such as dedendum and addendum, working depth, profile shift and many more. Except for the latter all of these have been taken care of in the tables presented, which, if followed, will provide good meshing gears with long life. It is as well to note that single tooth cutting, which these tables will work for, does not give as good a mesh or running characteristics as hobbed gears and should only be used for light work at high speeds. I think one can appreciate these remarks in the light of the span of gear tooth numbers for each cutter provided. For instance, Cutter 3 covers 35 to 54 teeth; only one tooth number, presumably 45, will be accurate, the others will be slightly less so.

Backing Off Tools

In much the same way as the normal lathe tool requires its edges to be given clearances, the form tool cutter will need some way of being shaped so it too will only cut on the leading edges. It needs a backing off tool set up, of which I have two, the first from Duplex, (Ian Bradley and Norman Hallows) and the other is the Eureka which was described some 40 years later by Prof Chaddock and Ivan Law. The Eureka and Duplex appear completely different from each other but I do not think there is too much difference between them when at work except the Duplex attachment cuts one tooth at a time; the Eureka attachment is self advancing.. The manufacture of them cannot be compared though; they are very different. In both there is a rocking motion derived from a prime mover, like the lathe, which is adjusted to cut just one tooth at a time, stopping and reversing so as not to run into the next tooth on a cutter. The Eureka is very much more compact than the Duplex but the latter is possibly, more easily understood as everything is on view and spread out. The Eureka's workings are partially hidden by the construction and if one makes it then take time over the drawn ratchet pawls, which did not quite operate as required and needed a lot of ticklish hand work to make them do so.

The Duplex Tool

The Duplex attachment for the lathe may look from the photograph as a fairly straight forward piece of equipment with very open dimensions and without much in the way of the unusual. Unfortunately, that is not the case as there are some critical operations to be done to end up with the correct settings for backing off. Figure 16 is my metric re-drawing of the Duplex design.

In both Duplex and Eureka, the positioning of two centres on the main shafting has to be carefully plotted and machined and does not allow for error or misalignment end to end of the shaft. The actual dimension is not that critical and cannot be easily obtained. In any case, what is required is that the centres are parallel to the lathe line. If one has a height gauge this will be fulfil all that is necessary. One can also place the rough machined round shaft on Vee blocks and then scribe the centres. For the Duplex I chose another route, starting with a 20 mm square bar. It does not, I think, have to be bright steel bar but that is what I selected. Plotting the centres then becomes quite easy.

The next difficulty is accurately converting them into popped centres. The two centres are 2.5 mm apart (a convenient dimension), which does not leave much in the way of room for a good size centre. In fact, these centre holes are simple drillings of 2 mm only without the usual countersink shape. The bar is machined down to the drawings using the correct set of centres for the end and middle sections. Keyways are necessary for the holding of the form cutters being machined, which adds some further work but with gear cutting comes key cutting!

Form tool shank, with adjusting screw

The shaft or cutter arbor, as Duplex called it, sits between an eccentric grouping and the tailstock of the lathe. The eccentric group comprises an adapter which sits in the three jaw chuck and carries an eccentric mechanism that drives a link which in turn drives back to the arbor. This arrangement allows the lathe to run at normal speed but the arbor only rocks back and forth a small amount which one can adjust to completely cut a gear tooth to specification and then back off that tooth without interfering with successive teeth. The action requires two links, a common pin or axle which is held in a base plate which, in turn, is held to the lathe bed and the return motion link picks up an eccentric arm which is a separate part that is clamped to the arbor. Duplex made his arbor with one of the arms solid to the shaft but as one has to be set with an angle of 15 degrees I think it is far easier to have a loose arm that can be clamped to the given angle. At the other end of the arbor is a second arm similar to the first that does a very different job. It has a 3 mm pin which engages the ring of holes drilled in the gear blank, one by one. There is also clamping nut and some spacers or washers which will hold the cutter hard up to the arm during the cutting and backing off processes. On my arbor one will see there is also a large diameter thread which was to be part of the hobbing backing off system.

The drive from eccentric rotation to oscillation of the shaft is through a pair of ganged links sitting on a platform which bridges the lathe bed. **Figure 17** shows the typical unit which will require some alteration here and there to suit any particular lathe. On mine the original flat plate had to be discarded for something to sit on the Vee bed of a new lathe. The cross slide must have stops so the cutting tool only advances so far. On my lathe this has been needed before for other work and consists of a pair of hangers to the rear of the saddle, a cross shaft and two adjustable blocks that come to a stop on the lathe bedways. The through pins are hardened and run in bronze bushes. The need for a bronze or other bearing material for the rocking links is merely a personal choice but I would think a lubricated pin is essential. The three clevises are relatively simple machining of square steel barstock. The fourth connection for the links is a plain thread tapped into the eccentric.

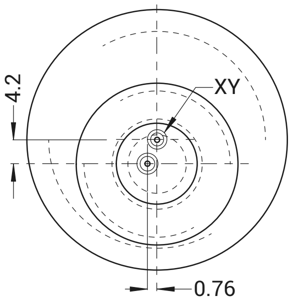
Photograph 28 shows the attachment at work and I hope it is fairly obvious what is happening. What is not quite so obvious is the need for a key and large diameter centre piece to the arbor; this is for future hob backing off.

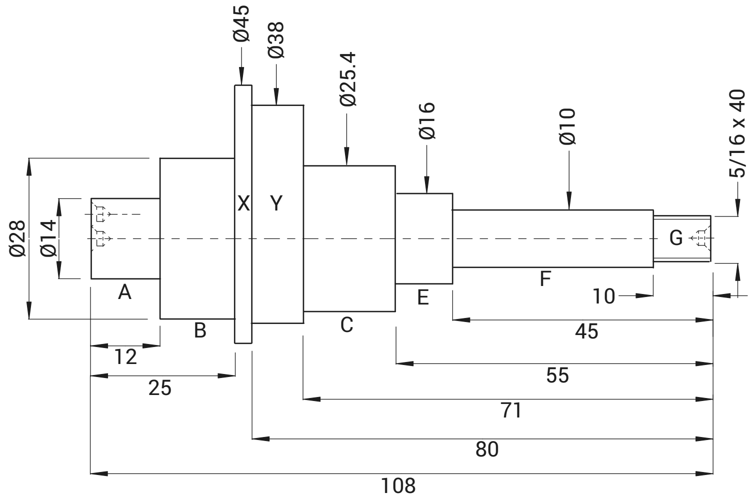
The cutter which does the backing off is the same cutter made for the initial shaping, set up exactly as before, including alignments of the tooling. Cutting with the Duplex is simply a matter of feeding the cutter into the oscillating gear tooth and, at first the distance travelled has to be adjusted with hand rocking operations of the cutter blank. Once the length of cut is fixed we can progress to machine operation. The decrease in number of teeth in a cutting wheel aims to reduce the adjusting effort, giving the cutter plenty of room for an over-cutting stroke. It now only remains to feed the cutter into the tooth being

Fig.18

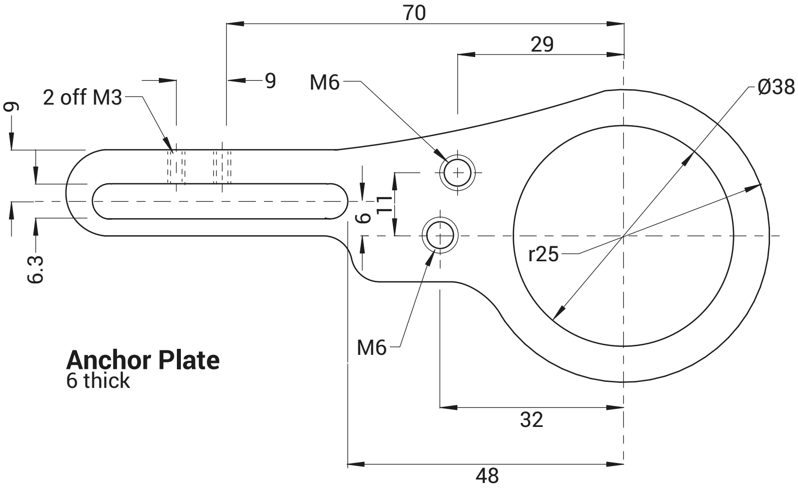
Eureka Backing Off Attachment

Original design by Ivan Law and Dennis Chaddock, redrawn with metric dimensions by Alan Aldridge

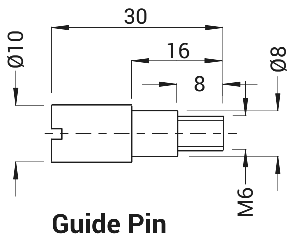




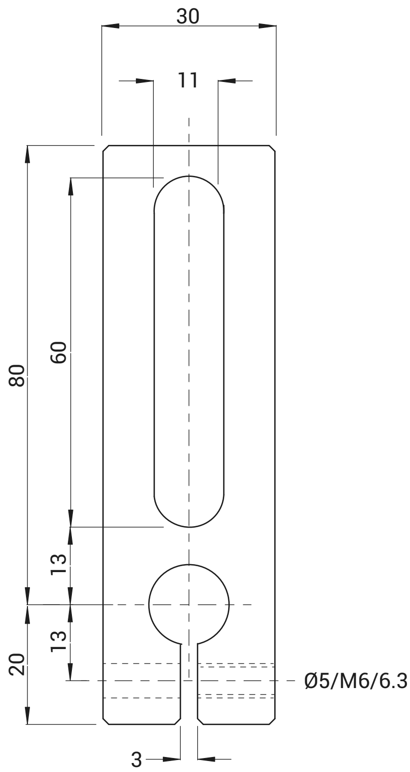
Mandrel



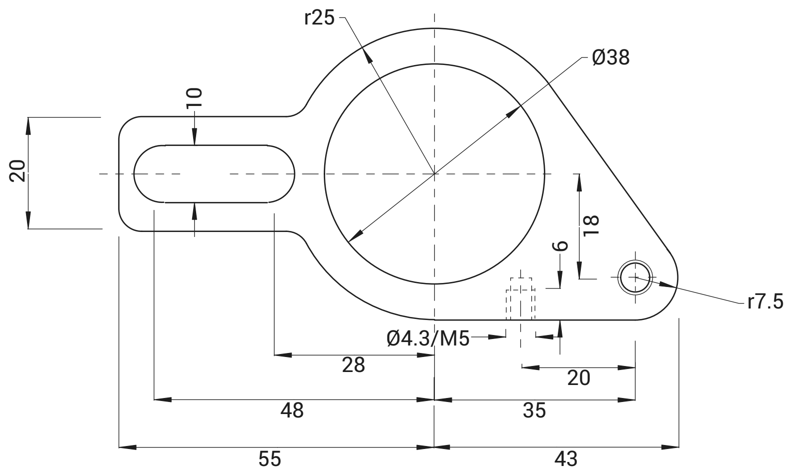
Anchor Plate
6 thick



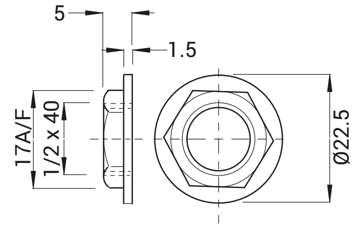
Guide Pin



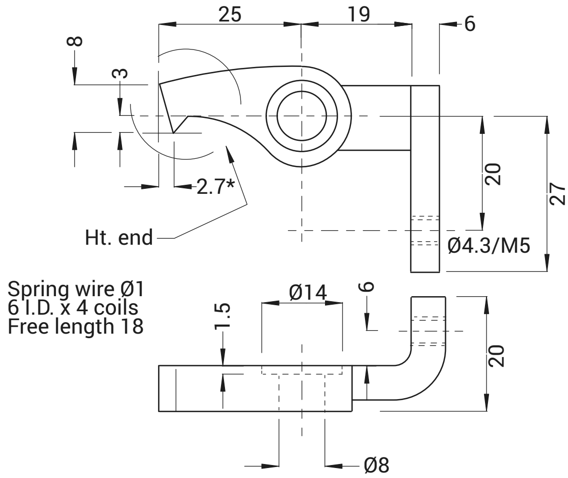
Drive Arm



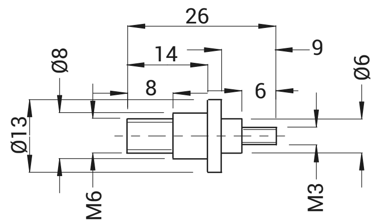
Ratchet Plate
6 thick



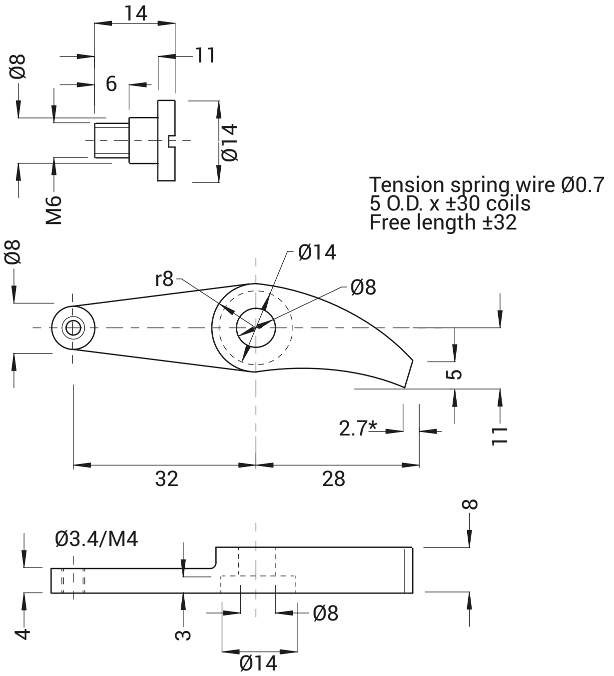
Clamping Nut

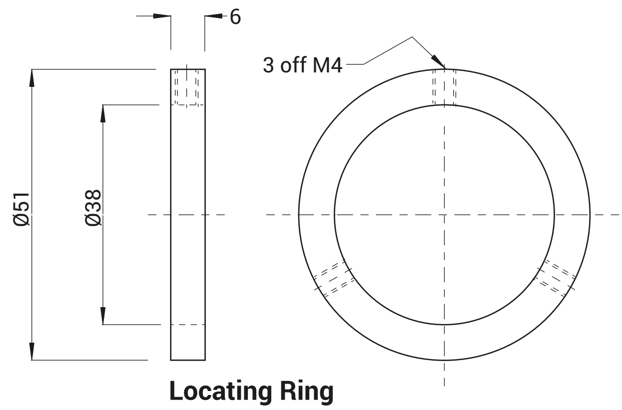


Ratchet Pawl

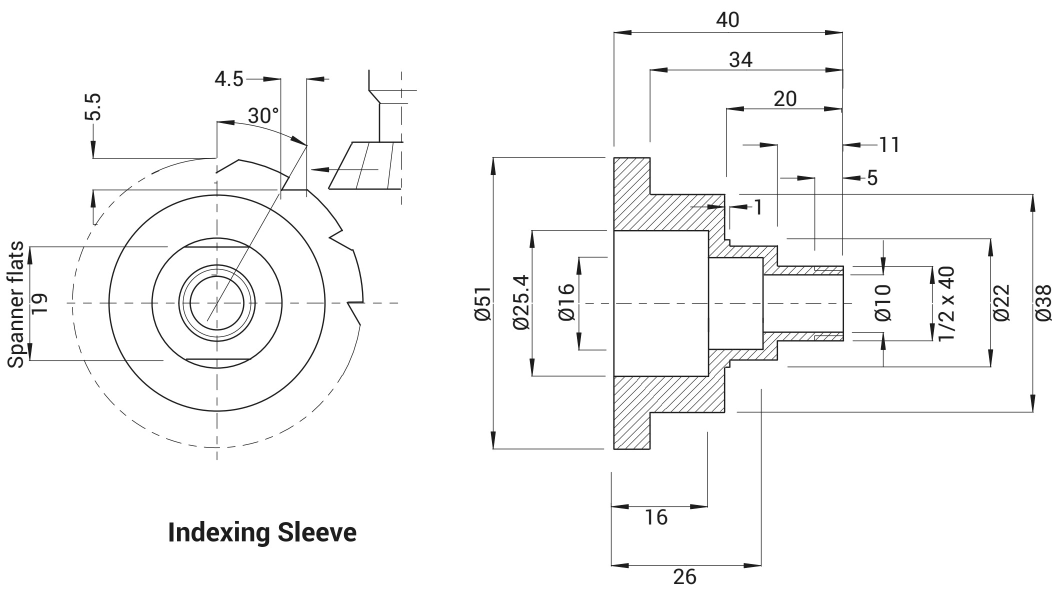


Pawl Pivot Pin





Locating Ring



Indexing Sleeve

backed off for which I paint the tooth in marker pen ink. As backing off proceeds the colour disappears and when the last dot at the extreme end goes – stop.

Eureka Attachment

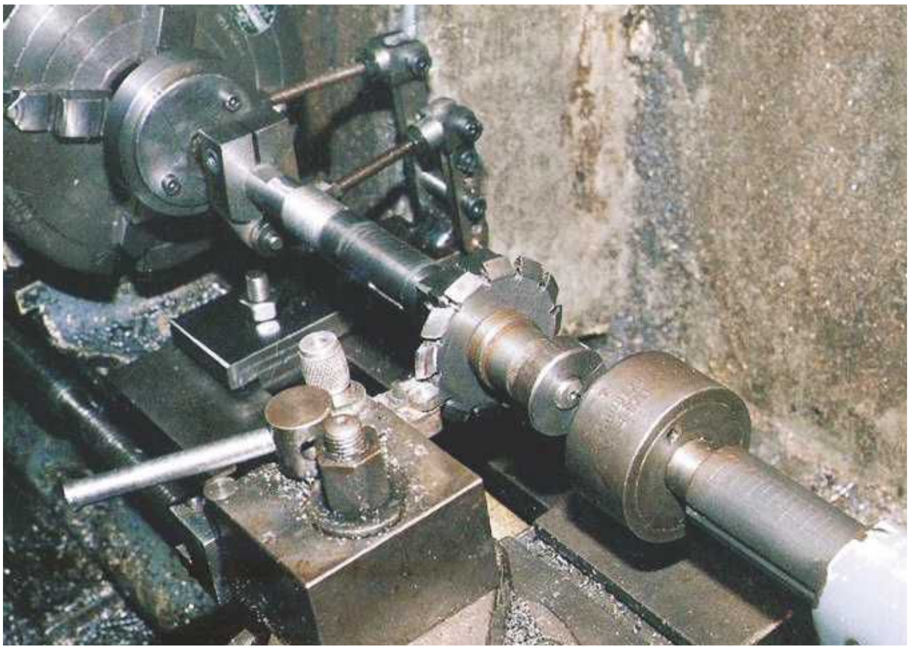
Though it does not appear to be so, the Eureka backing off cutter has much the same operating principle to the Duplex attachment but with two extra features. It is both smaller and self advancing as the mechanism includes a ratchet and pawls, **photo 29**. Cutting ratchets is not difficult and does not require a milling machine, they can be made with the shaft and ratchet held in the divider and toolpost or a similar arrangement as already seen and described, but the stepping of the teeth must be very accurate.

The drawings, **fig. 18**, are not quite the same as the original article of March 1987 (Ivan Law has kindly given permission for us to reproduce Alan's metric redraughting of the Eureka – Ed.). With respect to the pawls the drawing shows the ones I made after failing to get the originals correct. There is not much to choose between them but, and it is a big but, these items need to be hand worked with regular checking of the working assembly, which is tiresome but necessary to get the best out of the mechanism. I failed to get what I wanted from the bent wire springs and opted to use coil tension springs instead.

In the drawing of the mandrel one has all the worst challenges of the mechanism which consists of getting three centres into a single piece of equipment. On the mandrel drawing the cylindrical parts A to G lie on the "normal" centre line though there is no actual centre at either end for these items. Nor is there a centre for the two larger diameters X and Y. The only centre is the one which offsets everything to one side by a small amount, 0.76 mm. Finding, marking and drilling this one centre at each end is, as the original article suggested, 'tricky'. The mandrel as built by myself is also longer as I had a specialised use for the tool which we will come to.

Mandrel Machining

The starting point is a piece of 50 mm square bar. I have not used specialised grades but merely the normal En3A bar found at most suppliers. The amount of use this tool will see does not warrant hear treatment and special grades of steel. That is a personal opinion, of course, with which you can disagree and use better materials. The bar length is about 140/150 mm long which is sat in the four jaw chuck with at least 110 mm showing beyond the chuck. It is now possible to machine the parts X and Y to their correct diameter and widths. The square end will be found easier than starting with a round bar, for manipulating the bar to gain the correct offsets, combined with a good jaw purchase. That is, the square can be aligned to the lathe bed with bar sides perpendicular to the bed. By subtraction Y is 3 mm wide. The bar can now be dropped down in the top and bottom jaws by approximately 4.2 mm. At this stage precision is not necessary, that will come once we have a handle on the offset where we can actually measure the dimension. The easier end to machine first is the long one and one can reduce the long slender end without a centre supporting the end and without getting into trouble with relatively high feeds and feeds until the last millimetre of two are to be removed. The parts A and B are a little more difficult, as one will be working in a shorter and closed off space which really requires left and right hand cutting tools. The process is to cut down the area first to around 35 mm diameter, test for the offset at C with the square bar lying square to the lathe bed, which will duplicate the original alignment of X and Y. Once C is to the correct diameter the remaining diameters and lengths can be readily machined to good finishes and sizes. The parts that will sit on the mandrel should be made to fit it with the right clearances, which, by and large, are the model engineer's traditional one thou.



The Duplex backing off tool in use

The positioning of the centre at 0.76 mm off the true centre line needs some thought. The one marked XY on the drawing does not actually exist, yet we need to position the 0.76mm off set centre to it. Once again the reasoning behind the use of a square block comes to the fore. We have two sets of parallel lines from which to work, regardless that the block itself is not machined. The centres give the rocking action and I cannot think that a fraction up or down really matters, but getting them reasonably exact on the same axis does. A height gauge is a necessity. One of those centre pops with a magnifier would be nice as hand working is hardly accurate enough. I toyed with using toolmaker's buttons which are a constant resource for setting out centres, but for the mandrel it is necessary to be close to exact with the initial siting of the locking screw to make that process successful, which requires precision work with a centre pop, which brings us back to finding a centre. In the end I employed a bright light, a thin, long pointed pop and a lot of patience to get the markings at each end. Make sure that the siting of the centres as seen from the end A is to the left. Of course, the centre at the A end is in the square and not in the main body of the mandrel. Once the pop mark is in the mandrel can be reversed in the jaws to pick up square end again and the pop marking. The conventional centring process has to be modified, the square is brought to align with the tailstock mounted centre drill of any size and then the jaws are clamped up to lock the position. A normal drill , say 3 mm, is drilled in to the block followed by progressive drills to 10 mm and to a depth that will just be short of the mandrel proper. The final cut is with a 12 mm end mill that will cut into the mandrel to provide a flat bottom for the next centre drill to penetrated dead on line. Cut off the remains of the square end and dress, just skimming the centre hole.

Remaining Parts

The parts fitted on the mandrel in the most part are straight forward drill, saw and mill exercises. The anchor and ratchet plates have to have exact slots and bores which can be matched to the mandrel and indexing sleeve which are tested by hand with a little oil present. On my indexing sleeve to mandrel there is pronounced plop as the two are parted from each other which is the sort of fit I would look for.

The not so straight forward parts are the ratchet on the indexing sleeve and the pawls. The ratchet is not a standard form and at first I felt it would not serve its purpose but it is all right. The cutting of the vee requires some care in preliminary setting up. Once that is done then the indexing is 30 degrees each time to give the twelve teeth. It will obviously depend on what dividing tools one has in the drawer as to how one should proceed. The ratchet tooth numbers must match the actual gear form tool tooth number. The system shown requires a dovetail milling cutter dropped down from the ratchet outer diameter by 5.5 mm and set with stops to cut 4.5 mm into the circle.

With no luck with bent wire springing, the pawls were altered by brazing on extensions front and back to orient the springing and to be better able to trim the working end to sit into the ratchet as it clicked around. Therefore my drawings of the pawls are to be treated as notional. The mandrel and indexing together with all the other parts have to be built up aiming for getting the pawl ends correct. The spring anchors are not so rigid in their requirements. Both pawls should be made from a heat treatable steel which could be a piece of tool steel. One might make a soft steel pattern that does the job, then remake the pattern with a working nose in silver steel replacing the existing one, which is obviously tiresome but far less expensive than the first route.

Cutting One's First Teeth

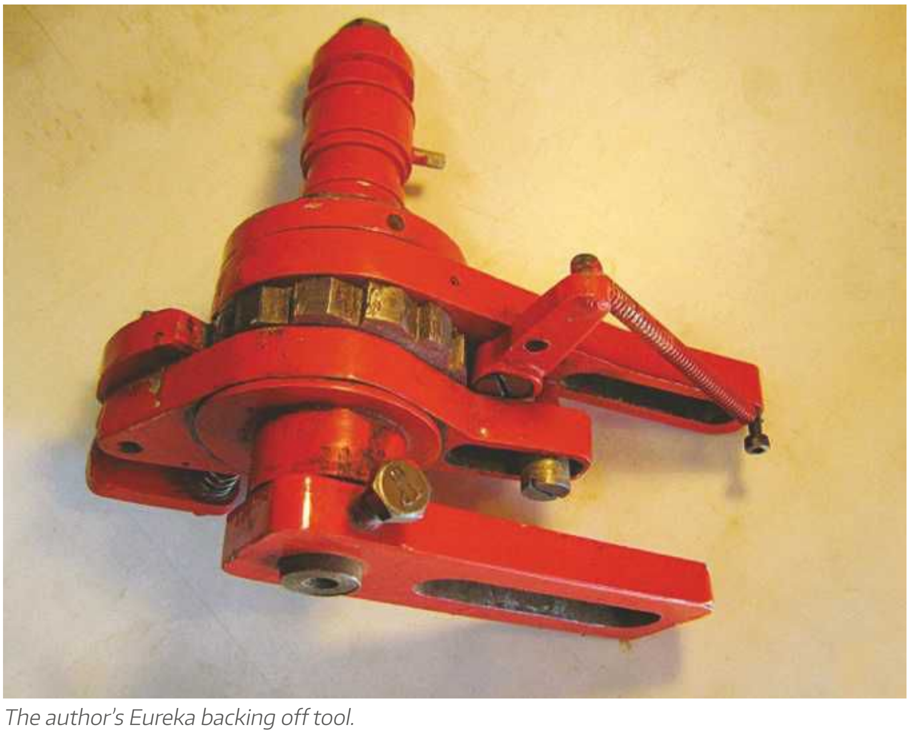
The gear cutter is made and in working operation. The gear form cutter has been made for the appropriate gears in mesh and is mounted on the cutter head shaft. The gear wheel blank is ready with respect to diameter, thickness and so on all derived from the tables, has a keyway and is put over the workhead shaft on an adapter. The material for the gear can be almost anything and depends on service conditions. Much of the gearing seen on the gear cutter is in aluminium; the service conditions are light with slow speeds where this material does quite well. In more demanding applications steel is often required. Plastics can be used for small gears but there are many grades and one will have to sort through these to make an educated choice. When cutting plastic wheels, add a brass backing to the wheel, which will stop fraying and run out on the rear edge. Copper alloys can be used and in some circumstances these are superior to steel. I have made small brass wheels, which I thought a poor selection for any gearing but, that is what my customer wanted and I have made hardened and tempered tool steel wheels for far more exacting service. However, by far the most used material in my work is good quality cast iron.

The wheel will be to the correct diameter and all that matters now is to set the wheel to the cutter so the latter will cut along the wheel's diameter. One cannot use the old dodge of putting a rule between cutter and wheel as there is no pointed edge, however, the workhead has a flat face on to which one can clamp a flat and true plate of bright steel which also reaches down to the cutter head shaft. With slips and feelers one can get a very good alignment. For many of the initial gears to be made, all straight spur, one can be sure the same alignment will remain in place, as only the vertical height will change in the set up. If the gearwheel is to run smoothly with other wheels it is crucial that the centre is found properly.

From here on it is a very simple operation to cut teeth. One will have to look at tables to select the number of turns made to change the ratios between the worm wheel and gear on the wormhead shaft and the actual wheel to be cut. To cut a gearwheel for 24 teeth with a worm shaft wheel of 40 teeth the ratchet selected will have an even number of teeth which could be 6 or 12 or 8, all of which are factors of 24. One complete revolution of the worm indicates one tooth change on the wheel being cut. To be able to cut less teeth than the 40 teeth wheel that drives the shaft around, requires the ratchet indexing to advance the rotation by 1 4/6 turns, or 1 8/12 or 1 3/8. For odd gear wheel tooth numbers the same process applies. For a 35 tooth wheel, the ratchet has to have 7 teeth and with a 40 tooth wheel in the indexing the ratchet turns are 1 1/7, one could use a 70 tooth wheel in the indexing and then the ratchet turns 2 teeth at a time. Once one has the 35 tooth wheel it can be used for other wheels divisible by 7, like 42, where the ratchet turn for the 35 wheel is 5/6.

Once the indexing has been set the rotating base slide can be advanced and lowered to touch the cutter. The touch is matched to the dial on the vertical slide by setting it to zero. The first cuts on the machine should be small, until one gets familiar with the process and the rigidity of the machine components. The first cuts might be considered scoring rather than cutting but it will show exactly how the indexing works, which should bolster confidence, and will allow the next cuts to be heavier, say 0.5 to 1 mm, taken slowly. The end point is when the correct depth of cut occurs as seen on the dial gauge. One change I made to the machine was to replace the small steel handle that drives the feed of wheel into the cutter to be a large wooden one which was easier on the hand and more sensitive.

This completes the description of the making of the first part of the gear cutting machine and some of the accessories. Gears and gearing offer so much to the model engineer in terms of compact drives, strength, flexibility and reality of scale and authenticity in transferring power and torque from one shaft to another. I see an ever increasing interest in diesel traction, which emerges as splendid representations of the outer bodywork, but in most cases batteries and various chains, belts and other drives are present inside the hood, which are not representative of the real transmission. If we want to follow full size practice as far as possible then that should spur many of us to see a gear cutter, not necessarily mine, to be part and parcel of the workshop and many new projects. I think that much of the resistance to proper gearing lies with the special cutters, the backing off and the implied maths. For most of us and the projects we want to do the vertical slide and rotating table are the only two pieces of equipment required. However, once made and once used, I believe the ambition will be to try more complex gear forms and trains. It is how I started off. ■



The author's Eureka backing off tool.

Readers' Tips

CHESTER MACHINE TOOLS

Vice alignment

TIP OF THE MONTH WINNER!

Our winning tip from John Hinkley for setting up a milling vice wins this month's Chester Vouchers!
I often find that I have difficulty setting the jaws of my mill vice parallel with the X-axis travel. In order to speed up the process, I start by using a combination of precision parallels to aid the initial set-up. First, I lightly clamp a large parallel in the jaws of the vice. The parallel has to be sufficiently long to overhang the jaws by about 10mm either each side. Loosen the fasteners attaching the vice to the mill table so that the vice can just rotate. Then I take a second pair of parallels, the wider the better, and set them against the protruding parallel in the vice and the dovetail of the vertical slideway as shown in the accompanying photograph. (I have used a couple of cable ties to pinch the swarf guard out of the way as I ran out of hands.) Lightly clamp the parallels between the slideway and the vice parallel until they are just snugged up. It goes without saying that the second pair of parallels should be of equal length! Tighten the vice clamping fasteners and complete the alignment in the usual way using a DTI. You are unlikely to get the alignment spot-on using this process, unless you are extremely lucky, but it will be very close, typically I've found, within 0.02mm over the width of a 100mm vice. It could be made into a one-handed operation by making a U-shaped tool to clamp in the vice. A project for another day.

Seeing Around Corners

Our runner up tip from Ken Willson will come in handy when you need to see round corners. Ken wins ten Shaviv deburring blades and a 'Mango' handle.

When you are milling on the side away from you, what is happening?

You can look from either side by leaning on the mill, but it is never satisfactory.

Solution, a hand held mirror (an old car mirror) held behind the work or propped up on the table as shown.

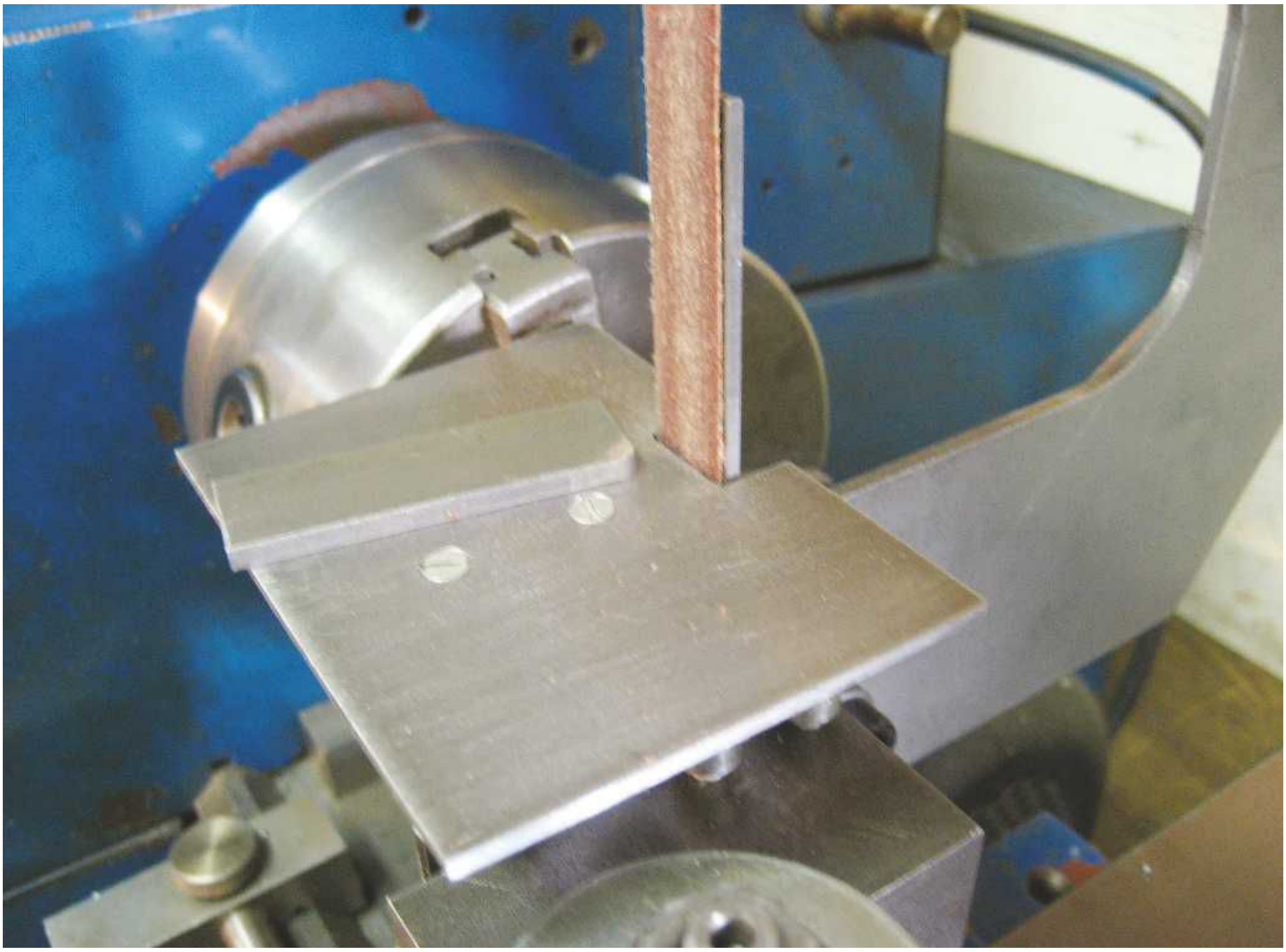
We have £30 in gift vouchers courtesy of engineering suppliers Chester Machine Tools for each month's 'Top Tip'. Email your workshop tips to **neil.wyatt@mytimemedia.com** marking them 'Readers Tips', and you could be a winner. Try to keep your tip to no more than 400 words and a picture or drawing. **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.chesterhobbystore.com** to plan how to spend yours!

Please note that the first prize of Chester Vouchers is only available to UK readers. Other prizes are at the discretion of the Editor.

Scribe a line

YOUR CHANCE TO TALK TO US!

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



Belt Sander

Dear Neil, Thought this was quite innovative device but personally I would devise a separate drive. Wouldn't want the abrasive dust on the slideways of my lathe.

Alan Tomblin, by email

It is true that, unless you protect the bed of the lathe and clean up well after using the belt sander, it could cause problems. Historically there have been a number of commercial sanders and grinders for use with lathes, so as long as sensible steps are taken to keep the lathe bed clean the sander should cause no problems.- Ed.

Belated Correction

Dear Neil, I have just picked up MEW 244 and have spotted my letter in Scribe-a-Line. It appears the requested correction didn't go through: the V-form threading-tool included angle was to have been 55°. I'm sure John at least will be onto it so you may need to print a brief correction. (Also, I like my new re-location to France, it's getting cold in this NEW ZEALAND Winter!).

Andre Rousseau.

My apologies to Andrew for the relocation – Our best wishes go to all our New Zealand readers and their families, we hope they have not been badly affected by the recent earthquake - Ed.

Collet Identification

Dear Neil, I have a machine collet similar to one that fits a watchmakers lathe, but the thread is an odd size. I make it 11/32" UNS 32 T.P.I, the thread diameter is .343" (8.80mm).

Do you have any idea what it could be for, or what it might fit?

Stuart Haywood, by email

Stepper Query

Dear Neil, Derek Sawyer (MEW 248) may be interested in reading the following link to an article by Douglas W Jones' of the University of Iowa: homepage.cs.uiowa.edu/~jones/step/circuits.html

Alas there are numerous types of stepper motor in circulation, many of which (e.g. ex-printer motors) that have part numbers specific to the manufacturer.

In that respect I am also struggling to make use of 'rescued' motors

Bernard J Greatrix, by email

High Voltage

Dear Neil, I read Tony Hicks' letter in MEW 248, (November 2016) in which he criticised Ted Fletcher's article in MEW 244 (August 2016) covering Single Phase, Fractional Horsepower Motor Connexions, and feel I ought to add my two pennyworth. The gist of Tony's criticisms appears to be that it was "cavalier in its approach" and that fault finding and repair of such motors "in the hands of your readership this may be this (sic) end of life".

Firstly, I should say that I am a Chartered Electrical Engineer with 50+ year's experience in industry (and a few more years previous and lately as a hobby electrician) and a Fellow of the Institution of Engineering and Technology (aka the IEE), so feel I am qualified to comment on Tony's assertions.

Far from being "cavalier" Ted recommends, quite clearly from the outset, the correct use of a "Megger" to test electrical isolation resistance before any work is carried out on the motor. He explains the use of test meters, such as the trusty AVO (of which I have, and use, a Mod 8 Mk IV) to check windings, then goes on to explain how to dismantle the motor – taking precautions to avoid damage to the windings – and, then, advocates the use of the "Megger" (other brands are available) to recheck the insulation resistance after the motor is re-assembled.

That is exactly what I, and many other qualified Electrical Engineers, would do – so why is this a "cavalier" approach?

Methinks that Tony is too bound up in his HSE Consultancy to "see the wood from the trees". Any Model Engineer, or casual subscriber to MEW, who owns a "Megger" and/or suitable test meter and knows how to use them will, most probably, know enough about electricity and its hazards, but may not know much about Single Phase Motors and their wiring – the subject of the article.

Should we destroy all technical and "how-to" books that attempt to teach Carpentry, Model Engineering, Electrical Engineering, Vehicle Maintenance, etc., just because they don't have disclaimers in them? I think not! They are instructional books and, like Ted's article, are meant to teach and enlighten, which his article, as far as my expertise goes, does very well.

Andrew Houston, Orpington

Thanks to everyone who responded to Tony's letter; a wide range of views were expressed and while Andrew's response seems to sum up the majority view, a wider range of opinions were aired on the forum at :
www.model-engineer.co.uk/forums/postings.asp?th=121985

In our Next Issue

Coming up in issue 250
On Sale 30th December 2016

Look forward to an exciting mix in our 250th anniversary edition to round off our 25th year!

Stephen Wessel describes the ingenious approach to patternmaking behind the detailed castings he exhibited at the Model Engineer Exhibition earlier this year

One Man and His Seven Lathes - as we return to the popular series with a bumper crop from **Jock Miller**.

Power Feed for a Centec Mill – **John Harris** describes his useful modification.

Bending Rolls Based on the G H Thomas Design

Howard Lewis makes a few changes to a classic design originally published in Model Engineer

Having read the G H Thomas book, The Model Engineers Workshop Manual, it seemed a good idea (at the time!) to make set of bending rolls, as detailed in chapter 18, to complement my small press brake.

My workshop tools are purely utilitarian, so unlikely to be polished or prettified to be exhibition pieces. Although the G H T design was for 10 inch rolls, the width was increased to match the 12 inch Bender. Also, although the drawings were dimensioned in Imperial units, any material bought today would be to metric dimensions. Also, given the intention, wherever possible, to use available material, some departures from the script were bound to be made, and so the device became somewhat of a hybrid.

The specified base was 1.5 x 1 inch, but a length of 3 x 1 inch was available, (scrapped from work, before I retired, and had spent some twelve years waiting "to come in handy"), so that was the first, but not the only, variation on the theme,

Although the threaded components that had to be fully machined, more or less followed the drawings and were Imperial; because M6 setscrews were available, hardware used purely for retention was Metric.

Having read the chapter, in haste, some material had been purchased, and work started, before reading more thoroughly. The majority of the chapter described making a set of rolls with just one roll providing the drive. Knowing that commercial bending rolls geared together the driving and pressure rolls, it was decided to follow that route. Rereading GHT, came the realization, that the metric material bought for the endplates would suit the ungeared version, but be too narrow for the geared version. Since the length of material purchased was greater than that immediately required, the obvious solution seemed to be to bolt on a small extra piece to provide a location for the two Idler Gear Shafts. So, in blissful ignorance of what was really involved, construction began.

Endplates

The material for these was 100 x 12mm bright mild steel (BMS), and two pieces were cut and then dowelled together (using the dowel holes that would eventually locate the endplates to the base), before cleaning up the cut edges and carrying out the rest of the machining, as per the original drawings.

Once this had been done, the various holes were drilled and reamed, and the slots milled, using the mill/drill in jig borer mode, by working to co-ordinates.

The end plates were then reoriented to drill and tap the holes for the straps that would carry the pressure screws for the adjustable rollers.

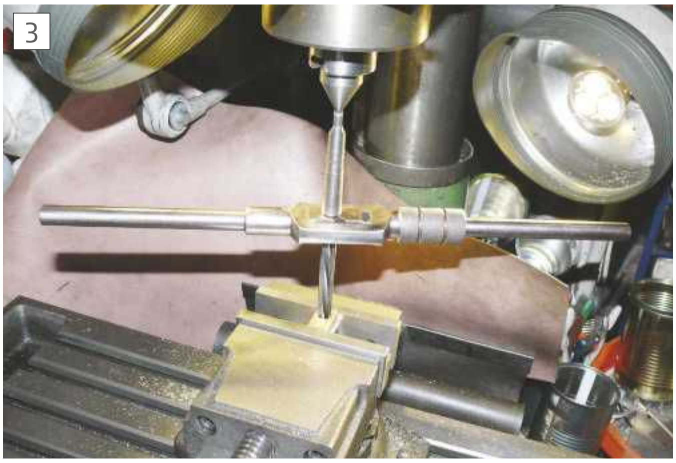
One of the plates was selected to be the driving end, and three holes drilled and tapped to secure the additional material planned to clamp the idler gear shafts.

The three tappings were positioned to avoid any of the other holes in the endplate.

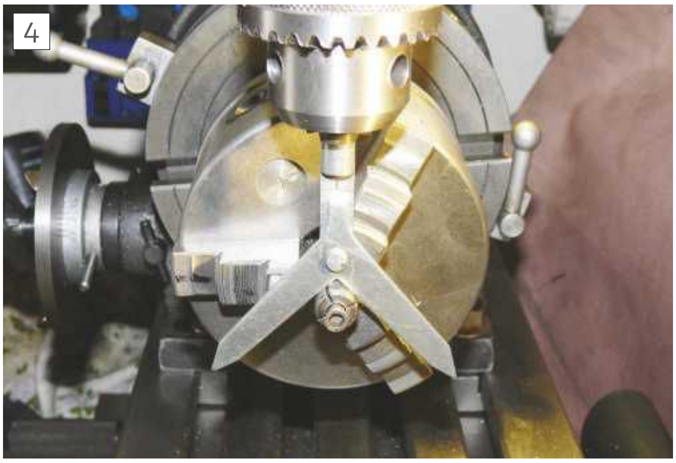
An extra piece of the 100mm x 12mm BMS was machined to clean up, and

The driving endplate

The 'free' endplate



Reaming a bush



Centring a bush under the mill

Rounding the bush

Drilling a hole for a dowel

then three m6 clearance holes drilled to match those in the endplate selected and machined for the driving end.

Before bolting this extra piece onto the driving endplate, a piece of cigarette paper was trapped between the two pieces of steel, ready to drill and ream the two 3/8 inch diameter holes.

The cigarette paper was removed before the two silver-steel idler shafts were coated with Loctite and clamped in position.

Although the ends of the driving and pressure rollers were ½ inch diameter, it was decided that the idler gears would be bushed, hence the diameter idler shafts being 3/8 inch.

Both endplates were fitted with brass bushes for the driving roller.

Since rotation speeds would be low, it was considered that brass would suffice for these tasks. **Photograph 1** shows the driving endplate, and **photo 2** shows the "free" endplate, during the assembly process.

Idler shafts

These were merely pieces of 3/8 inch silver steel of such a length to pass through the 12mm endplate, and carry the gears, with slight endfloat, and then drilled 5mm and tapped M6 at one end.

Roller bushes

These were made from brass, and began as a fairly straightforward milling, drilling and reaming job.

After drilling, each bush was reamed, with the reamer being steadied by a centre in the spindle of the mill/drill, whilst rotated by hand, **photo 3**.

An expanding arbor, held in a chuck on the rotary table, was then centered under the mill/drill, ready to hold the bush to mill the radius on one end, **photos 4 and 5.**

Base

This was cut from the 3 x 2 inch steel mentioned in the synopsis. Having cleaned up the cut ends on the mill/drill, it was too long to fit under the head, to drill, tap and ream for the setscrews to secure, and the dowels to locate the endplates.

A vertical slide was purchased, from ARC Euro Trade, designed for a SEIG c6 lathe, which meant another project to adapt it to my BL12/24 was necessary. Fortunately, the securing holes were on the same pitch circle diameter (PCD) as those for the front toolpost, so once a 25mm bung, with a 10mm reamed hole had been made, it was possible to fit the vertical slide to the lathe. (in the way in which every job spawns at least two others, an adaptor will have to be made for fit to the cross slide, in place of the rear toolpost, and to allow it to swivel - another round tuit!)

Drilling, tapping, and reaming for the dowel holes was then done, using the vertical slide and cross slide to set the co-ordinates. One turn of the vertical slide handwheel provides 1.5mm travel, so that each of the 60 divisions closely approximates to 0.001 inch.

The tap is held in a sliding tap holder, using er25 collets, which is normally used on an arbor in the tailstock, **photos 6 and 7**.

The four dowels were made from ¼ inch silver steel, ½ inch long with a chamfer on each end.

Whilst on the mill/drill, by careful repositioning in the vice, there was sufficient table travel to machine a chamfer along the upper edge of the base to ensure clearance for the driving roller.

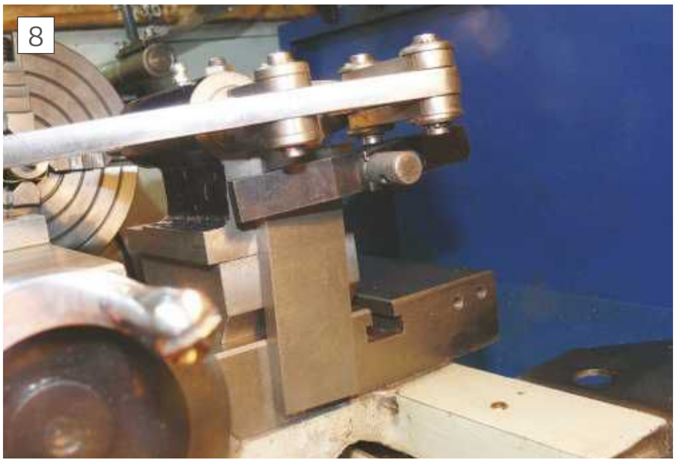
Rollers

The deflecting roller was just a piece of 18mm diameter BMS, faced to length, with both ends turned down to 3/8 inch diameter for ½ inch length at each end.

The driving and pressure rollers were made from 30mm diameter BMS, (lightly polished with fine emery), which had been centered in the 4 jaw chuck to give less than 0.0005 inch runout. One end of each roller was drilled 5mm and tapped m6, and a keyway cut, on the ½ inch diameter journal to leave a 12mm length clear before the shoulder onto the major diameter.

The keyway was cut, using a 1/8 inch square toolbit, carried in a slotting tool designed by the late Peter Robinson. The

Tapping in the lathe



Raising block

Keyway cutting

Using a home made floating reamer holder

casting for this tool was obtained from College Engineering Supply. This tool was designed for use on Myford 7 series lathes, and so required a raising block to bring it up to centre height on my larger lathe.

To align it onto the cross slide, a toolmakers clamp was used to clamp a parallel to the main casting of the slotting tool, and the parallel held against the rear of the cross slide, whilst the nuts were tightened to clamp it to place. **Photograph 8** shows the raising block needed for my lathe.

To allow sufficient travel for the handle of the slotting tool, the front toolpost was removed. The length of keyway was controlled by setting the slotting tool against its stop, in the fully forward position, and then moving the saddle to bring the toolbit to the position for the end of the keyway, before locking it in place.

Photograph 9 shows the keyway being cut in the end of the pressure roller.

Gears

The gears would be 20 tooth, 20dp. Since the raw material need to be turned to size, and then drilled and reamed before transferring to the mill/drill for gear cutting, the work holding method was as follows.

A 2 MT arbor with a Myford thread and register was fitted to the mandrel of the bl12/24, using suitable adaptor sleeves, and used to carry a small Myford fitting four jaw chuck.

The raw material was then centered in the chuck, faced and centre drilled so that it could be supported by a tailstock centre whilst the outer diameter was turned to size, over a length which would allow the four part finished gears to be machined before being parted off.

Once this had been done, a fixed steady was set up at the chuck end of the material, before being lubricated and moved near to the free end of the bar. The bar was then drilled progressively larger until it could be reamed with a ½ inch reamer held in a shop made floating reamer holder held in the tailstock, **photo 10**.

Once this had been done, the steady was removed, and the four-jaw chuck and workpiece transferred to the rotary table which had been aligned in the vertical position on the mill/drill.

The tailstock for the rotary table, having been lubricated, was inserted into the reamed bore of the workpiece, to provide support whilst the gear teeth were cut.

(the workpiece had originally been positioned in the chuck to allow clearance for the gear cutter, and the tailstock centre, similarly, was extended, to prevent teeth being cut on the centre or the tailstock!)

A number 6 gear cutter, mounted on an arbor, was aligned with the centreline of the workpiece, and cutting commenced. Since, the teeth were being cut to full depth in one pass, a slow hand feed was used. The hv6 has a 90:1 ratio, so the handle rotation needed between each cut was four complete turns plus ten holes on a twenty hole dividing plate, to give a tooth spacing of eighteen degrees. **Photograph 11** shows gear cutting in progress.

Once cutting the gear teeth had been completed, the arbor, chuck and gear were returned to the lathe.

The initial intent was to part off each gear to a width slightly in excess of 3/8 inch using an inserted tip parting tool in the front toolpost, **photo 12**. This was an expensive mistake, costing two tips before using the high speed steel parting tool just visible in the background.

Once the four gears had been parted off, the three-jaw chuck was replaced, and used to bore a piece of aluminium bar to size and size with the od of the gears, and deep enough to leave the gear protruding a little.

After making a slit with a small hacksaw, this was used as collet to face the gears to 3/8 inch long, and chamfer, before cutting a keyway in two of the gears, **photo 13**.

The other two gears were just faced and chamfered.

Two brass bushes were then turned with a ½ inch o d, and a bore reamed to 3/8 inch.

These two bushes were then coated with Loctite, and pressed into the gears with plain bores.

They were then placed on the idler

Cutting the gears as a 'stick'

Parting off the gears

Cutting the keyway in a gear

The finished rolls

shafts and checked for freedom of rotation when meshed.

The two gears with keyways were then offered up to the driving and driven rollers and the keys, (made from 1/8 inch square EN8 - a suitable tough steel) fitted to give good fit between the gear and the journal.

Straps and adjusters.

The adjuster screws were made to the drawing, apart from the adjusters having tommy bars, instead of the knurling shown on the drawings. The tommy bars were recycled from chromium plated coat hangers!

The straps were made from the 12mm material, but were drilled at both ends, rather than having a radial slot at one end.

The fixed bolts were machined so that the plain shoulder just allowed the strap to rotate when tightened down.

Handle

The rotating part of the handle had once been part of the handle of a now defunct lawnmower. Once cut to length, and chamfered, a brass bush was pressed into each end.

The brass bushes were drilled 10mm clearance, one being longer and counterbored to accept a 3/8 drive socket to fit the head of a washer faced M10 bolt. The washer face had been turned down to the across corners size of the hexagon, and the underside of the head faced to clean up.

The arm of the handle was piece cut from the arm of a failed door closer. One end was drilled and tapped M10, and the other end drilled 6.5mm. The arm was now linished, to remove the paint, and to radius each end.

Having temporarily assembled the driving roller to the endplate, with the driving gear, the length of shaft protruding was measured. A piece of ¾ inch diameter bar was then faced, with a large external chamfer at one end, (as weld preparation) to 0.010 inch less than this dimension, before being drilled and reamed ½ inch. A keyway was then cut through this piece of metal, before fitting a key, to give a good fit on the end of the driving roller.

It was then arranged on the roller, and clamped so as to protrude beyond its end. The arm was then clamped to this bush, using a m6 setscrew, so that the keyway was "inside", and away from where the welding would take place. The earth clamp of the welding set was attached to the arm, and the arm and bush were then welded together, over as much as possible of the external circumference.

For once, I managed to make a reasonable job of the weld, and after removal from the roller, the excess weld was linished off to the radius of the bush. When offered up to the driving roller, it became clear that the welding had slightly distorted the bush, and the key had to be refitted to give a good fit.

The rotating part of the handle was then attached to the arm, with a washer faced nut against the arm, and adjusted to give minimal endfloat, before locking the nut to the arm to prevent movement of the bolt.

Assembly

After the dowels had been fitted the 'free' endplate was secured to the base by m6 setscrews.

All the journals of the rollers were given a smear of grease, before being fitted into the appropriate bushes, and the driving endplate secured in place.

The idler gears are retained by a simple washer, 0.75 inch diameter BMS (in stock), 0.1 inch thick, with a central 6mm clearance hole and chamfered edges. To clean up the parted off face, the washers were held in a bell chuck, but could have been held in a purpose made collet for this operation.

The driven gear was retained on the driven roller by another machined washer and m6 setscrew.

The driving gear was fitted to the driving roller, followed by the handle assembly, again retained by an M6 setscrew.

To afford some protection to the gears, a simple sheet metal guard was made and secured by two of the setscrews holding the strap over the idler shafts. The end result is shown in **photo 14**. ■

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An Arduino Controlled Indexer

Carl Wilson uses a popular microcontroller board to create a useful workshop accessory

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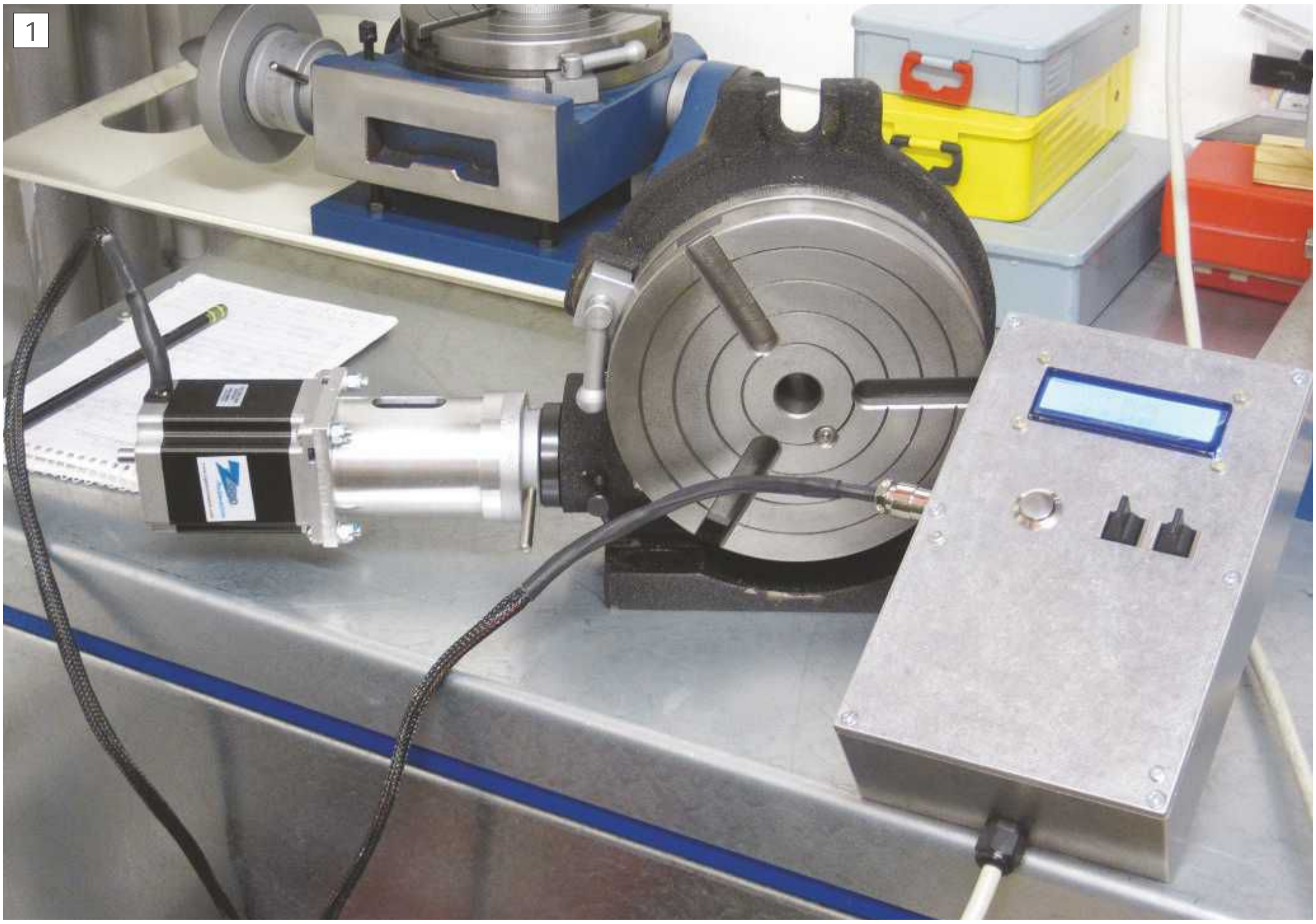

Completed Arduino Indexer showing control unit and motorised rotary table.

This article describes how I converted my 6 inch Vertex rotary table into an automated indexer, using a stepper motor and Arduino microcontroller board. The completed system is shown in **photo 1**.

The Electronics

As this is likely to be the thorniest subject for most, I'll get it out of the way first. There can't be many readers of MEW who have not heard of the Arduino. This is a USB programmable microcontroller board that was designed in 2005, specifically aimed at beginners. It has gone on to become the most popular device of it's type in amateur use today.

My rotary table conversion came about as a need arose in another project I'm working on. So I wanted a quick, simple and effective solution to the problem. Whilst searching the net for ideas, I came across Gary Liming's Step Index project. Gary writes for the US magazine Digital Machinist. Whilst Gary had produced his system for driving an indexing fixture of his own design, I quickly saw that it could easily be adapted to drive a rotary table. I then discovered that Gary had also modified his software to do just this.

I have Mr. Liming's blessing to use his system and to reproduce it here.

Photograph 2 shows an Arduino Uno. Note the USB connector, used for programming the device. Arduinos come in various shapes and sizes, differing mainly in footprint and memory size, as well as type and number of user pins. It can be seen that the Uno's user pins can be accessed via two rows of sockets called headers. These headers enable a wide variety of daughter

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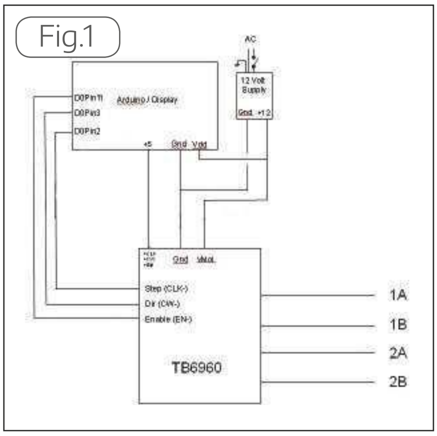
Arduino Uno microcontroller board. Note USB programming connector and I/O port headers.

3

Arduino compatible LCD and Keypad shield.

Fig.1



Wiring diagram for boards in indexing system.

boards called "shields" to be plugged in to the board. The shields add functionality, for example motor driving, LCD displays and wireless connectivity, in a simple plug and play format. The success of the Arduino is due in no small part to this concept.

Photograph 3 shows an Arduino LCD display and keypad shield. Mating this up to the Arduino gives a user interface for the indexing system.

The stepper motor I selected to drive my rotary table is a 2A per coil, NEMA 23 frame, bipolar type with a holding torque of 24kg-cm. Obviously, the Arduino cannot source enough current to run this directly, so the next component in the system is a suitable driver. **Photograph 4** shows the board used. This is based around a Toshiba TB6960 full bridge driver chip. Current limiting and micro-stepping values can be preset using on board DIP switches. I set the current to 2.5A to give the motor a little headroom. Given that my rotary table has a ratio of 90:1, I finished up setting micro-stepping to zero. I also altered the software to reflect this, on which, more later.

The TB6960 requires three of the Arduino's pins to control it. One to enable the board, (EN) one to select the direction (DIR) and a clock pulse (CLK) to step the motor the required number of times. It is important to note that the user has a choice of common anode or common cathode for the inputs of this board. As most microcontrollers can sink more current than they can source, this design uses the common cathode configuration. This means EN+, DIR+ and CLK+ are all connected to the Arduino's on board 5 volt supply.

The last piece of the sparky puzzle is a power supply to drive everything. **Photograph 5** shows the 12V 5A regulated supply used.

Photograph 6 shows the Arduino plus LCD/keypad shield, stepper driver, power supply and stepper connected up for bench testing.

Figure 1 shows the wiring for the system. I have adapted this from Gary's original, which included two temperature sensors, one each for the motor and the driver heatsink. I decided not to include these.

It can be seen that CLK- is connected to Arduino digital output pin 2, DIR- to pin 3 and EN- to pin 11. This seemingly illogical jump in the sequential use of pins is due to the large number of inputs and outputs the LCD/keypad shield requires for it's interface.

Photograph 7 shows the locations of these pins on the LCD/keypad shield.

The Mechanics

The mechanical aspects of this project were split into two sections. These were preparing the rotary table for motorisation, and then fabricating a suitable mounting for the motor.

Preparing a rotary table for motorisation is very well covered on a variety of websites, most notably that of Division Master. Hence I will not go into great detail here. Suffice to say that apart from removing the handle from the worm shaft, the chief objectives are to reduce friction and backlash as much as possible. The former is achieved by carefully adjusting the table thrust and worm shaft bearings and cleaning off the grease, to be replaced with machine oil. I used AWS 68 (the same as in the headstock of my Harrison M250). The latter comes about by careful adjustment of the worm shaft eccentric and bearing.

I decided to use a bellows coupling to connect the stepper and rotary table shafts. The table shaft is 12mm diameter whilst that of the motor is 6.35mm i.e. ¼ inch. I managed to find a bellows coupling with these internal dimensions. **Photograph 8** shows the stepper connected to the table drive shaft in an early trial.

The completed motor mounting can be seen assembled to the rotary table in **photo 9** and almost complete and exploded in **photo 10**. It is composed of a square plate connected to a tube that transitions to a

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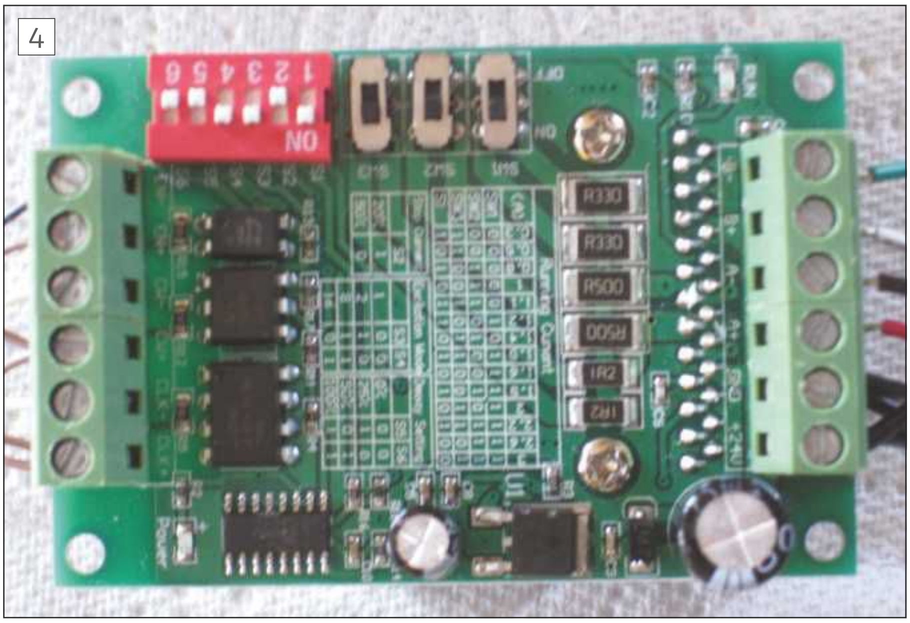
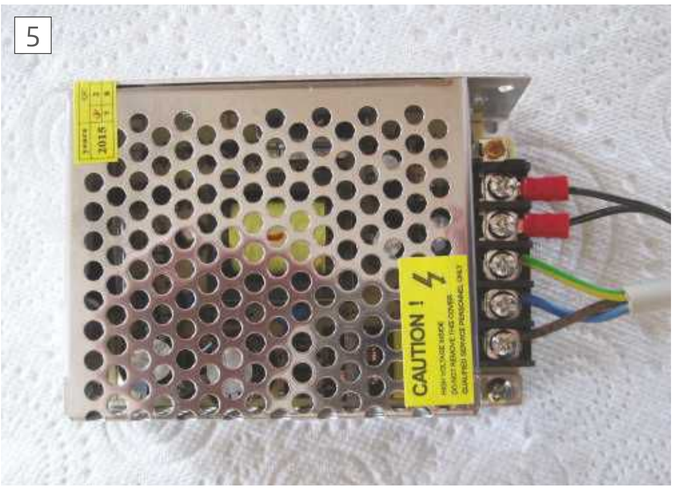
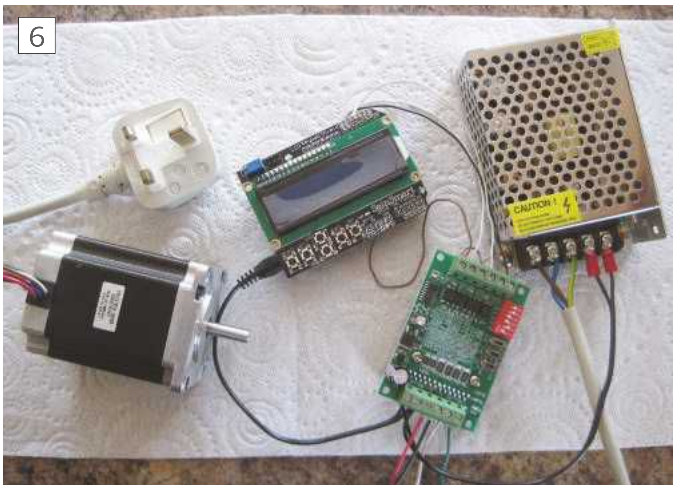


Stepper motor driver board based around Toshiba TB6960 driver IC. Note DIP switches for selecting current limit and micro-stepping level.



12V 5A regulated power supply. The preset potentiometer adjacent to the terminal strip allows fine adjustment of output voltage.

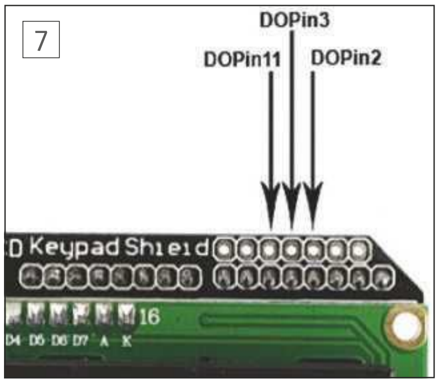


The components connected, the PSU must be fitted in an earthed case before connecting to the mains.

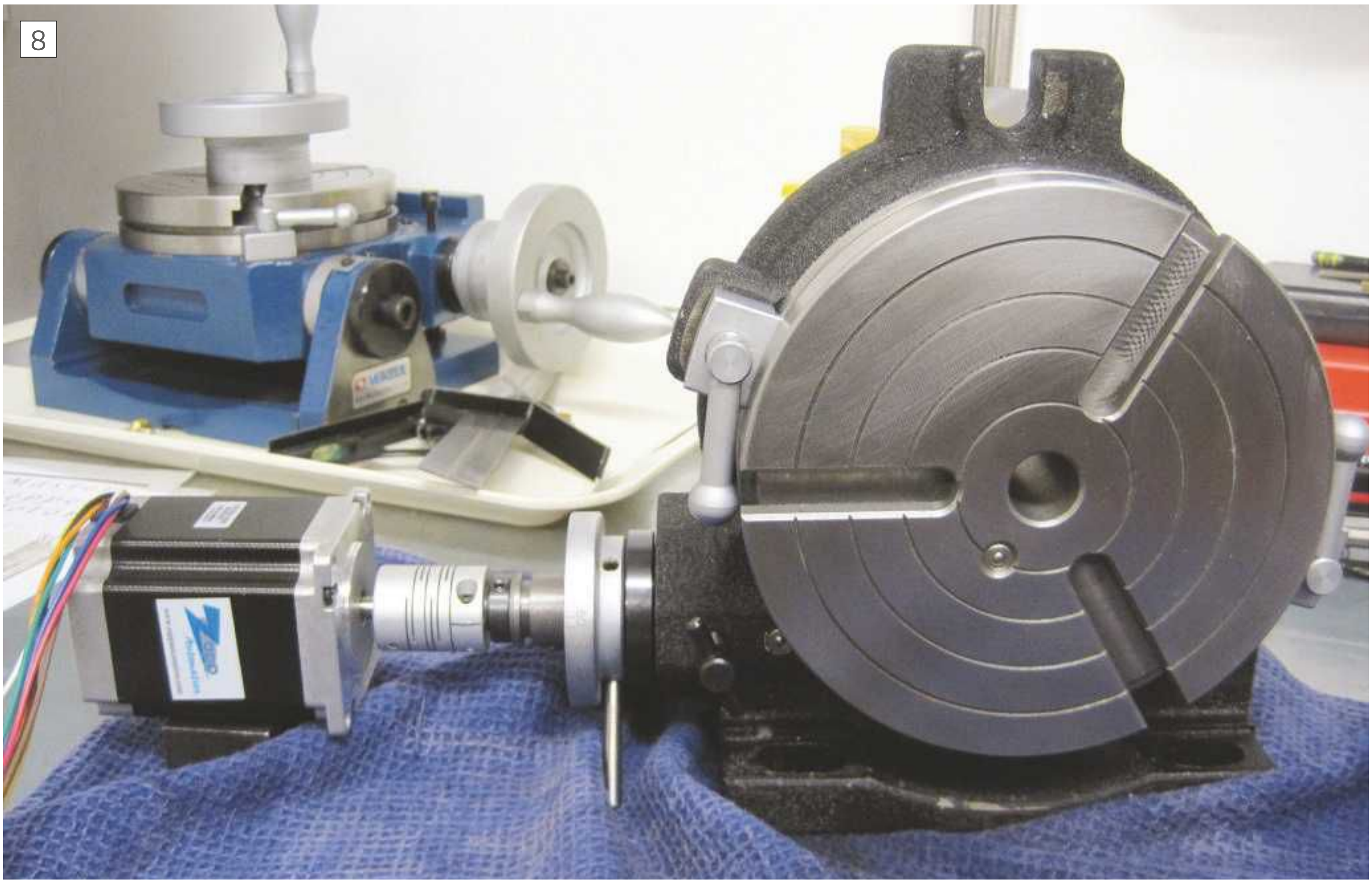
round plate bolted to the existing rotary table flange. **Figure 2** shows the NEMA 23 standard dimensions. I realised that I could use the 38.1mm register on the face of the motor to help maintain concentricity of the complete assembly. The square portion was cut from a piece of 6mm thick 6082 T6 plate. After squaring up on the mill, it was machined in the 4 jaw until as shown in photo 11. The plate is 56mm x 56mm, as per the NEMA dimension. The central hole was carefully bored to accept the 38.1mm register. Still located in the 4 jaw, the plate was then counter bored 48mm diameter to a depth of 3mm. This was done to locate the tube that joins the round and square sections of the mounting.

Next, a section of 2 inch x 10 swg 6082 T6 tube was turned down to exactly suit the outer recess in the square plate. Having turned the sides, the end was faced to ensure it would be square with the sides. The tube was then parted to length. The length was decided by the amount of room required to mill a slot for access to the bellows coupling grub screws. This turned out to be exactly 65mm.

The round portion of the mount started out as a section of 2 ¼ inch 6082 T6 bar. This was turned down to 56mm in the 4 jaw and then bored through to 21mm to suit the rotary table driveshaft outer sleeve. Once



Location of Arduino digital output pins carried through on to LCD/Keypad shield.



Stepper motor and rotary table connected up with bellows coupling for initial trial.

9

Completed motor mount attached to rotary table.

the central hole was complete, a 3mm deep recess was generated to fit the cylindrical portion. The three 120 degree spaced, M5 holes for the mounting bolts were produced using the mating part of the rotary table as a drilling template. **Photograph 12** shows the part prior to drilling the holes.

My initial thought was to TIG weld for final assembly. Instead, I managed to successfully bond the three sections using two-part epoxy. Once cured, the final operations were to mill the access slot for the bellows coupling and drill the four M5 motor mounting holes in the square portion.

Software and Programming

Don't panic. In modern mechatronic practice, software is considered as an integral machine element, like a gear or a bolt. That is what we shall do here.

Gary Liming's Step Index software for the Arduino is currently at version 2.3. Like all Arduino programmes, it is written in a form of the C language. The software is available to download at the Digital Machinist magazine website. Pasting the link in ref. 1 will do this automatically. The file contains all versions of the code from 2.1 to 2.3. There is also a Read Me file, which gives details of how to modify the code to add ratios or to make a specific ratio the default. Brief details of how constants may be altered will be given later on.

The software algorithm is based on the stepper motor resolution, in this case 1.8 degrees per step. This means 200 steps per revolution. With a 90:1 ratio this becomes 18000 steps per revolution, or 50 steps per degree. Dividing 360 by the number of divisions required and then multiplying the result by 50 gives the number of steps required per division.

In order to upload code to the Arduino it is necessary to download a piece of software from the Arduino site. This is the "Integrated Development Environment" or IDE. The IDE is where users develop Arduino programmes and open existing ones. The IDE can be downloaded for free at the Arduino website, ref. 2. Once installed, the IDE can then be used to open Step Index 2.3.

At the top left hand corner of the IDE screen you will see a tick icon. Hovering over this reveals it to be the verify function. Clicking here will verify and compile the code. Do this now. As Gary made an excellent job of his software there should be no errors, and after a few seconds you should get a done compiling message at the bottom of the screen. Clicking Sketch and then verify/compile has the same effect, as does the keyboard shortcut Ctrl+R.

Your Arduino will have come with a USB lead. Connect your board to your computer with this now. There is no need to connect anything to the DC power jack, as your Arduino will be driven by the USB 5 volt supply. You should see the power LED illuminate on the board.

In the IDE, select Tools then Board. Here you will see a list of Arduino devices. Select yours. In the case of this article, an Arduino Uno. You can now click on the arrow in the top left of the screen to Upload the code to your device. You should see the communications LEDs flash as the code is transferred. Alternatively you can select File then Upload or Ctrl+U.

Once the code is uploaded, pressing the reset button on the board or cycling the power will cause the Arduino to boot the programme and begin execution. Initially the splash screen will be displayed. This shows the software version currently running and

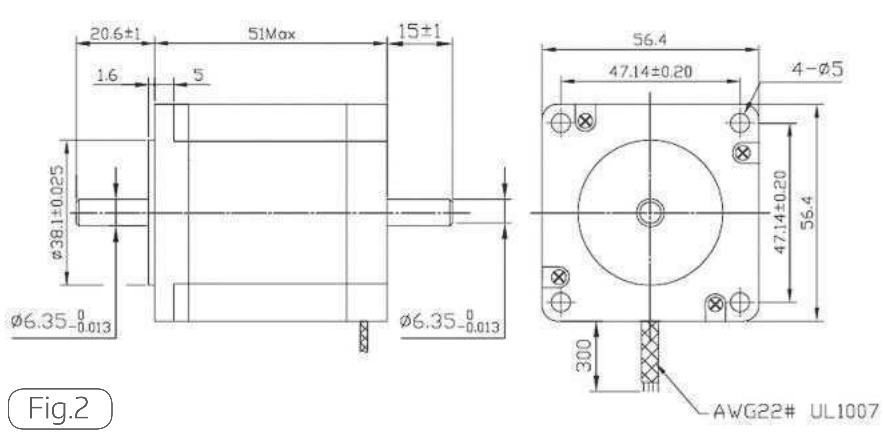
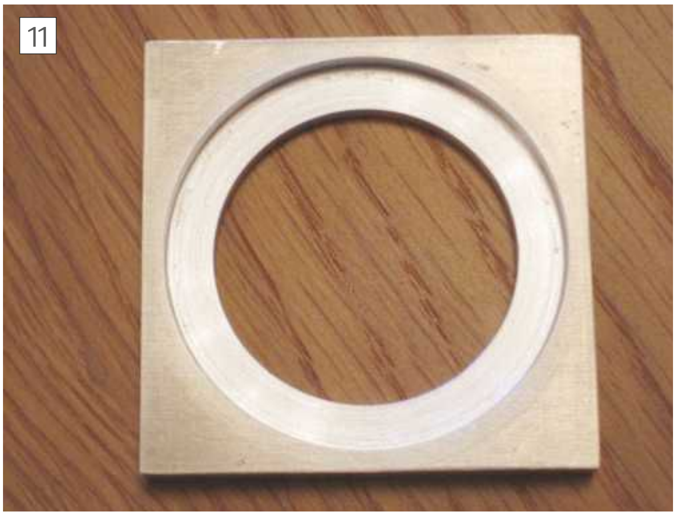


Fig.2

NEMA 23 standard dimensions.

Motor mount components, taken before mounting holes drilled in round portion.



Square portion of mounting showing 38.1 mm register bore and counterbore to suit cylindrical section.

Round portion of mount showing register bore for rotary table mounting and counterbore to suit cylindrical section.

Front panel of control unit showing LCD, paddle switches for menu navigation and select button.

the default ratio. In the case of my unit, this is 90:1. As mentioned earlier, Gary's notes in the Read Me file give comprehensive instructions on altering this.

The buttons on the LCD shield are used to scroll through and select menu items. Larger more user friendly switches were piggybacked on when the unit was fitted into a diecast case.

The menus are as follows:-

Ratio - Allows the user to select the ratio of the fixture being used. The software can be modified to include as many as are required, but 3:1, 40:1 and 90:1 are included as standard.

Temp - Facility to read motor and driver heatsink temperature, using two sensors connected to the Arduino's analogue inputs. I did not use this function.

Step - Enables user to specify a number of divisions. The motor is then incremented the correct number of steps for each division.

Angle - Similar to above except that the user inputs the angle the fixture is to be rotated through.

Run - The motor will run continuously with speed set by the user.

Jog - The motor can be nudged a preset number of steps.

The run function may be used to quickly move the fixture to a specific position. The jog function can be used to nudge the fixture incrementally. Although it is best to adopt standard practice and rotate in one direction only, the jog function may be used to take out backlash should a reversal be required. A default jog is one step, i.e. 1/50th of a degree. This can be changed by altering the relevant constant.

Changing constants in the code is

straightforward. If, as in my case, micro-stepping is dispensed with, then the relevant line in the programme must be altered to reflect this.

The screen shot in **fig. 3** shows the first section of the code. All lines defining constants begin with the command #define. The line defining micro-stepping has been highlighted. If no micro-stepping is being used, set this constant to 1, as per Gary's comment.

Similarly, if your stepper motor has a resolution other than 1.8 degrees, you can alter the relevant constant to make your motor work with the software.

Boxing Up

Once assembled and tested the indexing system was fitted into a diecast box. **Photographs 13** and **14** show the front and rear of the control panel. To make the layout less cluttered I used two paddle switches piggybacked on to the pushbuttons for menu navigation. A ruggedised push button serves to select menu items.

The Arduino, shield and motor driver are stacked and mounted to the rear of the panel by various stand offs. Mounting the boards in this way meant modifying them slightly to reduce height. This chiefly consisted of removing the screw terminals and repositioning two capacitors on the driver board, as well as moving the LCD contrast potentiometer to the opposite side of the shield.

Rectangular holes are milled in the panel for the LCD screen and the paddle switches. The power supply is mounted in the space below the switches and the mains lead enters via a strain relief gland.

Photograph 15 shows the stepper cables, protected with braiding, wired to a multi pin locking connector. This mates with a plug on the side of the box ensuring that the stepper lead cannot be accidentally pulled out during operation. This obviates the risk of damage caused by back EMF generated by the sudden collapse of the stepper's magnetic fields.

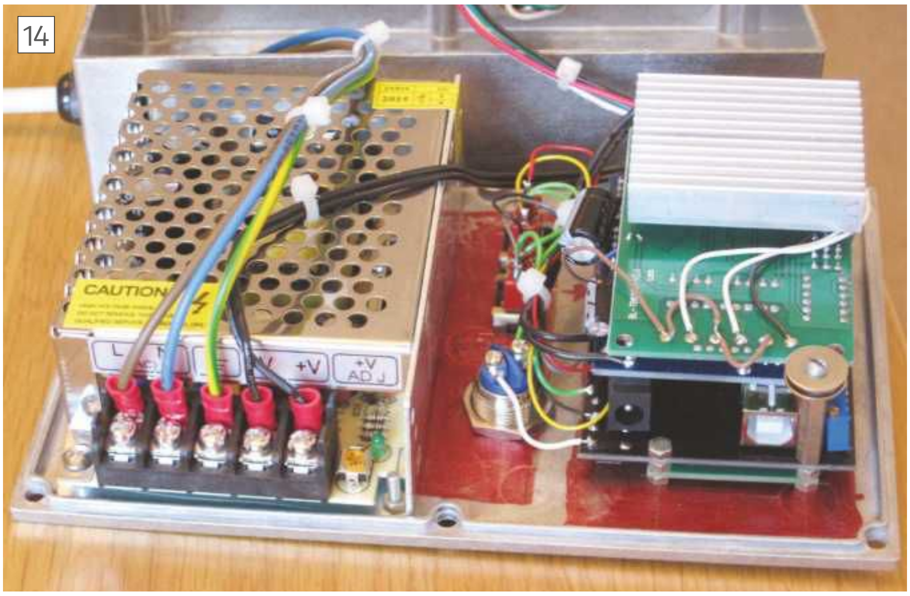
Concluding Remarks

Using an Arduino and online resources I was able to produce a capable indexing system in very short order and for reasonable outlay. Use of modular electronic elements eases system construction and minimises prototyping time. I hope this article has gone some way to showing how the Arduino can be used to solve problems in the Engineering Workshop. As mentioned earlier, the microcontroller and associated software is simply another machine element, to be integrated into a design as required. ■

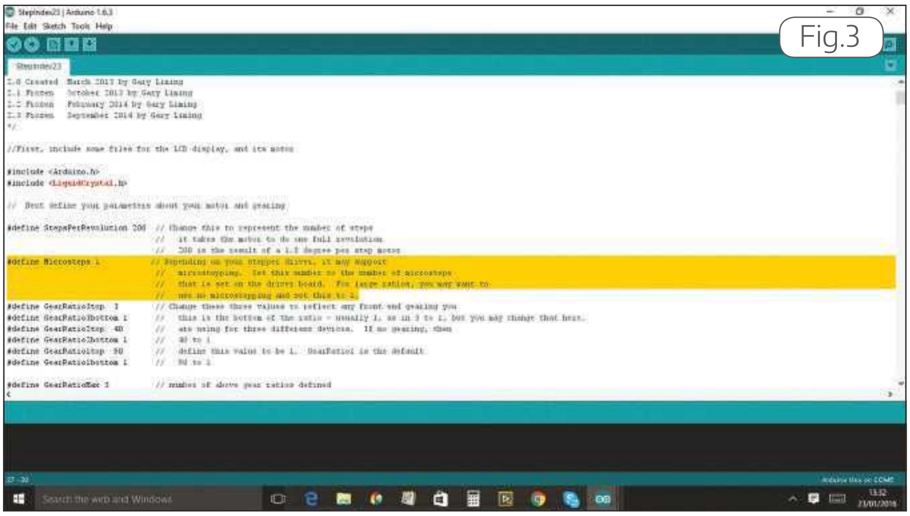
References

Ref 1 - http://www.digitalmachinist.net/wp-content/uploads/2015/06/DM8.4-Liming.zip

Ref 2 - https://www.arduino.cc/en/Main/Software



Rear of control unit front panel showing mounting of stacked control boards and power supply. 6BA mounting hardware. Mains lead enters through strain relief, stepper cables exit via locking multi pin socket.



Screen shot of Arduino IDE showing Gary Liming's step index software. Highlighted portion shows constant controlling multi-stepping.

Multi pin locking plug connected to stepper motor.

Novel Ideas

Murray Eddington describes some interesting ideas that may spark the imagination of readers.

I started thumbing through the latest MEW that landed through my letter box yesterday. The Editor was asking for some unusual ideas for tooling. Here's a couple:

Super Simple Boring Head

On the subject of boring heads, I reckon this is the simplest boring head you can come up with - almost boringly simple. It's just a piece of round stock with an eccentric hole bored in it, with 2 radial grub screws, that can be held in a standard collet, **photo 1**. You can vary the bore diameter by twice the eccentric distance, **photo 2** and figure 1. A graduated angular (vernier) scale would be ideal. I made a short post on the Model; Engineer forum about this some time ago, lost in the threads of time. **Photograph 3** shows some of the results.

Joining Pipes

When you join 2 pipes of the same diameter together at an angle on the same axis, the

Boring bar in eccentric hole

Effect of rotating the holder

Finished holes

Two pipes showing joins at 90 degrees.

Notched pipe

Set-up for notching


The setup from another angle


Another view of a notch


Two pipes joined


Die head for pipe bender

lines of intersection are always at 90 degrees, **photo 4**, regardless of the angle of incidence. So there are 2 basic ways of preparing pipes - either 2 flat cuts at 90 degrees (in planes perpendicular to the axes of the pipes, meeting and stopping where the axes coincide) or a cylindrical cut to one of them of the same diameter as one of the pipes ("pipe notching") as in **photo 5**. The former method is only applicable to pipes of the same diameter on a common axis. The latter works for different diameters and offsets.

A novel way to carry out the latter machining process is in the lathe. I fitted the hole saw part in a collet chuck and welded a piece of square bar stock on the slide of the original pipe clamp so it could be held in the toolpost, **photos 6** and **7**. Then you can clamp and present the pipe at almost any angle, use power feed and coolant and get a nice clean job. You can see the characteristic 90 degree lines of intersection that comes about naturally, **photo 8** and **9**

I made 3 sets of die heads for the pipe bender in the photos - for different pipe diameters, **photos 10** and **11**. The sectors were made from a single piece of steel. They were interesting to make, not least when one of them came loose on the faceplate. That's all part of the fun... ■

Pipe bending jig

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