A CLOCK WHEEL AND PINION CUTTING MACHINE

Charles Woodward
cuts his teeth

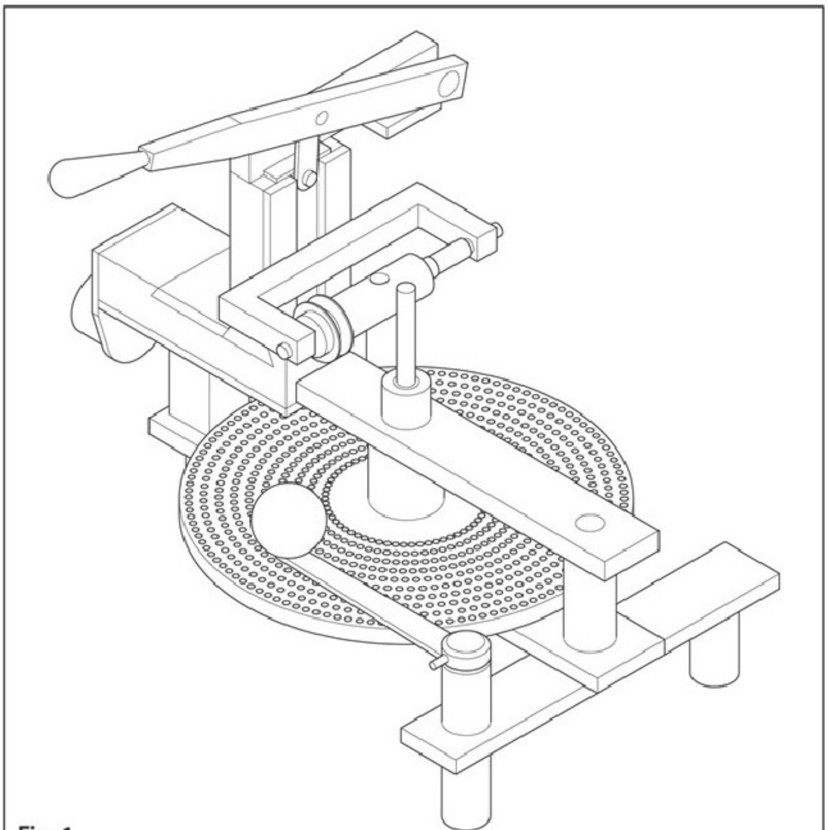


Fig. 1

Background

I decided to design a Wheel and Pinion cutting machine after I had received a "challenge" on a course at the British Horological Institute (BHI). I had been attending a Wheel and Pinion cutting course using a "conventional" type of wheel cutting engine and a pinion cutting machine.

Those of you familiar with wheel cutting machines will know it consists of a horizontal bar, which supports an indexing disc, through which a spindle passes which holds the work. The cutting tool is at right angles to the disc, and is arranged to slide parallel to the work spindle. The cutting spindle is mounted on a vertical slide and driven manually on the very old cutting engines (this design of cutting engine is extremely old). On more modern designs the cutter is driven by a small electric motor and a round elastic belt, see **Fig. 1** showing a traditional wheel cutting engine.

The pinion cutter we used was of a more modern design; in construction it was similar to a miniature horizontal milling machine with the cutter in a fixed position in relation to the motor, the pinion blank being fed up to the cutter and then traversed past to cut the pinion. An indexing plate was fixed to the pinion blank at the end of the table.

The design process

I found using the wheel cutting engine was very unsatisfactory. Having always worked in production engineering and machining components weighing several tonnes I expect machines to be built for purpose. The basic design of the wheel cutting engine is probably 200 years old and would originally have had the cutter driven by hand. At the time it would have been "Hi Tec" and one of the first purpose built machine tools. As such it would have been well suited to its task. The modern version has simply substituted a motor drive for hand operation. There have been a number of machines in the past which have been designed to overcome the limitations of the wheel cutting engine whilst retaining the original layout. These machines would be more efficient at cutting clock wheels but would not have the rigidity to cut steel pinions.

I found the limitations of the wheel cutting engine I used to be:

a) The basic layout had a horizontally fixed plate allowing brass swarf to be liberally deposited onto the indexing plate and consequently blocking the indexing holes.
b) Because the motor was fixed and the cutter position adjustable, the motor belt had to be very elastic. This ensured lots of belt slip was available, with consequent cutter jamming if the cutter was not fed through the wheel blank very gently and evenly.
c) The design is fine for hand operation of the cutter but too flimsy for motor drive, which will produce higher cutting forces. Various designs have overcome these objections in the past and the basic design has been strengthened and modified for cutting wheels, but not apparently, for combining the two functions.

Using the pinion mill was no problem and it was a pleasure to use, because of the fixed cutter position in relation to the drive motor constant tension could be applied to the drive belt, and the machine was solid enough to absorb the much greater forces experienced when cutting steel pinions.

Like all things in model engineering (I consider the type of clock making I do as a branch of model engineering, just as making a steam train, boat, or tool and cutter grinders, to me, are all aspects of model, or perhaps I should say miniature engineering), there is more than one way to skin a cat. For the small number of clocks I am likely to produce I could just as easily cut the wheels and pinions on my milling machine, or have made a portable milling spindle. I could then cut them both on the Myford, but I like a challenge, also I like making and modifying machines so a purpose built machine it would have to be.

The basic requirements for a combined wheel and pinion cutting machine

1) The machine must cut pinions and wheels equally efficiently.
2) The drive to the cutters must be constant for all conditions and not dependant on belt drives with variable centres,
3) Swarf must be controlled and not fall on the indexing plate.
4) The machine should be simple to set.
5) It must be quick and simple to change from wheel cutting to pinion cutting.
6) Dividing should be accomplished using the minimum number of dividing plates.

I would use a layout with a vertical indexing plate because of problems mentioned earlier. If money was no problem, I could have bought a CNC indexing device and eliminated any problems of swarf blocking indexing holes completely. However, to me, money is a big consideration and I did not feel I could justify spending too much on what would be an experimental machine. A CNC indexer could always be retrofitted.

With these criteria in mind, I sketched out a basic design configuration for the machine and looked around in the workshop to see what materials I had available. I started building the machine around some 1in. square BDMS and a cast iron block I had purchased to make a new slide for a lathe I had previously owned.

The machine in this article is the much modified original machine, with a number of modifications which were applied as I thought them necessary or desirable.

I think it took me around 12 months to make, I was in full time employment at the time, I am now retired and recently made a Stent tool and cutter grinder in about the same time, so in real time this machine was designed and made faster than the Stent. With the Stent a lot of time was spent drawing it in 3D CAD. I made only a few GA drawings and no detailed drawings for the wheel and pinion cutter. These were taking longer to prepare than the machine took to build, and I keep thinking of further refinements which would have, of course, to be incorporated into the final drawings.

At the time, I made the machine about 9 years ago I did not have access to CAD, which would have made the design process a lot easier and quicker.

Design details

The slides

The two slides are at right angles to one another to provide adequate adjustment for cutting wheels and pinions and to provide the drive to the cutting spindle from a fixed point. The slides are made from 12mm dia Silver Steel and the slide assembly is tilted through a 30deg. angle ensuring swarf falls clear of any working parts and giving a reasonable view of the cutting area for wheels and pinions. **Photo 1** shows a general view of the machine showing the machine set to cut wheels. **Photo 2** shows the rear view of the machine with the tool tray removed.

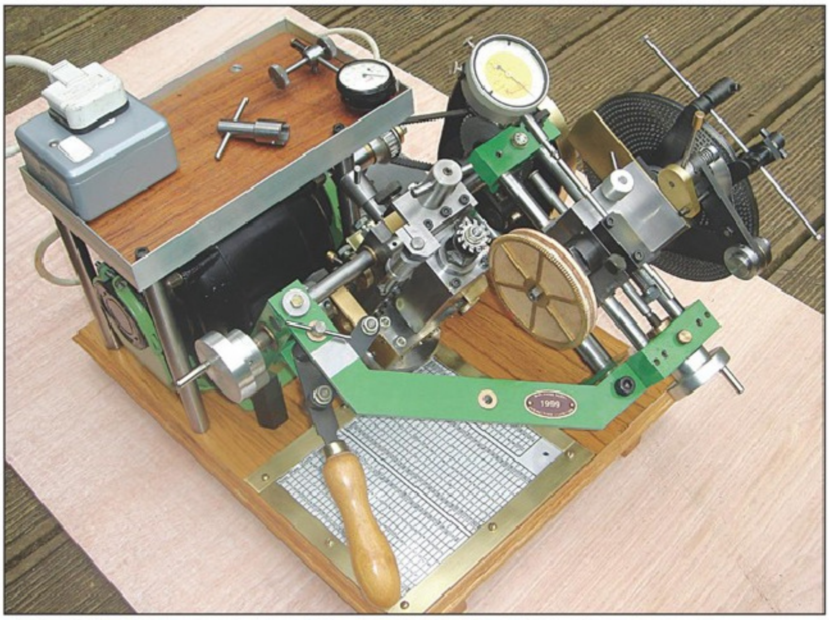


Photo 1. Shows a general view of the machine set to cut wheels.

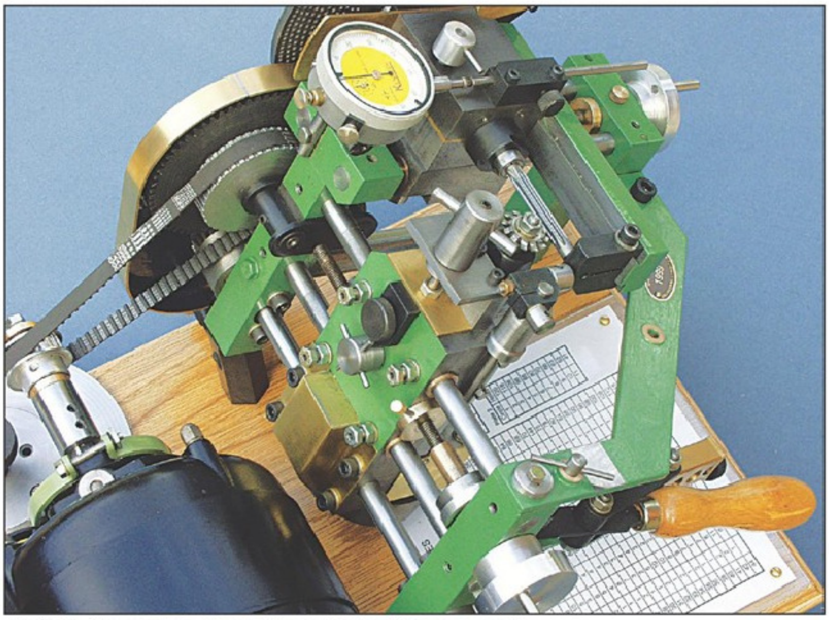


Photo 2. A rear view of machine with tool tray removed.

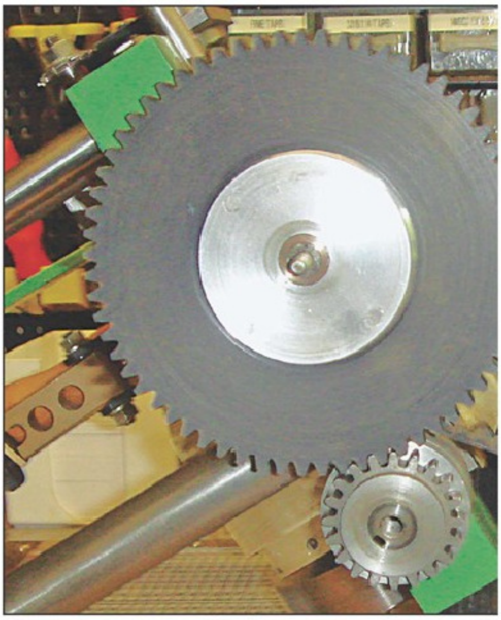


Photo 3. Shows the pick off gears.

The cutter drive train

The motor is mounted at the rear of the machine and drives the cutter via two pick off gears giving cutter speeds of 233 and 2450 RPM; the gears are reversed to change speeds. A limited slip device using Belleville washers and mounted on the motor shaft reduces the kick when the machine starts at the higher speed. Drive to the cutter spindle is by a pair of skew gears, the drive shaft being parallel to the cutter slides.

Photo 3 shows the pick off gears; the large gear was made on the machine out of a plastic disc. **Photo 4** shows the limited slip arrangement on motor shaft and **photo 5** is of the skew gears and flywheel at the rear of the machine with the motor removed.

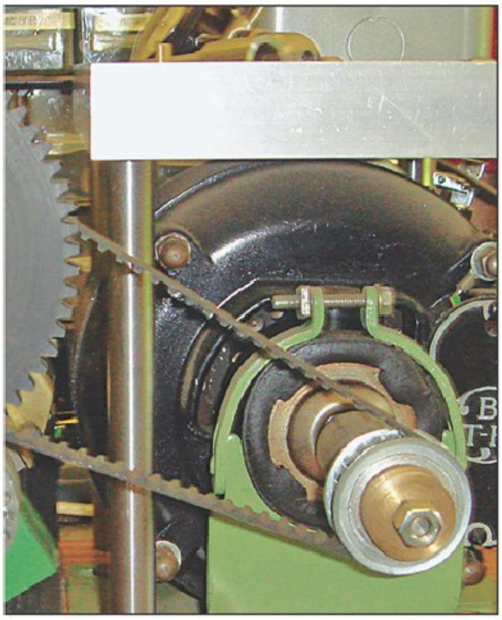
The spindle

The cutter spindle is mounted on a slide giving vertical adjustment to the cutter; a cutter centring device is used to ensure easy and accurate centreline adjustment. The cutter spindle bearing arrangement is to my own design using a double combined thrust bearing at the front of the cutter spindle and ball bearings at the rear. A heavy flywheel fitted to the cutter spindle evens out any tendency to "lumpiness" when fly cutting. **Photo 6** is a side view of the cutter setting device and **photo 7** is a top view of the cutter setting device. **Fig. 2** is of the sectional view through the spindle.

The handle and screw feed of the cutter slide

This was designed to act as a traditional lever feed when cutting wheels from brass and screw feed for cutting pinions. The lever clamps onto the feed screw for the cutter spindle carriage and a stop is adjusted to provide movement via the lever. When the lever is disconnected (one thumbscrew), the stop is clamped against the frame to provide screw feed. **Photo 8** shows the actuating handle assembly in use for cutting wheels, note the top bar has been removed for clarity.

Photo 9 is the actuating handle assembly.



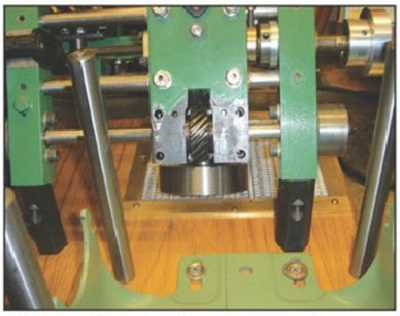


Photo 5. Skew gears and flywheel viewed from the rear of the machine with the motor removed.

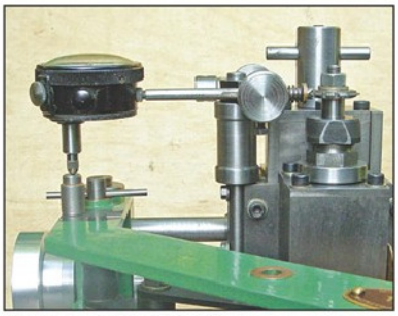


Photo 6. A side view of the cutter setting device.

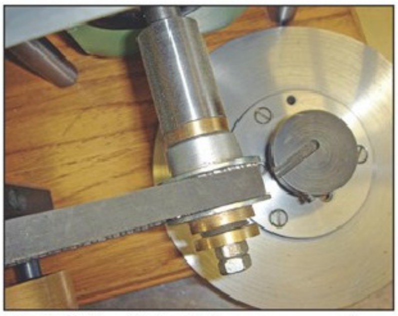


Photo 4. The limited slip arrangement on the motor shaft.

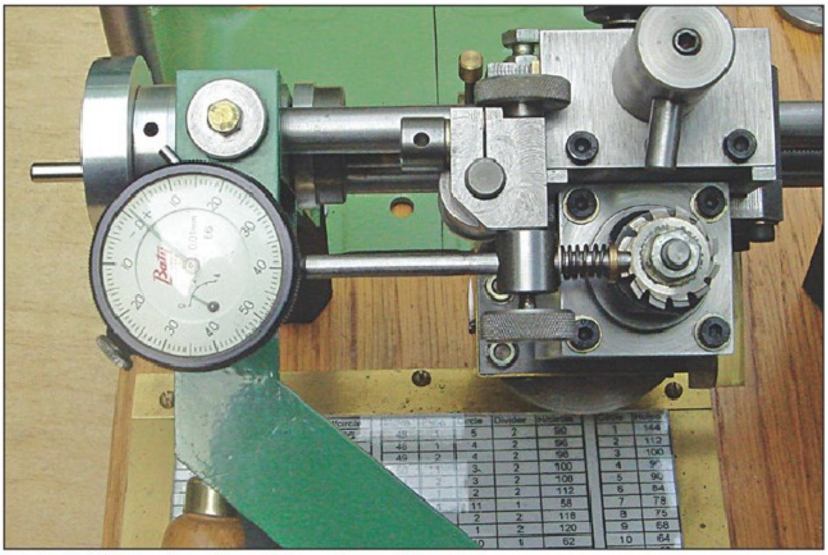


Photo 7. This is a top view of the cutter setting device.

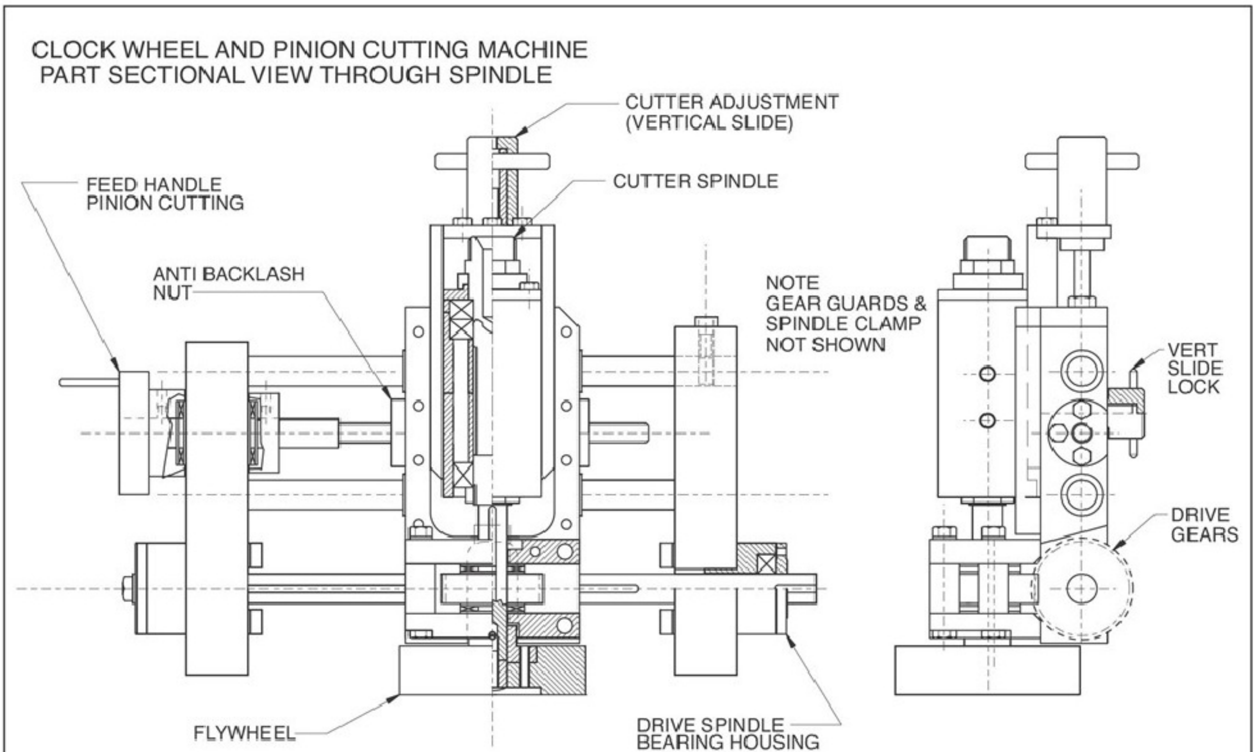


Fig. 2

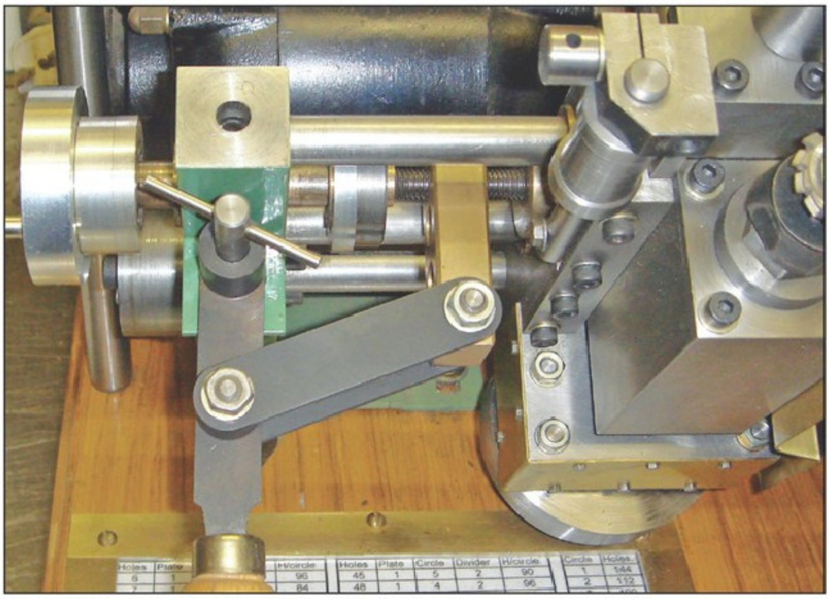


Photo 8. The actuating handle assembly in use.

The work head

A dial indicator fitted to the workhead dispenses with the normal requirement for accurate screws and divisions on the hand wheel; the indicator can be graduated in either millimetre or imperial dimensions as required. The workhead is moved by an actuating rod with a limited amount of thread (approx 1in.). This thread screws into the actuating handle fixed to the frame and is sufficient to give adequate movement of the carriage into the workpiece after first moving the carriage manually. In operation, the carriage is moved into an approximate position and clamped to the plain portion of the actuating rod. Using the handle, the wheel or pinion blank is wound towards the cutter until it just touches the wheel or pinion blank. The dial indicator is then set to zero using the measuring rod attached to the top of the carriage.

The advantage with this method is the carriage can be unclamped from the actuating rod and moved out of position. The division sectors are set to span the number of holes required and then

Photo 9. The actuating handle assembly.

Climb milling of pinions

This is controversial, but at the time I considered it necessary in order to direct the cutting forces into the work head. It was necessary to design the machine to cut wheels towards the work head in order to give enough support to the wheel blanks. Unless the spindle was reversed I would have to cut pinions in the same direction. I devised a very simple anti backlash nut on the spindle carriage, which can be applied or removed by a lever. This makes it possible to sink the cutter into the pinion blank adjacent to the work head (no undercuts to start the cutter required) and machine the pinion towards the blank support. Because of cutter action, climb milling is much easier on the cutters which should last longer, but it does require some kind of anti backlash device.

In industry, climb milling is always preferred on CNC machines and all such machines are equipped with precision ballscrews as anti backlash devices. I used a standard off the shelf piece of screwed rod for the spindle carriage screw and with my antibacklash nut, low cutting forces and manual operation succeeded in making it work. I plan to replace the screw one day with one I will cut in the lathe as the screwed rod I am using is a bit uneven. **Photo 10** shows the anti backlash nut with actuating lever. **Photo 11** Is of the pinion blank with the removable pinion support in place.

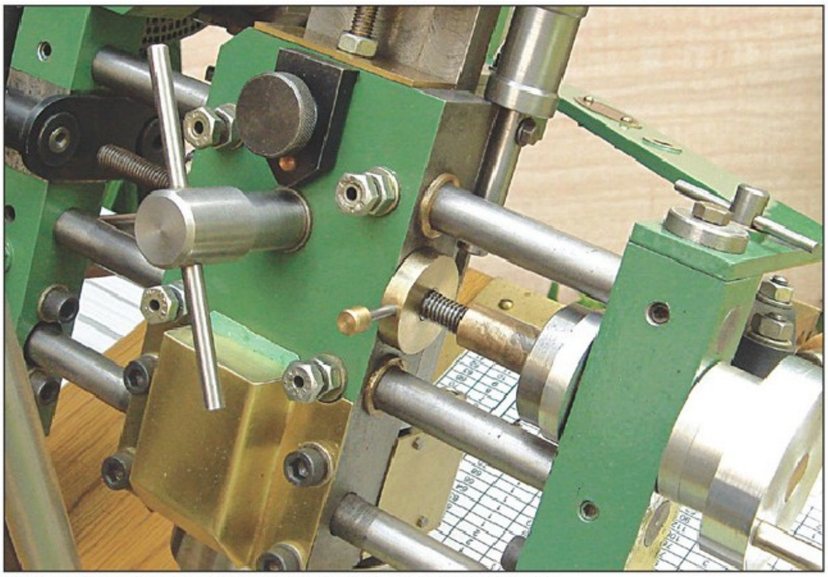


Photo 10. Shows the anti backlash nut with actuating lever.

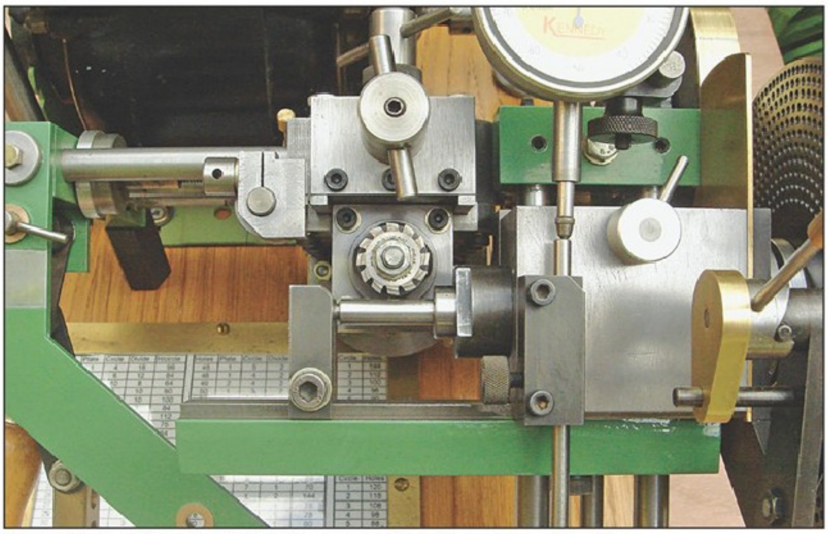


Photo 11. A pinion blank with the removable pinion support in place.

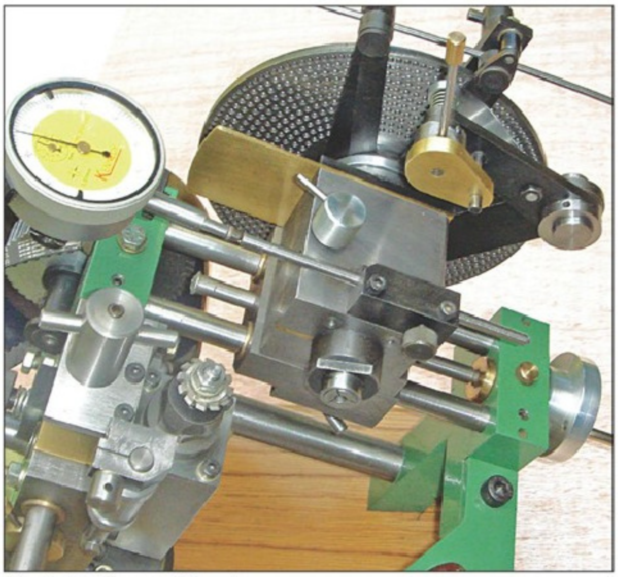


Photo 12. The work head.

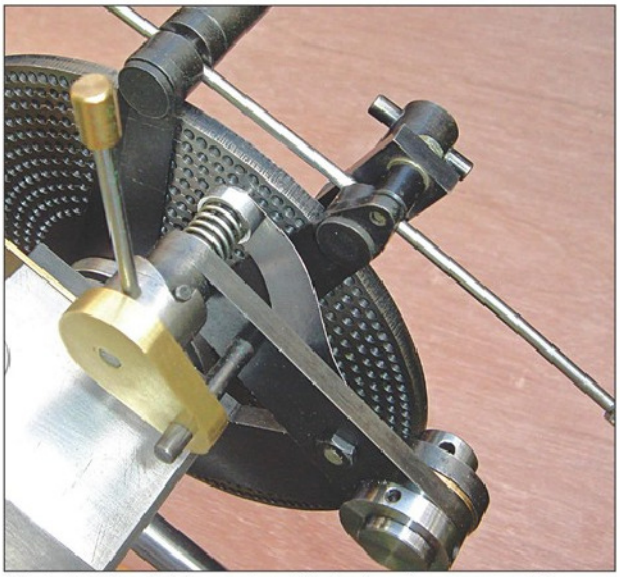


Photo 13. The division sectors & indexing plunger assembly.

clamped together using the connecting rod. The division sectors can also be clamped to the indexing plate; the work may then be rotated for inspection. When this is complete, the workpiece is rotated back to its original position with the division plate plunger against one of the sector arms. The carriage can now be returned to an approximate position before the full depth of cut, clamped to the actuating rod and wound back to its original setting against the measuring rod. An additional clamp is provided below the workhead which clamps the work head against the ways. **Photo 12** shows the work head.

Division plunger

This combines a coil spring and a flexible spring return with a rigid and accurate plunger location. This easy to disengage plunger has a cam device. The traditional fine adjustment of rotation of the division plate has been retained with an eccentric on the plunger arm. **Photo 13** shows the division sectors & indexing plunger assembly; the eccentric bush to obtain fine movement of the division plate is at the bottom of the picture.

Division Plates

I made two division plates to cover as many tooth combinations as possible, the number of holes in each plate are as follows:

Plate 1 144-112-100-96-90-84-78-75-68-64-58

Plate 2 120-118-108-98-88-80-70-66-63-62-41

The chart fixed below the cutting area is covered with Perspex for quick reference, and easy set up. **Photo 14** is of the two division plates; the total hole count for the plates is 1883 holes; yes, it took me ages to drill them. I did get 1 hole wrong, which was bushed.

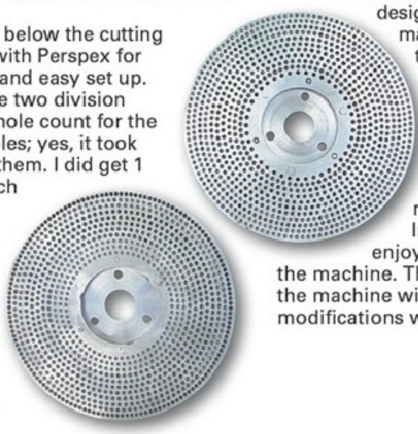


Photo 14. The two division plates.

The tool tray

This slides under the base of the machine and contains all the tools needed to set and operate to machine, **photo 15**.

Photo 15. The tool tray.

Has the machine been a success? Did it do what it was designed to do? Although I haven't used the machine a great deal, I do find it easy to set up and use. It is particularly good at cutting wheels and will machine brass wheels without hesitation.

Because of the vertical indexing plate and the shield (the brass plate in **photo 11** on the LH side of the workhead) I am not troubled by swarf. Indexing is trouble free and a real effort is required to miss index. The chart on the base of the machine makes it simple to set up the indexing.

Pinion cutting in Silver steel is of course much more difficult than cutting wheels in brass, but the machine does what is required of it. It is possible to sink into the blank and climb mill a 0.75 module pinion in 2 cuts per leaf (depth of cuts 1mm), with a good finish. When climb milling, the anti-back lash nut works satisfactorily and, as anticipated, it is better to sink the cutter into the blank near the workhead than near the support, although it is possible to machine pinions both ways (towards and away from the work head).

Would I change anything about the design of the machine? The main change I would make is to beef up the spindle slides to 16mm diameter and space them wider. I think this would make the spindle carriage more stable, it should then be possible to cut 0.75 module pinions in 1 cut.

In conclusion, I really enjoyed designing and building the machine. Thinking of the way to build the machine with its various wrinkles and modifications was very stimulating. I got on a "roll" and looked forward to the next session working on the machine, which is probably why I built it in so short a time. I started in model engineering some 34 years ago, after seeing a M.E. exhibition at Stockport. I started building a Simplex as I was advised that this was a good engine for a beginner. I am still making it and with a fair wind hope to finish this year. I have found making something like a machine, or a clock, gives you complete freedom of action, without constraints, (I suppose the same is true of steam and I.C. engines) which I find more stimulating than making models to a plan. Not sure what I will be making next but a wooden clock made according to John Harrison's principles is high on the list of top ten things to make, or perhaps a steam lorry, we shall see.

Machine Specification

- Spindle speeds 233 RPM and 2450 RPM from pick off gears.
- Maximum dia of wheel the machine will cut is 125mm (5.0in.), this represents 144 teeth at 0.8 module.
- Length of pinion the machine can cut is 38mm (1.5in.).
- Tooth spacing is by 2 division plates with an adjustable divider. Indexing plates can be changed without removing the component from the chuck.
- Cutter centring is by self centring device which automatically puts the cutter on the centre line of the wheel or pinion blank.
- Approximately Weight is 25-30kg. ■