

Hoping to Graduate

Although I like to work to the highest standard possible, I know that my performance usually falls short of my aspirations. I recently purchased some equipment from a man whose health had caused him to cease model engineering. Like many model engineers, Elvet Goodwin's workshop was part of his garage, sharing space with the washing machine and the car. His workshop once featured in *Model Engineer*. (Ted's Travels ME 17th March 1995.) One item I purchased from Elvet was a small rotary dividing table which he had built to the MES design from castings. (Photo 1).

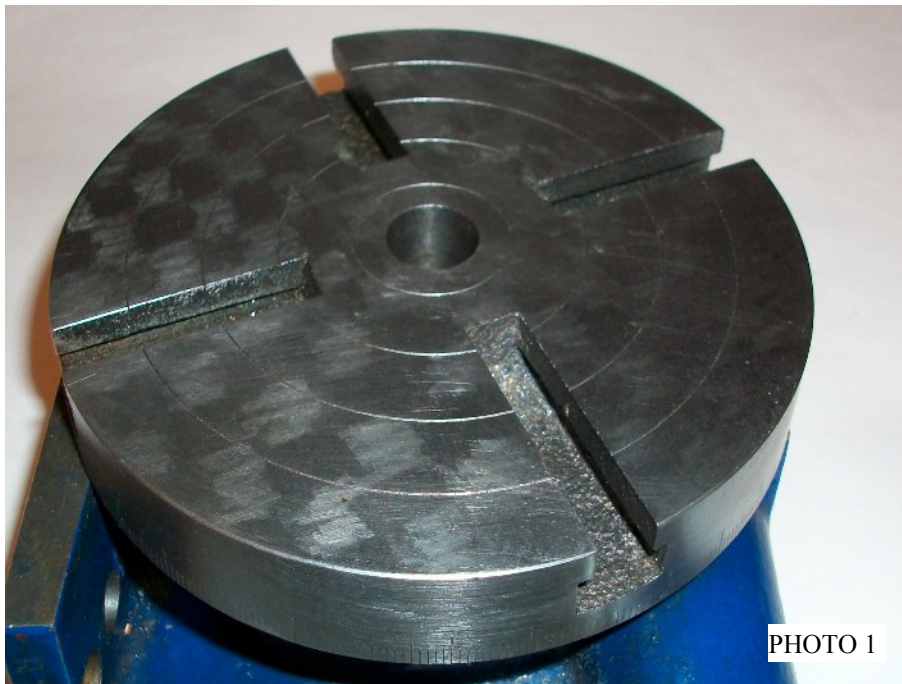


PHOTO 1

The care he had taken was exceptional. Whereas I would have been satisfied with a machined surface on the table, Elvet had scraped the table to a perfectly plane surface.

Elvet's health had prevented completion of the project, and he had not yet graduated the table. I sometimes feel that taking on someone else's project is taking on their mistakes. However, it is also taking on their achievements, and in this case the achievements were considerable. I am very conscious that although I have far superior workshop resources to those available to Elvet, I will be hard pressed to match his workmanship.

I had never done any graduation work before, and gave some thought to the approach I would employ. Following standard practice, I would make the marks at 10 degree intervals the lon-

gest, with the 5 degree marks intermediate and 1 degree marks shortest. The photograph shows the setup on the Astra Mill, (Photo 2) which I had also purchased from Elvet.

The table is fitted with a digital readout, but the response time is modest and the digits small, so I decided to rely on my clock gauge for determining the length of the graduations. However, I first checked that the DRO and clock agreed with one another. This proved a useful precaution since the job was interrupted several times and the clock gauge was inadvertently disturbed more than once. With reference to the DRO, I was able to reset the clock gauge readily.

I realised that trying to carry out the graduation one degree at a time would be fraught with difficulty. In this case, one degree was equal to 1/6th of a turn of the index arm. Trying to keep track of which length of mark I was supposed to be scribing would be asking for trouble. It would also be too easy to waver slightly in positioning the index arm in such a small fraction of a turn possibly introducing some backlash error as a result.

I decided that the best approach was that at each move I would advance the table by an amount which would ensure positive drive to the worm. I also decided to graduate the 10 degree marks first, followed by the 5 degree and finally the individual degree marks. In that way I would avoid confusion over the length of any particular graduation.

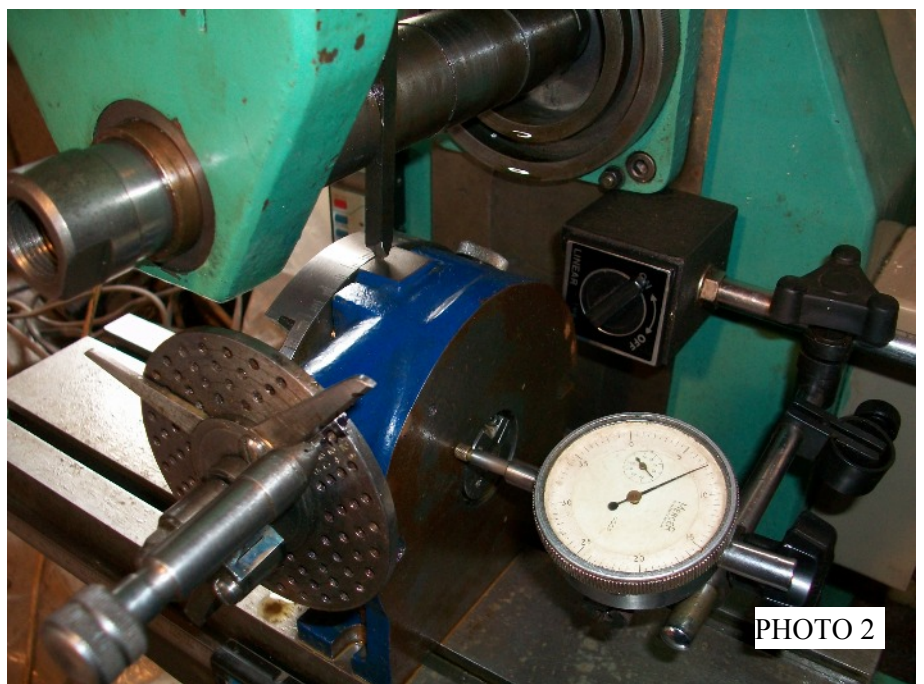


PHOTO 2

The penalty is that instead of requiring only 60 full turns of the index arm, the job would require rather more than that. Ten degrees corresponds to 1 and 2/3rds of a turn, so with the fingers set for 2/3rds of a turn, I proceeded to graduate the 10 degree marks. On completion, the cutter arrived perfectly in line with the first mark.

I was pleased to see that I had not skipped any holes along the way. I then indexed forward 5 degrees and repeated the exercise, graduating the marks to the intermediate length. I was comforted to note that the new graduations fell neatly between the 10 degree marks as they ought to do. Once again completion brought the tool directly in line with the first of the 5 degree graduations, confirming that I had not lost the place.



PHOTO 3

The 1 degree graduations remained to be done. With marks now made every 5 degrees, error would be picked up readily and could be corrected. However, I remained conscious of the possibility of backlash creeping in through indecisive movement of the index arm.

I decided to continue as I had begun, but to simplify matters, instead of using one and 2/3rds turns, I would make one complete turn of the index arm at each step. This advanced the table 6 degrees each time. In addition, every fifth turn would bring the cutter in line with one of the existing marks, providing an ongoing check that everything was in order. Having completed another circuit, I advanced the table one degree and repeated the exercise.

In hindsight, for the reasons I have given regarding backlash, I would

have been better to advance the table by 7 degrees before starting each circuit. In the event I could see no visible error resulting from my use of a single degree step at the start of each circuit. I found the exercise rather satisfying as the gaps between graduations which have a somewhat random appearance in the early stages, were progressively filled in until the process was completed. (Photo 3)

As can be seen from the photograph, there is a slight gap between the table and the face on which the datum mark is scribed which means that reading the graduations to better than half of one degree is a bit optimistic. I have always been something of a fan of vernier scales, and intend to make a close fitting curved vernier to attach to the table at some time in the future. However, with the table set up in the mill, the temptation to make an "Approximate Vernier" proved too much for me to resist, despite the apparent contradiction in terms.

I settled on a resolution of 0.2 degree as my target, requiring 5 divisions each side of the central datum. These 5 divisions take up the same length as 4 degrees, so that each gap corresponds to 0.8 degree. Consequently the distance the table must move between alignment of one vernier mark with a table graduation and the next vernier mark with a table graduation is 0.2 degrees.

The finished diameter of the table was 5.1". One degree works out at 0.044506" on the circumference. This gives 36 thou for 0.8 degree. So the 5 gaps would each be 36 thou. This completes the Vernier calculation. The necessary graduation marks were soon made. (Photo 4)

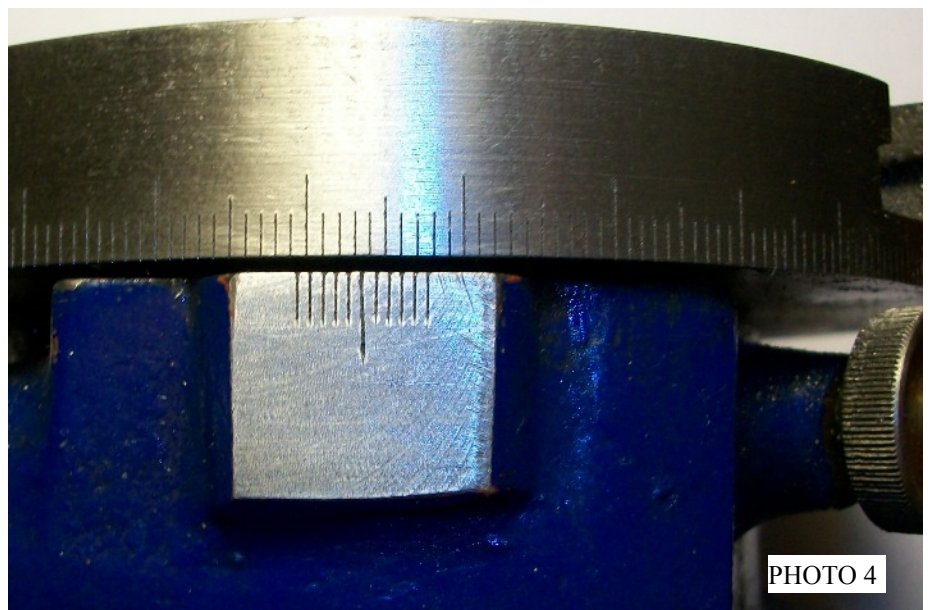
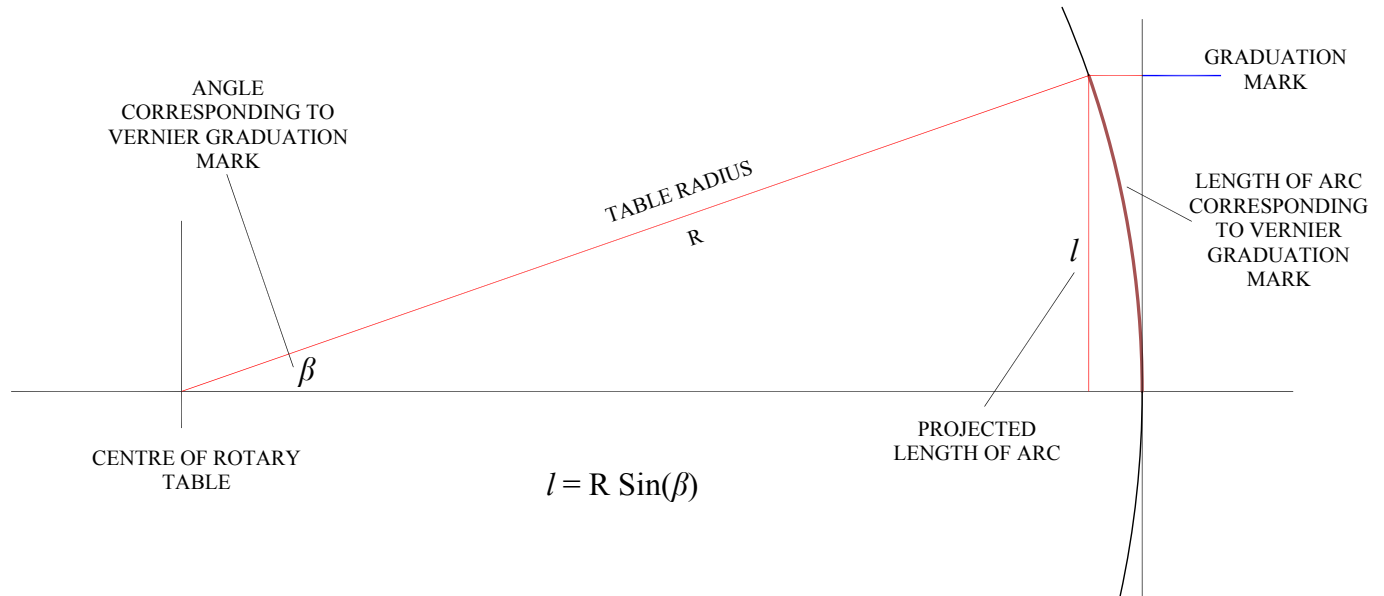


PHOTO 4

No sooner had I finished the vernier graduations than I realised that I had not thought the problem through fully. The surface on which the original datum is marked is a flat surface. I did not wish to machine this to match the curve of the table, so that when I make an accurate curved vernier scale it will be easy to secure. Consequently each mark further away from the original datum mark is also slightly further from the table. The figure below illustrates the problem.



The 36 thou settled on in the vernier calculation is a circumferential distance which is projected onto the flat surface. The projected length is determined by taking the product of the radius of the table and the sine of the angle between the central datum and the vernier line under consideration. The table of values shows the figures I ought to have used.

ANGLE	ACTUAL CUMULATIVE GAP LENGTH	CORRECT PROJECTED LENGTH	ERROR
0.8	0.036	0.0356	0.0004
1.6	0.072	0.0712	0.0008
2.4	0.108	0.1068	0.0012
3.2	0.144	0.1424	0.0016
4.0	0.18	0.1779	0.0021

At 0.8 degrees the difference is under 0.5 thou increasing to just over 2 thou in the total length at the fifth division. The difference between the arc length and the projected length is actually *much* less than the error caused by my rounding the calculated arc length to 36 thou. Allowing for parallax error, exacerbated by the physical gap between the datum surface and the table, and considering the error due to the thickness of the graduation itself, there would be little point in seeking any higher degree of accuracy than is provid-

ed by using the figure of 36 thou. For those reasons I had regarded the vernier scale as an approximate one from the outset. Nevertheless, the unnecessary systematic error I introduced annoys me. I should have thought the problem through fully, but was just too impatient.

One of the strengths of the vernier arrangement is that successive vernier lines can be judged as being to the left or right of corresponding graduations so that the

final reading settled upon is a visual average of three or more lines.

Just the same, I am well aware of what is going to happen whenever I try to take a reading. That scale is going to accuse me of being sloppy. One of the lines beside the datum will snigger, *"Tee He, I'm half a thou to the left!"* Then its opposite number will retort *"So what! I'M half a thou to the right!"* The extreme lines will pipe up together. *"That's nothing. We're BOTH more than two whole thousands away from where we should be!"* One of the other lines will moan *"I don't mind being a bit out of place, but I wanted to be slim for MY graduation and he's made me much too WIDE!"* At that there will be a chorus of *"We're ALL too WIDE."* *"That clown hasn't a clue what he's doing. Look at all the facilities he has and he can't even draw US properly!"* With that, all the graduations will start giggling and dancing about before my eyes so that I won't have the slightest chance of making any meaningful reading. I should have quit while I was ahead.

Numbering the scale is for another day, but I hope Elvet would not be disappointed with progress so far.