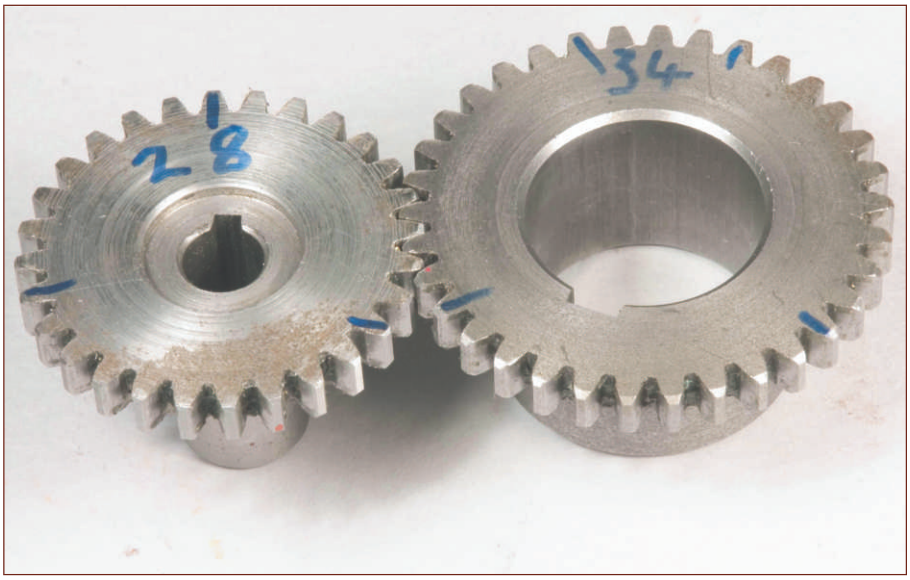
MODIFICATIONS TO THE X3 MILLING MACHINE

Dick Stephen makes further changes in search of perfection

Replacing the gear drive with an HTD belt



1. The two drive gears removed from the mill.

The first modification I carried out after the retro fit on the X3 was to replace the two gears on top of the head with an HTD belt. Naturally this requires that the motor runs in reverse sense. Fitting the belt drive wasn't quite as easy as I had initially envisaged. The problem, I soon realised was that the belt had to be fitted between two existing shafts. Further, the available belts only come in specific lengths. As a consequence I had to spend quite some time experimenting using CAD until I found a suitable combination of pulleys and an available belt that would fit correctly between the two shafts. The combination I eventually came up with used a 300 mm 5 mm pitch HTD belt, a 30 tooth drive pulley and a 32 tooth spindle pulley. This combination gives a speed ratio of 0.9375:1 and, compared to the original gear arrangement, an increase in spindle speed of some 14 percent. The next problem I encountered was the pulleys. It proved to be impossible to use commercially available pulleys as these would not fit in the space available. The only option was to make the pulleys myself. By this time I was beginning to have severe doubts about the eventual outcome of the project. The major problem that I now faced was making the spindle drive pulley. I couldn't risk modifying the spindle gear or for that matter the drive

Background

The majority of milling machines available to the model engineer are essentially general purpose machines. If like me, you have a rather specialised interest, mine being clocks, the standard "off the shelf" machine may not precisely suit one's specific requirements. To get around this problem it may be necessary to modify the machine to suit your own particular requirements. This does not imply that there was anything wrong with the mill as delivered, rather you want something just a bit different. This was the situation when I took delivery of the X3 mill from Arc Euro Trade. The mill was delivered in first class condition, this however did not deter me from starting to dismantle it as soon as it arrived.

During the dismantling process, modifications, other than the CNC conversion, to configure the mill to my specifications occurred to me. Readers will already have read the earlier articles covering the CNC conversion I carried out. I use CNC for profiling the plates of the skeleton clocks I design as construction projects. The finish of components profiled using CNC depends critically on the amount of vibration generated during cutting. Vibration can arise from a number of different sources. Significant table vibration can generated by the stepper motors, particularly if they are driven in what is known as full or half stepping mode. The majority of stepper motors used for CNC require 200 step pulses to make one complete armature revolution (full step mode). In half step mode the number of pulses is doubled to 400. At most feed rates it is easy to feel each individual step by the vibration generated in the table. This vibration can be almost eliminated by using micro stepping drives, such as the Gecko 201 or Arc Euro Trade drive units. The Gecko units that I have been using increase the number of steps by a factor of 10 to 2000 steps per revolution effectively almost completely eliminating the vibration.

Another potential source of vibration is the mill spindle drive. Almost all the mills available to model engineers are Mill/Drills. The drill facility requires that a sliding spline feature be incorporated in the spindle. In order to slide freely, the spline must have a little clearance, and under circumstances involving intermittent cutting, is a significant source of tool vibration.

In the X3, the gear drive in the head (which must necessarily have slight backlash) is therefore a further possible source of torsional vibration. The drive is taken from the motor by toothed belt to the input shaft of the two speed gearbox, through the gears in the box and from its output shaft by a pair of gears to the splined spindle. This last pair of gears was thought to be a significant source of noise/vibration, and therefore I replaced this part of the gear drive in the head with an HTD toothed belt drive. This was a very successful modification since it not only eliminated much of the head vibration but also reduced the noise level when the machine was running. Later on, I thought more about the splined spindle, and came up with a completely redesigned head, which will be the subject of a future article.

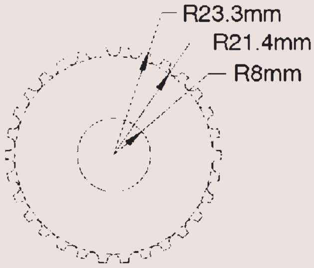


Fig. 1 30 Tooth drive pulley

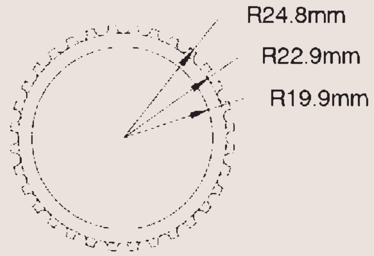


Fig. 2 32 Tooth spindle pulley

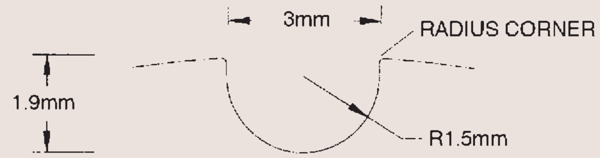


Fig.3 HTD pulley tooth profile

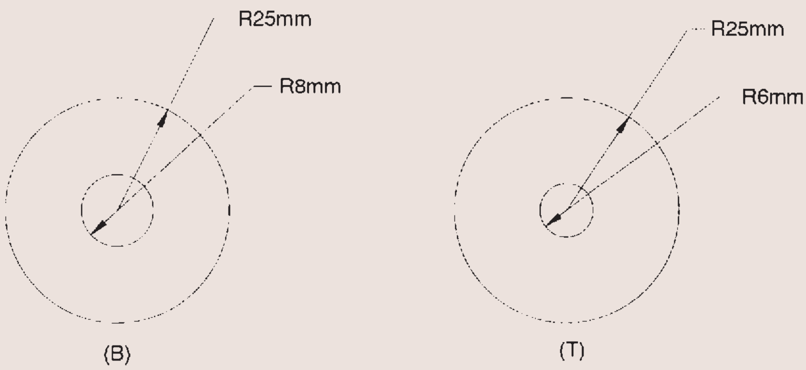


Fig.4 Drive pulley flanges

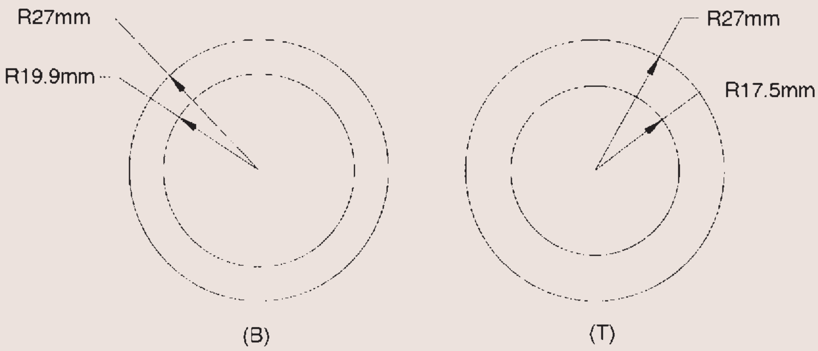


Fig.5 Spindle pulley flanges

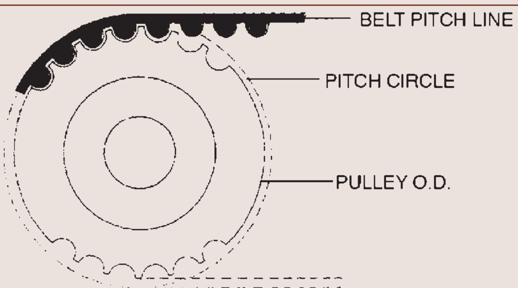


Fig.6 Belt and pulley

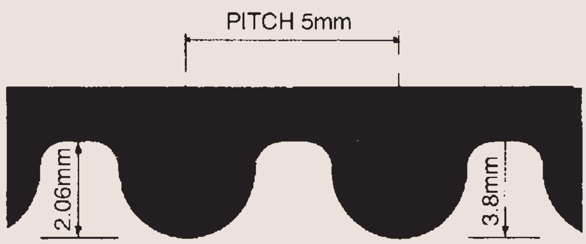


Fig.7 Belt detail

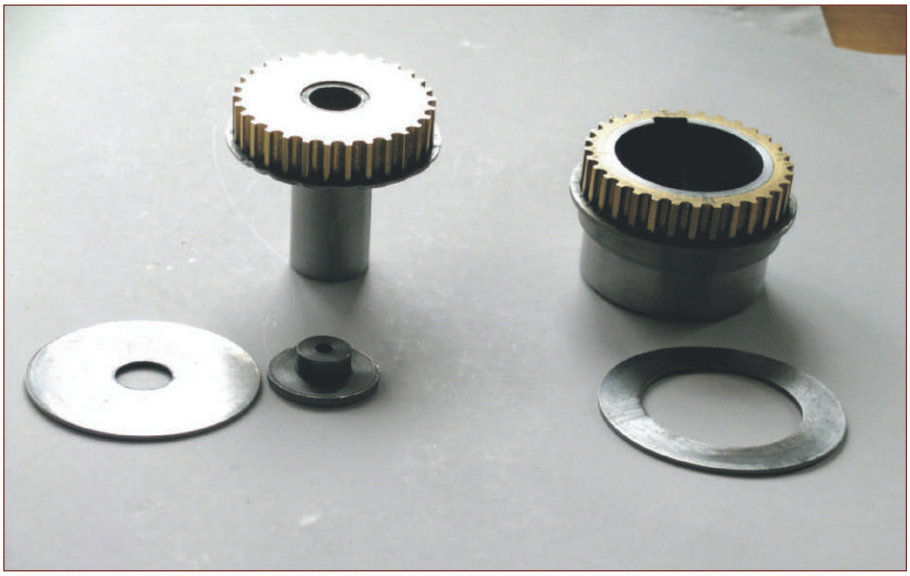
gear (see **Photo 1**) to fit the HTD pulleys in case the project didn't work. I would then be left with an unusable mill. All I could do was to remake the both units from scratch shown in **Photo 2**. This was rather difficult, particularly cutting the keyways by hand. Eventually both pulleys were made and fitted to the head and the belt attached. I have to say I was very relieved that the modification worked perfectly and produced the significant reduction in both vibration and noise that I had hoped for. Fortunately readers will not have to undergo the same problems I encountered, as, now that the system has been proved, they can modify the spindle and drive gears to fit the HTD pulley with confidence. The modification has recently been carried out successfully by a friend who recently bought an X3. He like me was delighted with the reduction in the noise level.

Making and fitting the HTD pulleys

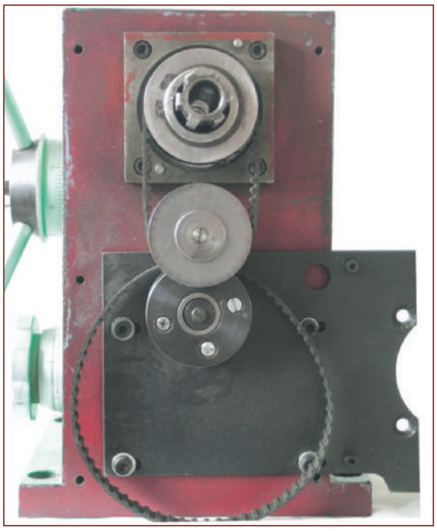
The HTD belt drive was designed for a 9.0 mm wide 5 mm pitch 300 mm long belt. To allow for a bit of belt freedom the pulleys were made 9.5 mm in thickness. This is the maximum thickness of pulley that can be accommodated under the head cover. The dimensions of the 30 tooth drive pulley and the 32 tooth spindle pulley are shown in **Fig 1** and **Fig 2** respectively. The outline for the tooth belt profile is shown in **Fig 3**.

The pulleys can be made in two ways. You can make the pulleys as I did out of brass and machine the existing gears to accommodate the pulleys. The pulleys are then secured to the machined gears with Loctite 326. If you decide to make the pulleys as separate items as I did then use free machining brass or aluminium. I used brass for my pulleys as I had two suitable oddments in my scrap box. Alternatively it may be possible to reduce the diameter of each gear, and then cut the pulley profiles directly into the steel blanks, or machine replacement items from scratch. How you decide to proceed will depend on the machining and dividing facilities at your disposal.

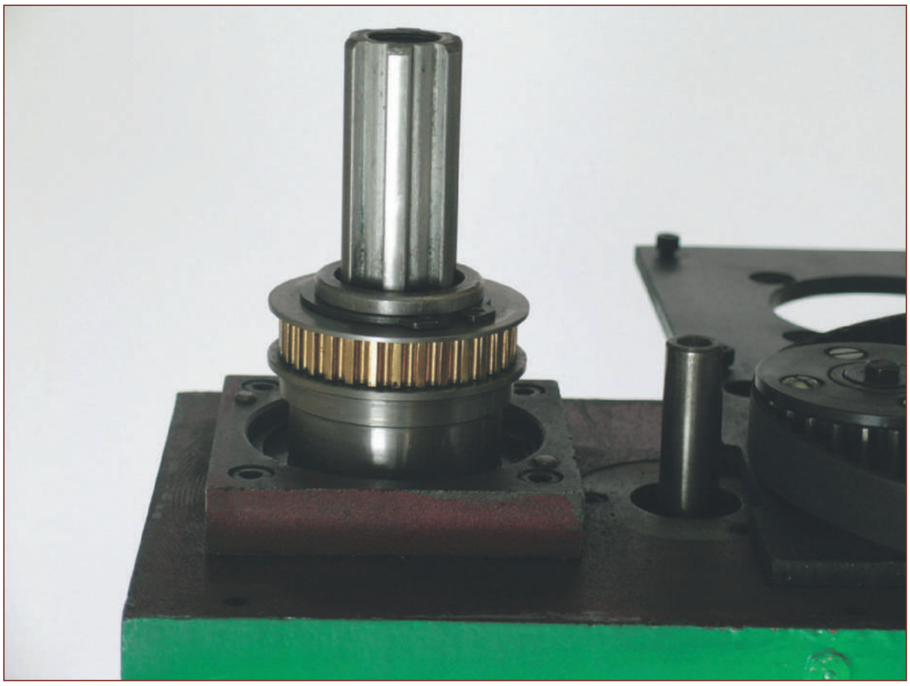
Begin by turning the two pulley blanks to the diameter shown in **Fig 1** and **Fig 2**. The blanks were mounted horizontally on a dividing head on the mill. To cut the belt profile in the pulleys I used a 3 mm slot drill. I plunged the slot drill through the blank taking nine sets of 0.2mm cuts and finishing with a 0.1mm cut to the final depth of 1.9 mm. After making the final cut leave the slot drill at the full depth and slowly withdraw the drill radially to clean up the sides of the profile Once you have cut the profiles on both pulleys radius the



2. Assembled pulleys.



3. View of belt drive from above



4. Pulley fitted to spindle.

corners of each of the profiles with a fine file. The radius of the corners is not critical. Remove all sharp edges that may cut the belt. If the pulleys have been made as separate parts these need to be bored to the sizes shown in **Figs 1** and **Fig 2**. The gears need to be turned down to accommodate the pulleys.

To ensure that the belt does not slide off the pulleys, at least one pulley has to be fitted with flanges. I chose to fit them to both pulleys, and they are made next. The dimensions of the flanges required are also shown in **Fig 4** and **Fig 5**. If you have made the pulleys using only the gears, the dimensions of the flanges will have to be altered to suit. These are made from 1mm mild steel sheet. Readers having made the pulleys as described should have little difficulty fitting the pulleys and the belt to the head of the machine. The general arrangement viewed from above is shown in **Photo 3**.

Making pulleys – Other methods

From later discussions with John Stevenson at Nottingham, it emerged that he has employed other methods of producing HTD pulleys, methods which could well be easier to execute. Firstly, John's examination of commercial pulleys has demonstrated that some variation exists in the radius of the tooth profile. Testing with drills had shown that groove radius can vary from 1.5mm to 1.65mm, and here it should be observed that for a spindle drive application, this sort of tolerance would not be amiss. However for ballscrew drives, where it might give rise to backlash, I would aim for the lower figure, which will deliver a tighter fit. Secondly, John's experience in using belts in high speed, high life locations, indicated that the outer diameter of the pulley might be reduced by 0.8mm. The tooth then becomes semicircular in section, and the belt rides on its teeth, just clear of the pulley O.D. Production of a pulley to this slightly non standard format is then a more simple exercise starting with an oversize blank, drilling the required number of holes (3mm dia.) on the appropriate hole pitch circle, and then turning down the O.D. to leave half of each hole. John's method for finishing is to give the article a good rub on a wire brush wheel, which takes off the burrs and leaves a slight radius on the teeth.

It is also possible to employ either a 3mm ball nosed cutter or a fly cutter whose end is ground to a radius of 1.5 to1.65 diameter, and thickness 3 to 3.3mm. In both of these cases start with a blank turned to the correct size, and cut the tooth depth 1.9mm as described above.

General calculations for pulleys

The belt standard adopted here is the 5mm pitch. Thus for any pulley of "N" teeth, the pitch circle circumference is given by 5N mm, and the pitch circle diameter by 5N/pi mm. If using a rotary table, the movement between teeth is 360/N degrees. Because the theoretical pitch line of an HTD belt lies within the tension member of the belt, this is actually at a greater radius than the O.D. of the pulley.

It is important to make the distinction between the belt pitch circle, which is 1.14mm greater than the pulley O.D. and the pitch circle used for drilling holes, which is 0.8mm less than O.D. Hence, the important point is that having calculated the belt pitch diameter, then the hole PCD would be 1.94mm less. **Figs 6 and 7** illustrate the salient details for the 5mm pitch belt and pulley.

As an example, a 20 tooth pulley would have a pitch circumference of 20x5 = 100mm.

The pitch diameter would be 100/pi = 31.83mm, and the pulley O.D. would be 31.8-1.14=30.69mm.

To make a pulley by drilling holes, these would be on a P.C.D of 30.69-0.8=29.89mm. To allow easy drilling, the blank would need to be at least say 34mm dia. thus leaving a little meat on the outside of each hole.