The spacer above the top bearing must be reduced at both ends if the belt drive conversion is made.

The shortened spacer leaves room to fit the pulley.

The ring nut used to apply bearing preload.

This photo shows how the ring nut clamps the pulley to the spindle.

IMPROVEMENTS TO AN X2 MILL 2

Neil Wyatt upgrades his milling machine.

The X2 mill, as sold by many suppliers, is a popular entry-level machine for model engineers. It shares many features in common with the popular mini-lathes and, like them, it can benefit from a number of relatively inexpensive and straightforward modifications that greatly increase its utility.

One non-reversible alteration needs to be made to the mill, and that is shortening the sleeve that goes between the bearing preload ring nut and the bearings. It needs to be reduced by the thickness of the large pulley, do this asymmetrically so that you can still use a tommy bar in the hole in the sleeve to lock the spindle (**photos 14** and **15**). Note that the ring nut has a short grub screw in it that needs to be loosened so you can slacken the nut (**photo 16**). Equally importantly, the ring nut has a left-hand thread! The ring nut in the photograph has been skimmed on both sides in order to increase the amount of thread showing to take the cap for my self-releasing drawbar. You need not thin the nut for the belt drive modification alone. **Photograph 17** shows the finished pulley in place. The ring nut is used to pre-load the spindle bearings. With standard bearings only light preload is appropriate, but if angular contact bearings are fitted (see later) you can use significantly more preload.

The small pulley (**photos 18** and **19**) is an even simpler job; at least it is if you don't make the centre hole too large. I don't have a 9mm reamer, so I drilled the hole in my first attempt from stainless steel and it came out 0.25mm oversize! The initial result was very noisy as the pulley rattled on its shaft. I made a replacement in brass that was a much better fit. Because of the small bore, I had to file the keyway by hand; it was easier for the brass pulley than the stainless steel one!

As the original motor mount cannot be used with the belt, a new motor mounting plate is needed (**photo 20**). This is a simple cutting out and drilling task in 3mm steel. I suggest using a step drill (**photo 21**) for the centre hole if you have one, they make drilling large holes in sheet and thin plate an absolute doddle. Mine only drill in discrete 2mm steps, so the cone drill is useful for sizes between steps, but it doesn't create parallel-sided holes. Use neat cutting oil and keep the drill speed low, especially as the diameter increases.

An irreversible modification needs to be made now. M5 threaded holes are needed in the mill head for countersink screws in the spacers which attach only to the front part of the mill head but overlap the back part. You can't remove the holes, but if you do change your mind later they could be filled with threaded plugs and filed flush. To locate the holes, spot through the spacers (**photo 22**). These motor mount

18

About to cut the fourth groove in the small pulley.

19

The small pulley is just 19mm in diameter.

20

The motor plate and small pulley before cutting the fixing slots.

21

A series of step drills and a cone drill.

22

Four tapped holes need to be made in the head for the spacers.

23

Counterbored holes in a spacer and fixing screw washers.

spacers are very simple (**photo 23**), but mark the positions of the holes for the clamp screws using the motor mounting plate as a guide, to ensure that it can move freely. It is worth making the washers for the M5 motor clamp (**photo 24**) as this allows them to be done up nice and firmly with reduced risk of distorting the mounting plate.

The belt I used with the pulley sizes and spacing given is a 312-PJ (312 millimetres is the circumference of the belt) with four Vee-ridges. It should last years, but you can save on delivery charges (the belts are cheap) by ordering an 8-Vee belt and splitting it in two. This Goodyear belt has very little stretch, but because of the very good grip of these belts there is no need to risk over-tensioning it, which could lead to increased bearing wear.

It is possible to just hold the motor to tension the belt and tighten the screws, but a tension adjuster (**figs 7** and **8**) is very simple and should not cause any difficulty to make (**photo 25**). The nut for the tension screw is best fixed to the mounting plate with small (e.g. M3) countersunk screws to avoid partly blocking the gap in the motor end plate, which is part of the path for the cooling air. The tension adjuster is also an insurance against the motor shifting at an awkward moment, causing belt slip. Be

24

The clamp bolts and spacers hold the motor in place.

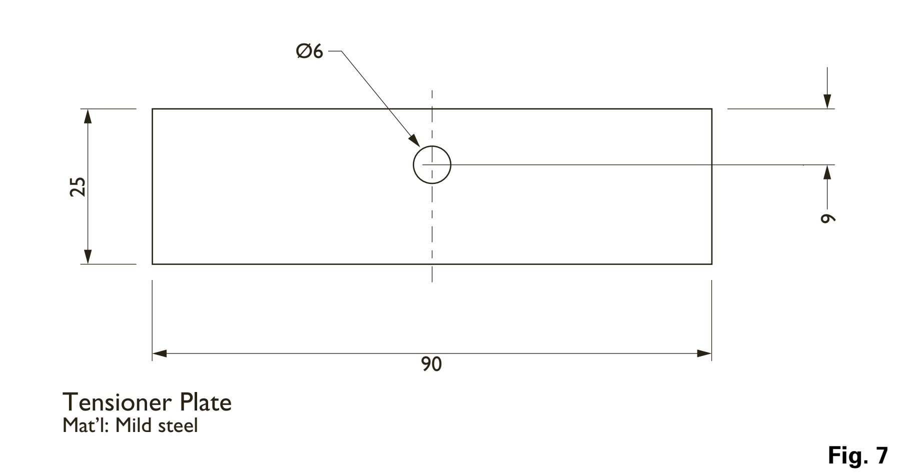
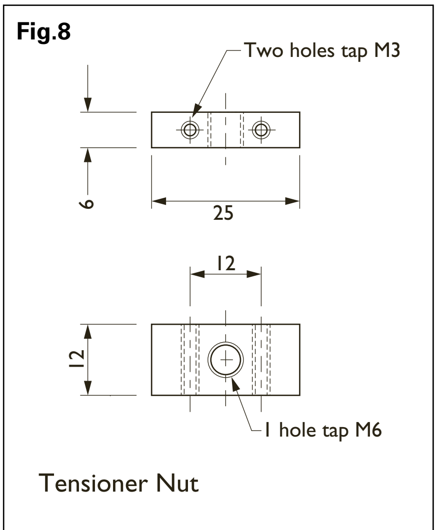


Fig. 7

Fig.8



aware that Poly-Vee belts do not need as much tension as traditional Vee belts and too much tension will just cause unnecessary side loads on the bearings.

The finished belt drive arrangement is very simple and neat (as was shown in photo 11). The picture also shows my self-releasing drawbar in position. Compared to the geared head, the Poly-Vee belts are almost silent, to the point where it is possible not to realise the mill is switched on, so take care. I think it is worth fitting a guard to make sure hair or fingers can't get caught in the belt. I have noticed that some articles state that the author 'hasn't got around to making a guard yet' or it has been 'left out of the photos for clarity'. Just to prove it isn't an onerous task, I spent ten minutes folding up a simple guard from aluminium sheet, held in place with Velcro pads. I might make a neat guard one day, but for the time being the belt is covered. It isn't particularly pretty, but then neither are most injuries (**photo 26**).

Using the dimensions given, my mill now operates between 0 and 1,600 rpm, in contrast to the original 0-1,100 and 0-2,600 (nominal) ranges. By raising the mounting blocks another 10mm or so it would be possible to have double pulleys for two ratios, although you would need to recess the large pulley for the spindle ring nut. However, I have not yet found the single speed a limitation, as there seems to be adequate torque for end mills up to 12mm (½ inch) diameter, and I rarely use very small cutters. If I wanted to regularly run the mill very fast with small or carbide tools, then it would be worth considering a different pulley ratio.

Angular contact ball bearings

I understand my X2 mill was one of the first batch imported by Arc Euro Trade. While considering my options after the gear problem, I had been in touch with Arc regarding replacements. Arc's Ketan Swali asked if, whatever option I went with, would I try fitting a pair of heavy-duty angular contact bearings to the mill as an upgrade and let them know how I got on. (The angular contact bearings are : 7206-B-2RS (2 off). These are only suitable if you have an MT3 spindle. At the time of writing, ARC were working on a solution for the R8 spindle, which has a different size bearing at the bottom of the spindle.) Some years ago I described fitting taper roller bearings to my mini lathe (**ref 1**). I had been sceptical that these would produce a noticeable improvement, but I actually found they virtually eliminated chatter and made parting off a doddle. I was therefore keen to see if a bearing upgrade would benefit the mill, and decided to take up this offer.

Ketan explained that angular contact bearings would better suit a mill spindle (as against a slower lathe spindle) as they are better suited to higher speeds than roller bearings, but offer more accurate alignment than normal bearings. Also, unlike the roller bearings fitted to my lathe, these would be dimensionally identical to the original bearings, so there would be no loss of headroom under the spindle.

The difference between normal deep groove bearings and angular contact bearings is that the latter are asymmetrical, so they can take significant end thrust, as well as side loads, but in one direction only. They are normally fitted in opposing pairs and preloaded. They take more preload than deep groove bearings, normally enough to exceed the expected axial loads, so that under normal use the bearings always remain fully in contact at both ends of the spindle. This gives much more accurate running under load than the usual bearings.

Removing the original bearings

There are a couple of things you should pay particular attention to when changing bearings, which rely on very close fits. The mill head is cast iron; if you get a bearing misaligned, or your bearing puller or other device accidentally catches on the casting, you could fracture it and render the entire mill scrap. The solution is simple, check your set-up before starting and, if when you are tightening a puller it suddenly becomes hard work – STOP! The bearings should go in and out with firm pressure, and you will not need brute force. If things seize up, check because this probably means something is wrong.

My second caution is less dire, but equally important. If you are not doing a belt drive conversion you will need to follow a slightly different order of assembly. If you keep the gears then you need to fit the lower bearing to the spindle

25

The tension adjustment plate.

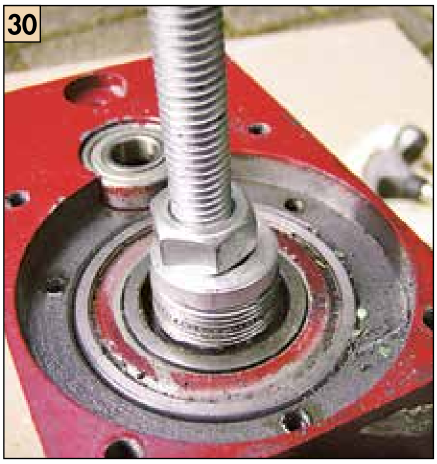
26

A simple belt guard.

The spindle housing, note the bearing cover.

The lower end of the spindle with the bearing cover removed.

The initial setup for drawing the spindle.



Revised set up to draw the last part of the spindle through the top bearing.

The spindle immediately after it has come free of the top bearing.

before fitting it into the mill head, otherwise you will not be able to fit the key for the gear, and will have to take it all apart again!

Pulling bearings (out or in) requires a setup to pull or push on the bearing race relative to the casting, and a way of applying the force. An alternative is to use devices like a slide hammer or brass drifts and a mallet. Personally, I prefer the slow but steady approach of using a screw driven bearing puller.

I used about 18 inch of M12 studding and nuts to suit, a large plate or flat bar with an M12 hole tapped in it (or a clearance hole and a nut) and a shorter bar (or piece of angle iron) with a 12mm clearance hole. Ideally you also need a large diameter tube (big enough to fit around the bearings) and a smaller tube that's an easy fit around the spindle. My large diameter tube was the casing from a burnt out mini-lathe motor! If you don't have these you can work around by using packing pieces, but these tend to fall out at the most awkward times. A few big washers will also be useful. If you don't have M12 or ½ inch studding you could use M10 or ⅜ inch, but I would not go any smaller than that.

Assuming you have removed the head from the mill as described earlier (**photo 27**) and removed the fine feed mechanism and other excrescences, the first task is to remove the bearing covers that are held in place by three M5 screws. The shorter of your pulling bars needs to be a loose fit in the cavity revealed when the covers are removed (**photo 28**). Now

The spindle and the final drive gear. The keyway on the spacer is misaligned.

The keyway after removal of the spacer.

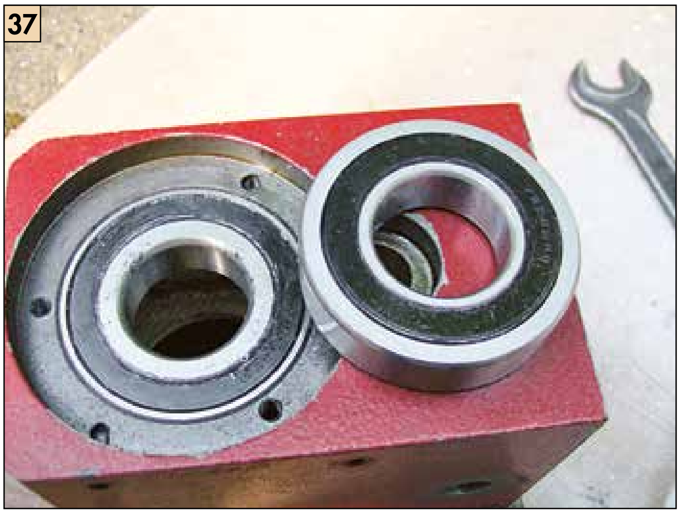
you can pull the spindle free. The studding passes right through the spindle and the large tube into the flat plate beneath (**photo 29**). Turning the nut pulls the spindle into the large tube. The spindle will bring the lower bearing with it, as the key for the final gear will not pass through the bearing. I found that I had to swap the bar at the top for a thick washer to allow me to pull the spindle right through the top bearing (**photos 30** and **31**). Once everything is free loosen off the studding and take the spindle out, leaving the gear behind. It comes out through the end of the mill head along with the bearing and a spacer for the gear. If you intend to stick with gear drive remember to reverse what you have just done for the final assembly i.e. fit the spindle with the bearing attached with the key and spacer in place, threading it into the head and through the gear. If you are only replacing the gears and not changing the bearings, then at this stage all you have to do is thread it all back together and draw the spindle and bottom bearing back into place.

If you look carefully at **photo 32** you will see that the keyway in the plastic spacer is somehow out of line with the key. I would love to know how this could have happened! This made the spacer incredibly tight and impossible to turn to the correct position. As I would not be refitting the gear I would not need the spacer, so I split it at the keyway with a chisel. The key itself was then easy to remove (**photo 33**).

The spindle came free with the bottom bearing.

Using a brass drift to extract the top bearing.

Everything has been taken apart.



Comparing the two sides of the angular contact bearings.

Once the spindle is free, you will discover you cannot see the outer race of the top bearing through the hole left by the bottom bearing (**photo 34**). This means you will have to pull the top bearing out by its central race. This is where I cheated and used a tubular brass drift (**photo 35**) against the middle race, a nice bit of narrow boat tiller, in fact! This needed very little force, so I doubt the bearing suffered at all, but bear in mind that the object of the exercise is to replace this bearing. Once you have fitted angular contact bearings the different geometry means you will be able to brace a puller across the outer race should they ever need to be removed.

The bearing on the spindle was not particularly tight, so, using aluminium protectors on the vice jaws, I put the spindle nose loosely in the vice with the bearing resting on the top of the jaws. With a piece of wood on the other end of the spindle a few taps loosened the bearing right off. I could move it along the spindle by hand, but it became tight again near the end and needed just the gentlest persuasion to come right off. Again, it would be possible to rig a puller to do this gently, but I was not planning to re-use the bearings.

Photograph 36 shows everything fully disassembled. Note that one of the gear spacers is missing from the picture. It had twisted over the key and although I had to split it to get it off, it would probably have been OK to reuse.

Fitting the new bearings

I was now ready to get the angular contact bearings into place. I stress again that I was not refitting the gear, so I decided to fit the angular contact races into the mill head and then draw in the spindle. The races are quite different on each side (**photo 37**) the races being thicker on the side designed to take the load. This means they must be fitted so that thicker sides of the inner races are on the outside (**photo 38**). Before starting, make sure the bearing and its seat are completely clean, although if everything is a little oily or greasy, that will facilitate fitting. I found the bearing could be pushed in a short way by hand, and this helped ensure it went in nice and straight. I did not do this for the second bearing and it went off axis. You may be able to see from the picture (**photo 39**) that the far side has entered the seat more than the near side. If this happens everything will stiffen up. Do as I did, slacken off the nut and use a brass drift to tap the bearing back in line. It should then go home with the minimum of fuss (**photo 40**).

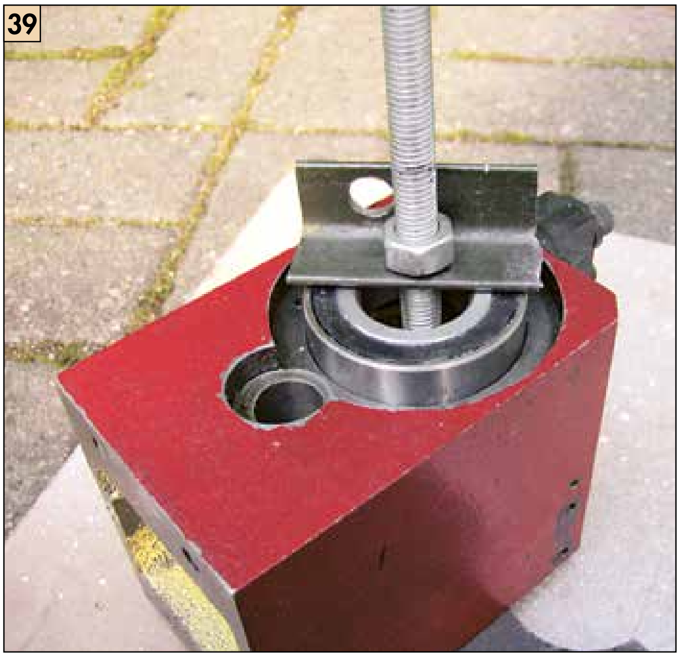
I was then ready to fit the spindle. In order not to make everything too unstable, I used a simple setup to draw the spindle into the bottom bearing (**photo 41**). Once the spindle started to pass through the top bearing (**photo 42**) I had to add in a tube to clear the spindle (**photo 43**). It was then just a case of keeping up firm pressure until the spindle was fully home in the bottom bearing (**photo 44**).

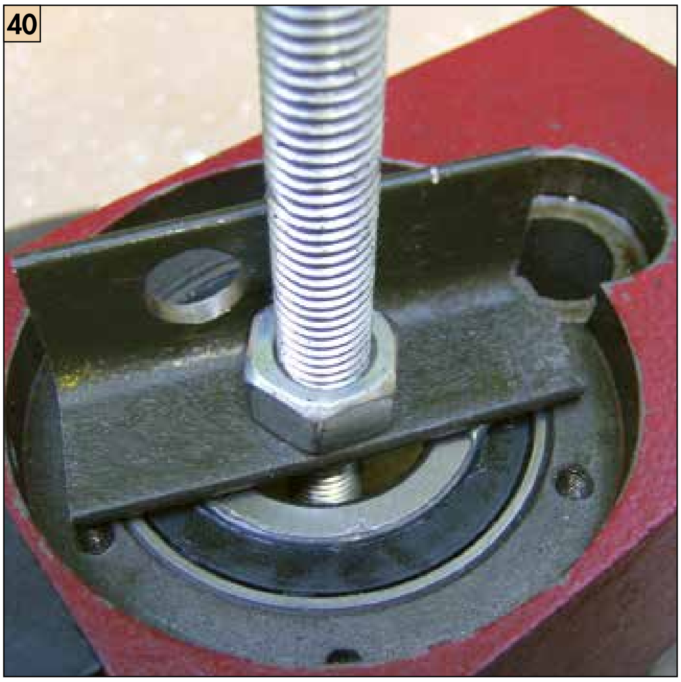
If you are not making the belt drive conversion, you will need to follow a different sequence. Fit the lower bearing onto the spindle and then fit the key for the output gear, before fitting the lower bearing into the head. Fit the upper bearing to the head. Now put the output gear into the head (making sure it is the right way up!) Thread the spindle into the head and into the gear from below, making sure the key enters the keyway in the gear. You will need only modest force to draw the spindle into the upper bearing, but you will need some mechanical assistance towards the end to pull the lower bearing into its housing.

Once both the bearings and the spindle are in position you can refit the spacer tube at the top of the spindle, the pulley (if you have made the belt drive conversion), followed by the left-hand threaded ring nut. Before completing the setup, you need to refit the two parts of the mill head to each other. Careful inspection seems to indicate the upper surfaces of the two parts are the reference faces for their alignment. I used my surface plate (a chunk of granite worktop), with some sheets of paper as a shim, to ensure the two parts were accurately aligned (**photo 45**). Once they are securely reunited, they can be re-assembled to the column of the mill and the drive and downfeed components re-attached.

The ring nut is used to pretension the bearings. The new angular contact bearings can have higher preload applied than the old style bearings, which means


38
Drawing in the top bearing.


39
Drawing in the bottom bearing.


40
The bottom bearing fully home.


41
The set-up to start drawing in the spindle.


42
The spindle starting to enter the top bearing.


43
A stout tube allows the spindle to pass through the top bearing.

The spindle back in place.

Using a surface plate to true up the milling head.

they will run more truly under heavy loads. Quite how much preload to apply is difficult to advise. An internet search didn't help, as I don't know what the working loads are to use in the calculations I found. I used an empirical approach, tightening the nut firmly, loosening it off and then tightening it back up by hand. This seemed fine but after about an hour's use there was a little noise under load, and I discovered the spindle had slight play. As I had previously experienced this with the mini-lathe, I think it was caused by failure to completely pull in the outer races, which then bedded down into the head casting under load. A gentle re-adjustment of the bearings restored the spookily silent running given by the belt conversion.

Conclusion

Have these three modifications made any difference? Certainly the mill is much more rigid now, and I can take larger cuts at faster feed rates, enough that the overload cut-out has stopped the motor once or twice in protest at me taking too greedy a cut. The belt conversion means a single speed range now, up to about 1600 rpm, which seems ample for my needs. As for the bearing change, I am convinced that I am now getting a better surface finish. Before typing this I tried taking a very fine surfacing cut (say 7-10 thou) over some steel plate with a freshly sharpened 12mm endmill at about 1400 rpm. I then took some deeper cuts (50 thou) the full width of the endmill. Although the familiar circular milled finish was still visible, both surfaces felt smooth to my fingertips and fingernail, certainly a quality of finish I had never achieved with the old bearings.

Overall I think the combination of all three modifications addresses all the potential key weaknesses of the original style X2 mills. The machine is now rigid, smooth and reaching its potential. With firmly tightened gib strips and modest cuts, up to ¼ by 1/16 inch in mild steel at a feed rate of about 2 inch a minute, I have been able to use climb milling and get a superb finish when cutting dovetails. And that was the task I was doing when the gear failed, so I think I had better end here. ■

The X2 mill before bolting down to the bench.

Reference

1. http://www.arceurotrade.co.uk/machineguides/C3%20Mini-Lathe%20Dismantling%20and%20Reassembly%20Guide.pdf