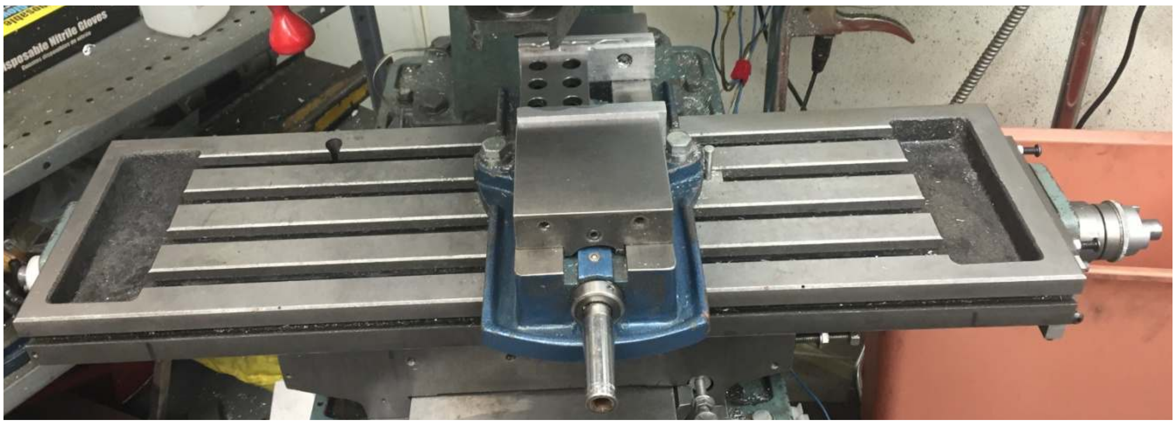
Reducing X Axis Backlash on a RF-30 Mill/Drill, Version 1.2

By R. G. Sparber



Conclusion

I was able to reduce X axis backlash to 0.002 inches without binding of the leadscrew. This was accomplished by preloading the bearings, modifying the take up nut, preventing any slip in the gib, and aligning the leadscrew.

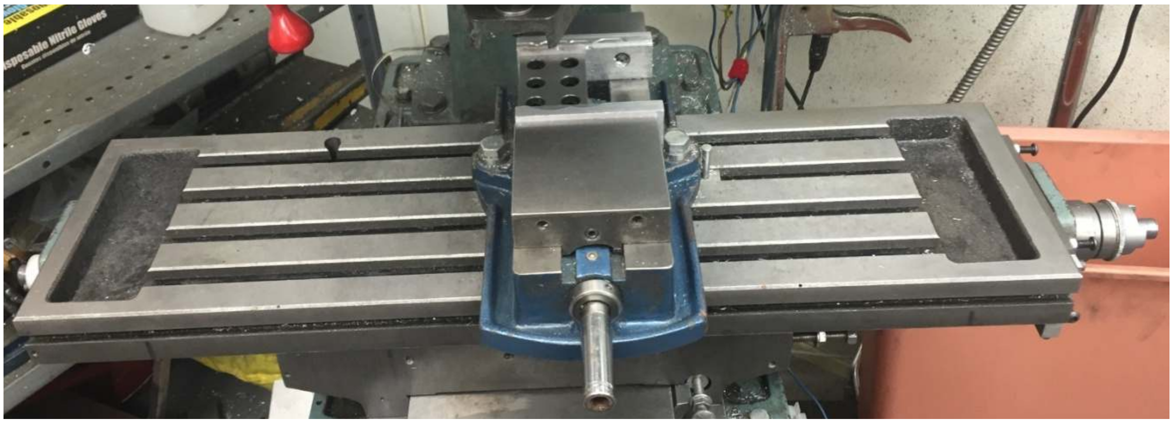
Of all of these, aligning the leadscrew was the most challenging aspect. I had to deal with the fact that the leadscrew must be aligned by addressing six different parameters: X, Y, Z, roll, pitch, and yaw.

It is best to deal with the X axis first before addressing backlash on the Y axis. Otherwise, the Y leadscrew will block access to the screws that secure the X take up nut.

Contents

Why Fuss over Alignment?

Before we talk about how to precisely align the X axis leadscrew[2], let's talk about why this is important. After all, can't we just tighten the take up nut until all play is removed? Nope. ***As backlash goes to zero, alignment must approach perfect.***



The RF-30 Mill/Drill uses a leadscrew and take up nut to move the table along the X axis (left/right movement). When converted to Computer Numerical Control, minimizing backlash in the leadscrew/nut arrangement becomes critical. It must also change as little as possible as the table moves. This is because the CNC software can cancel a fixed backlash but any deviation will become positional error.

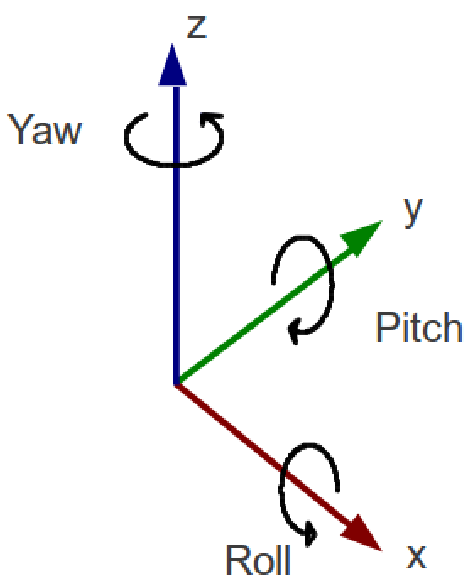
In order to minimize backlash, three requirements must be met:

1. The take up nut must be aligned with the leadscrew.
2. The leadscrew must be aligned with the ways parallel to the XY plane.
3. The leadscrew must be aligned with the ways parallel to the XZ plane.

[2] Although I am dealing with a leadscrew and take up nut here, alignment is even more critical with a ball screw where backlash is far less.

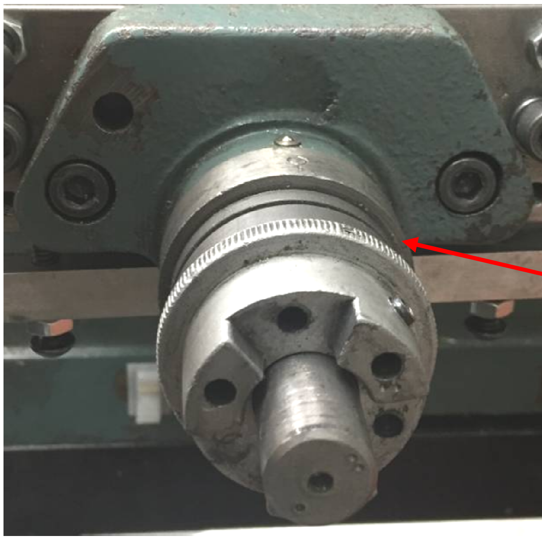
Terminology and Strategy

The X leadscrew can move in six different ways relative to the take up nut.



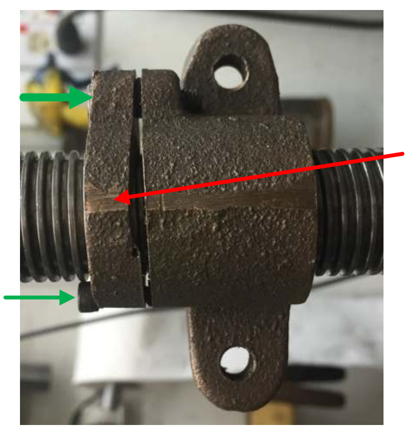
- Movement along the **X axis** - this is caused by bearing play and we can minimize it
- Offset along the **Y axis** - this sideways misalignment must be minimized. Having the take up nut securely holding the leadscrew does that.
- Offset along the **Z axis** - this up and down misalignment must be minimized. Having the take up nut securely holding the leadscrew does that.
- Rotation around the X axis - this is called **roll** and is the only motion we want.
- Rotation around the Y axis - this is called **pitch** and we will adjust the bearing support positions to reduce it to as close to zero as possible. Zero pitch is when the leadscrew is parallel to the XY plane.
- Rotation around the Z axis - this is called **yaw** and we will adjust the bearing support positions to reduce it to as close to zero as possible. Zero yaw is when the leadscrew is parallel to the XZ plane.

Unwanted Movement along the X Axis



Inside the right bearing block are ball bearings that are intended to permit easy rotation of the leadscrew while preventing movement along the X axis. As manufactured, the leadscrew was able to slide in and out about 0.01 inches. The addition of a variable thickness washer let me preload the bearings and remove all but about 0.0001 inches of axial motion. This axial motion directly adds to my X axis backlash. See http://rick.sparber.org/VTW.pdf for details.

Y and Z Axis Offset Error



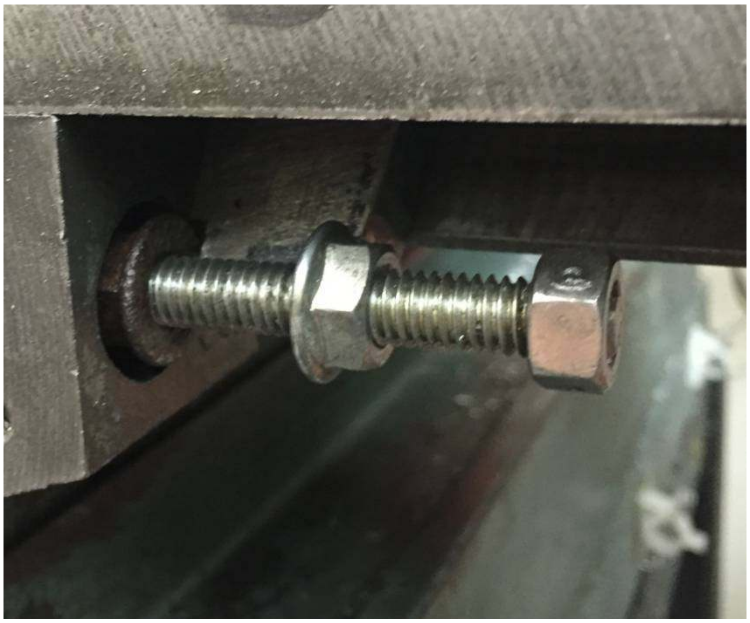
The first requirement, "The take up nut must be aligned with the leadscrew", is satisfied by using the modified take up nut. The adjustable part of the take up nut applies pressure axially to the leadscrew threads. This tends to center it due to the profile of the threads which are tapered. The original design put pressure only on one side which drove the leadscrew off center.

I initially tighten the two backlash adjustment screws (green arrows) such that the leadscrew cannot turn. This tends to center the leadscrew in the take up nut. Later on these screws are loosened to permit normal operation. See http://rick.sparber.org/XTUN.pdf for details.

Rotating Around the X Axis: Roll

Rotation of the leadscrew is what moves the table. This is the only motion I do not want to restrict.

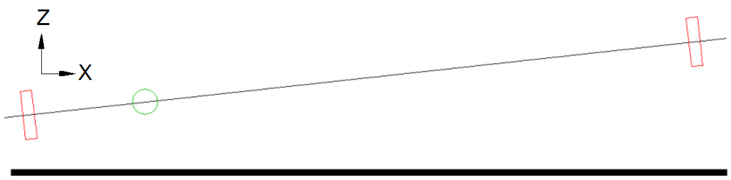
I do have to insure that the drag on this rotation is minimized and constant.



The key action here is to carefully adjust the X gib to be snug but without "excessive" drag and lock its position relative to the apron. See http://rick.sparber.org/GR.pdf for details of how I modified the locking mechanism.

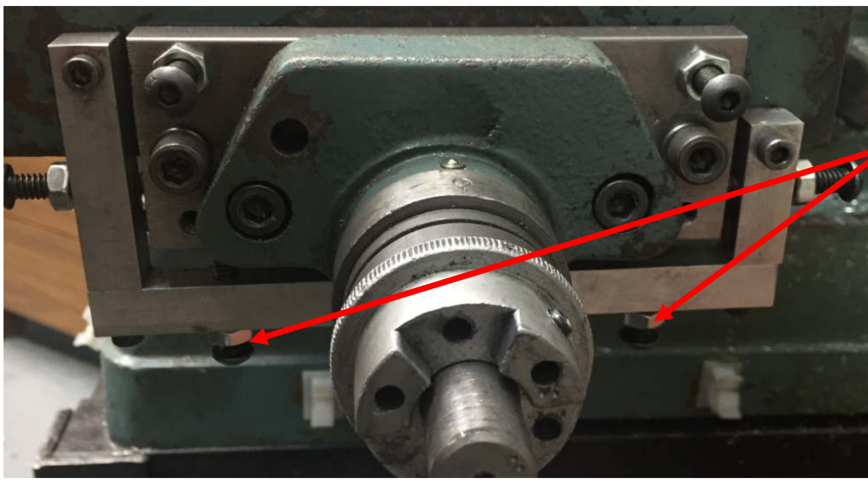
Rotating Around the Y Axis: Pitch

Side view:

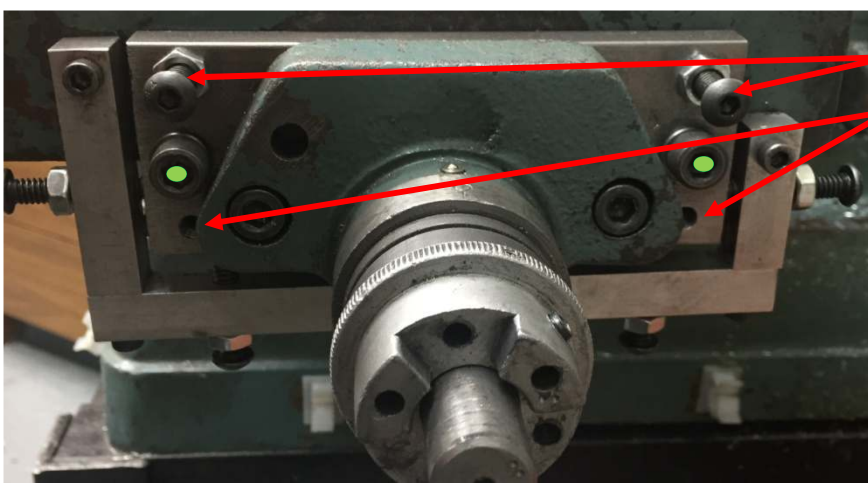


The thick black line is the ways. The two red rectangles are the bearings and the green circle is the take up nut. The right bearing is higher than the left.

As the table moves, the leadscrew will rise relative to the nut and they will bind up. In order to make the leadscrew level, we need to lower the right bearing. That will rotate the leadscrew clockwise on the XZ plane and make the pitch zero.



Jack screws on the bottom enable us to perform this motion.

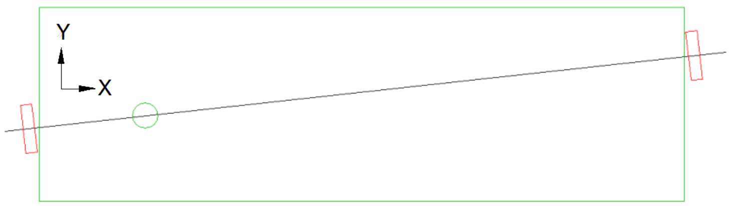


Two top screws plus two bottom set screws carry the force of the two mounting bolts (under the green dots). In this way, the mounting plate can be tilted as needed to follow the leadscrew.

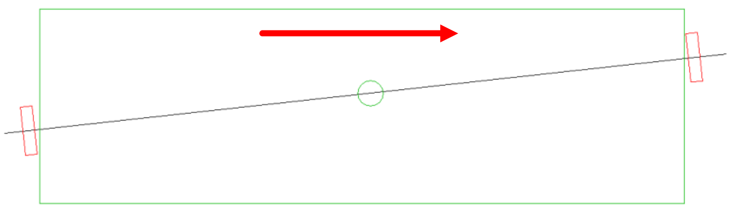
Rotating Around the Z Axis: Yaw

This time, let's take a closer look at how things bind up. We are looking down on the table.

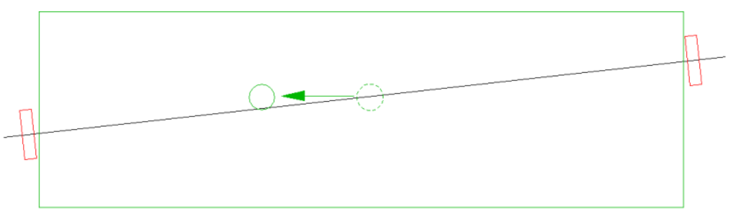
Top view:



The leadscrew is not parallel to the movement of the table. However, the leadscrew bearings are bolted to the table forcing the leadscrew to follow the ways. The nut (green circle) is bolted to the apron which contains the ways.

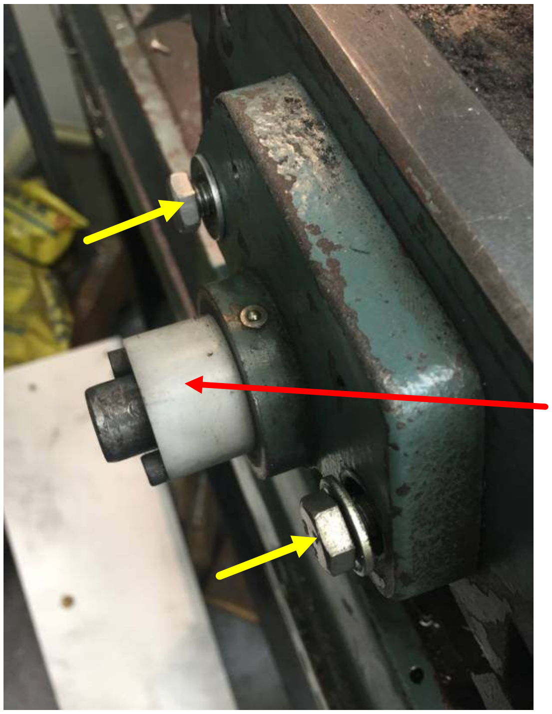


As the leadscrew is turned clockwise, it will attempt to move the table to the right with respect to the nut.



This is the same as saying that the nut moves to the left with respect to the table. Due to the misalignment, the nut will see both this rotation and a movement perpendicular to the table motion. When the leadscrew hits the inside of the nut and the threads bottom out, table movement stops.

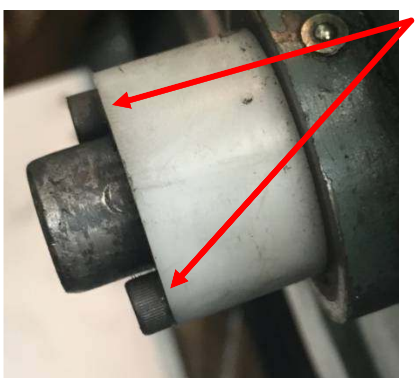
As I reduce backlash, the green circle tightens around the leadscrew. This means that I can't move as far before I bind up. Alternately, as the backlash is reduced, alignment of the leadscrew becomes more demanding.



The left bearing support was badly worn after 25 years of half hearted lubrication. I saw about 0.02 inches of play between "bearing" and leadscrew shaft. This bearing was just a hole through the casting. Since I'm trying to align the leadscrew to within 0.0005 inches over its length, I cannot live with this much slop.

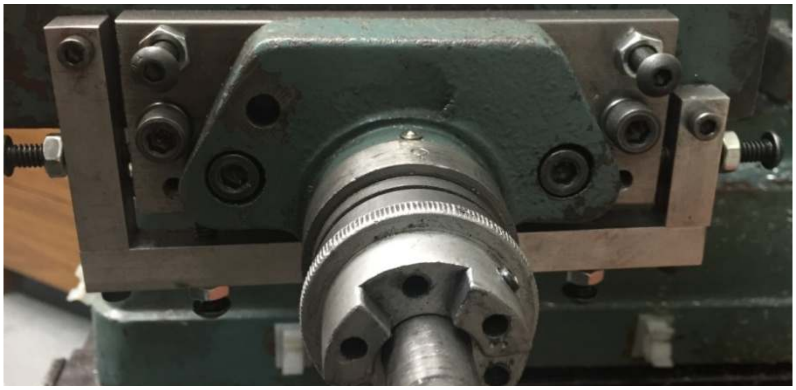
The solution involved a short length of acetal plastic. First I cleaned up the outside of the shaft, removing all raised features. Then I bored out the plastic to a sliding fit on the shaft.

The mounting holes (yellow arrows) were enlarged by 0.2" to permit me to move the support plate around. More on this when we discuss the alignment procedure.



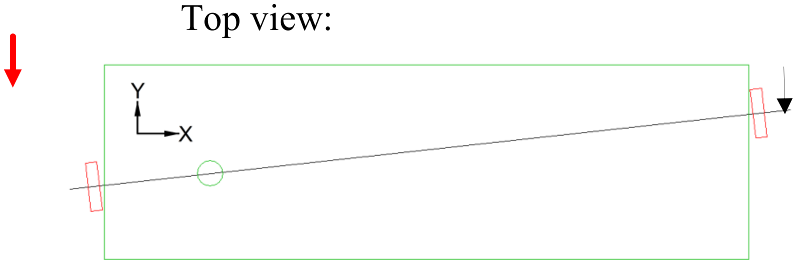
Two 6-32 screws were added to secure the plastic. The only force on this new bearing is the weight of the leadscrew so these small screws are adequate.

The right bearing support is where all the action takes place. As it came from the factory, there was no way to adjust the right bearing block.

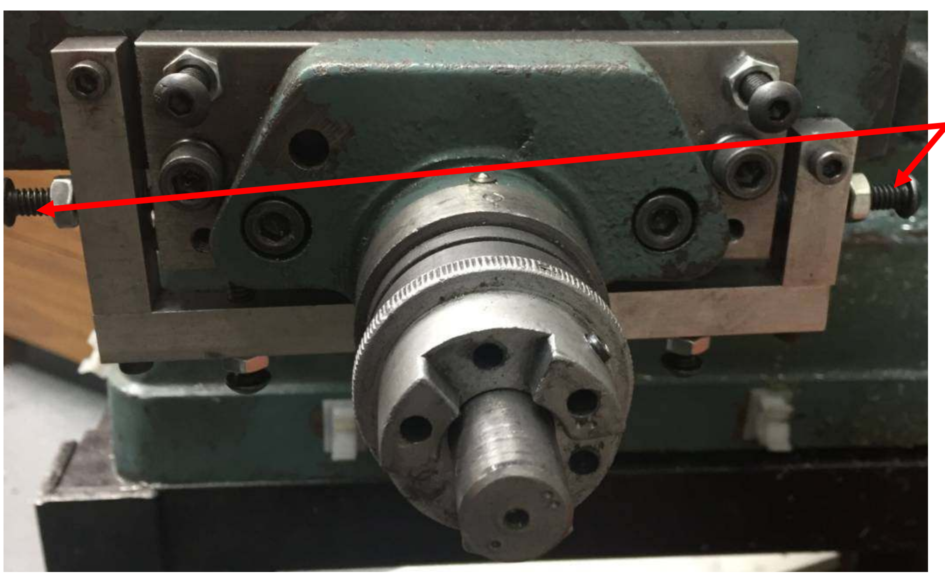


My solution was to make a new surface for the bearing block. This surface can be set at any small angle relative to the end of the table. In order to minimize deflection, the surface is made from ½" steel.

Top view:



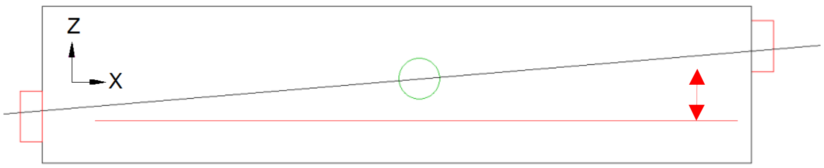
In this top view, you see that the right bearing is crazy far out of alignment with the left bearing. We need to push it forward. This will rotate the leadscrew clockwise on the XY plane. Recall that this motion around the Z axis is yaw.



This end view of the right bearing shows a pair of jack screws that enable this motion. Loosen one and tighten the other.

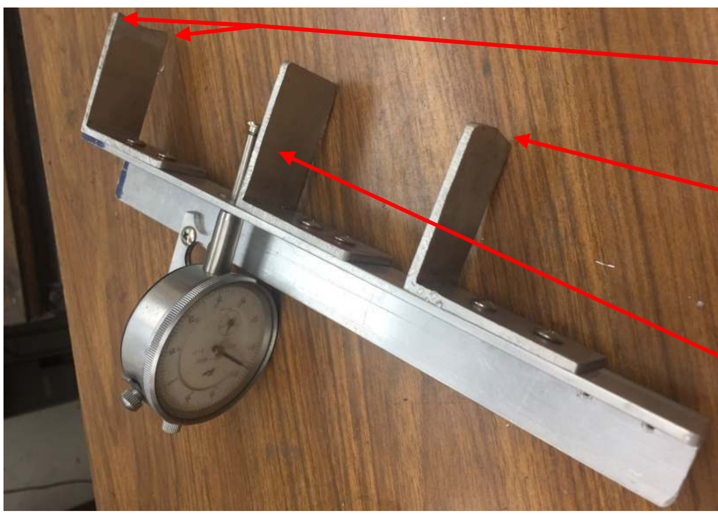
Measuring Rotation Around the Y Axis: Pitch

Side view:

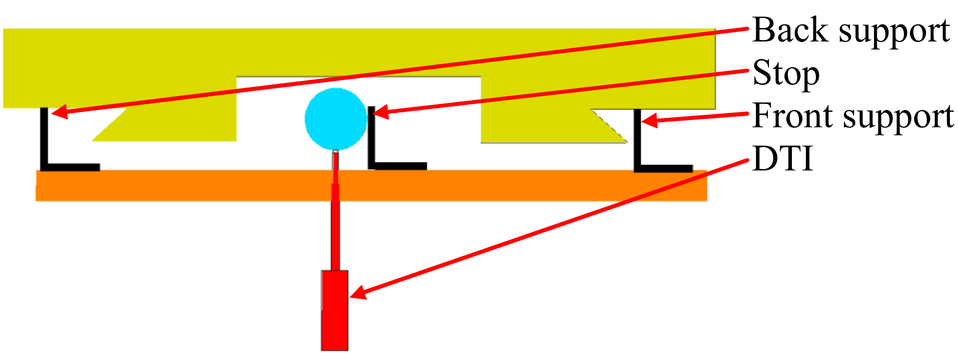


This instrument can tell us when we have zero pitch. When pitch is zero, the leadscrew is parallel to the XY plane.

The instrument that measures alignment in the XZ plane must squarely contact the ways which face down. In order to provide access to these ways, the table is centered.



Note that the back support has been cut concave. This leaves just the corners to contact the far ways. The front support was cut with a point. In this way I have 3 points contacting the ways. As long as these 3 points are in contact, there will be perfect alignment with the ways and no rocking. I have a stop flanked by my DTI to align to the leadscrew and measure its surface. The end of the DTI's push rod has a large flat screw in it to bridge the threads.

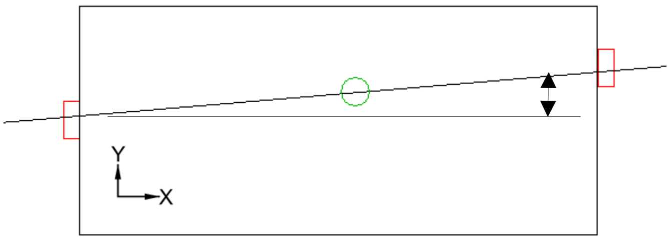


With the instrument in place near the left bearing, the DTI is zeroed.

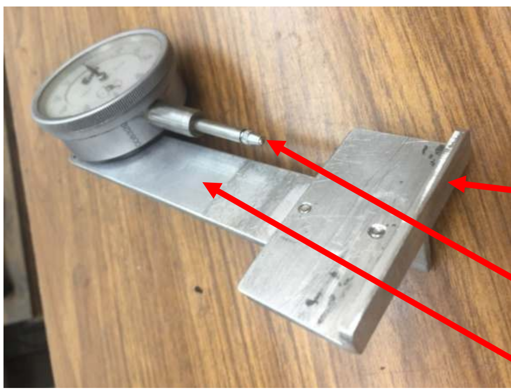
We now have a means of smoothly moving the leadscrew both for pitch and yaw plus a means of measuring it. The final piece of this puzzle is having the procedure.

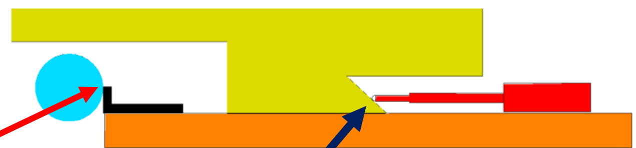
Measuring Rotation Around the Z Axis: Yaw

Top view:



This instrument can tell us when we have zero yaw. When yaw is zero, the leadscrew is parallel to the XZ plane.





The cut down angle part contacts the leadscrew and the DTI contacts the dovetail.

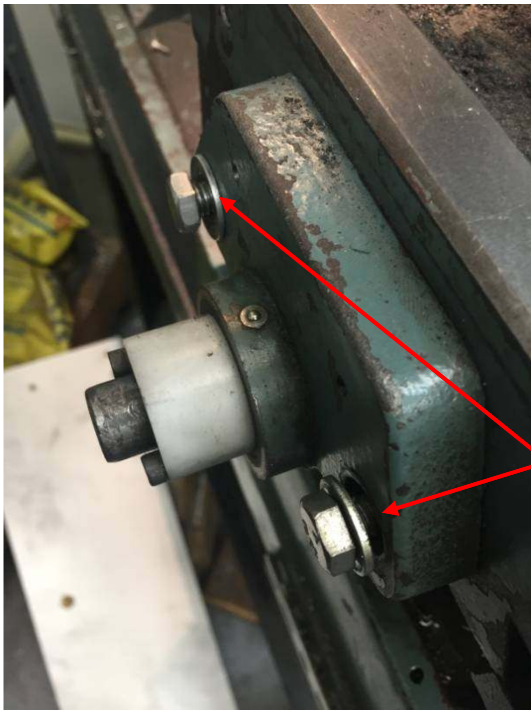
The horizontal flat part contacts a surface parallel to the ways to keep the instrument horizontal.

With the instrument near the left bearing, the DTI is zeroed.

Then it is moved to near the right bearing. In this case I read zero so the leadscrew is aligned to its ways in the XY plane. Yaw is now zero.

The Alignment Procedure

Minimize Y and Z Axis Offset Error



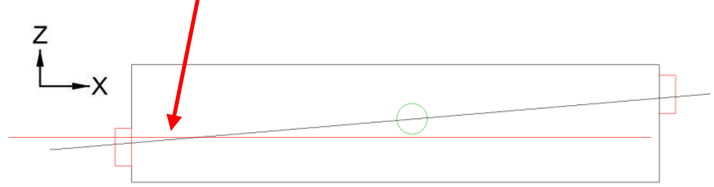
The take up nut is first tightly bolted to the apron and the leadscrew fed through until it enters the left bearing. This is loosely attached to the table. The right bearing is then loosely fitted.

We start with the take up nut tightened until the leadscrew can't turn. This tends to center the leadscrew in the nut as long as you are using the modified nut.

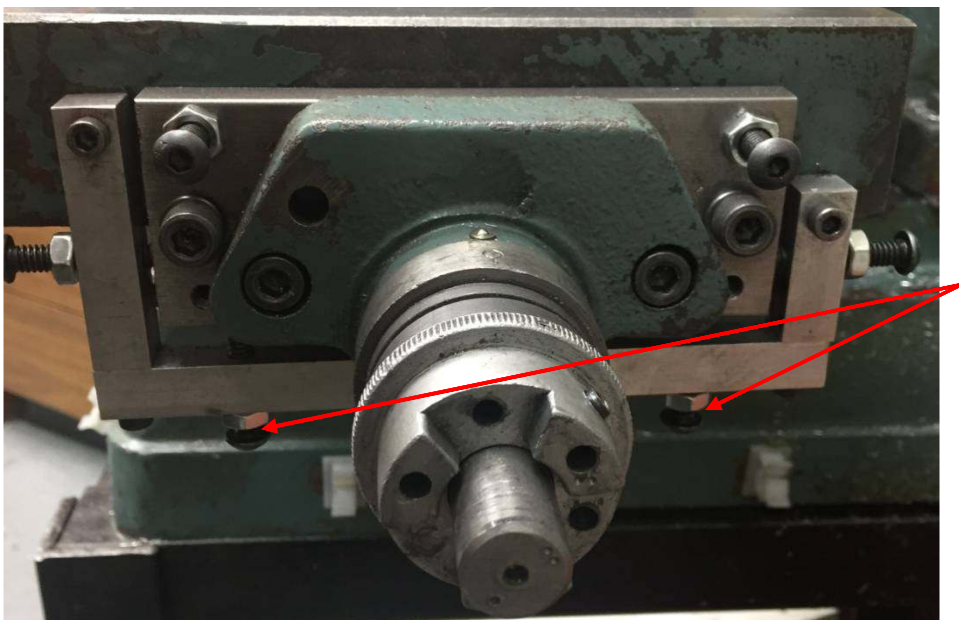
Next the left bearing bolts are tightened. This insures that the left end of the leadscrew is aligned with the take up nut along the Y and Z axes.

Zero the Pitch

The pitch instrument is then zeroed on the leadscrew near the left bearing. Side view:



Moving to near the right bearing, we read out the difference in height.

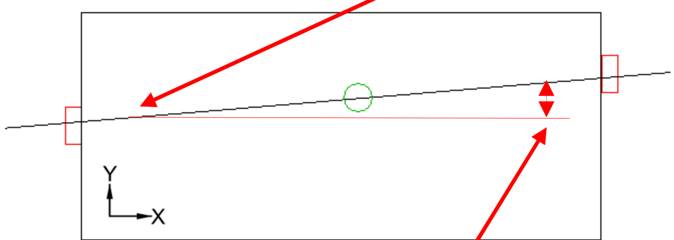


Then we use the vertical jackscrews to adjust the height of the right bearing until the DTI reads zero.

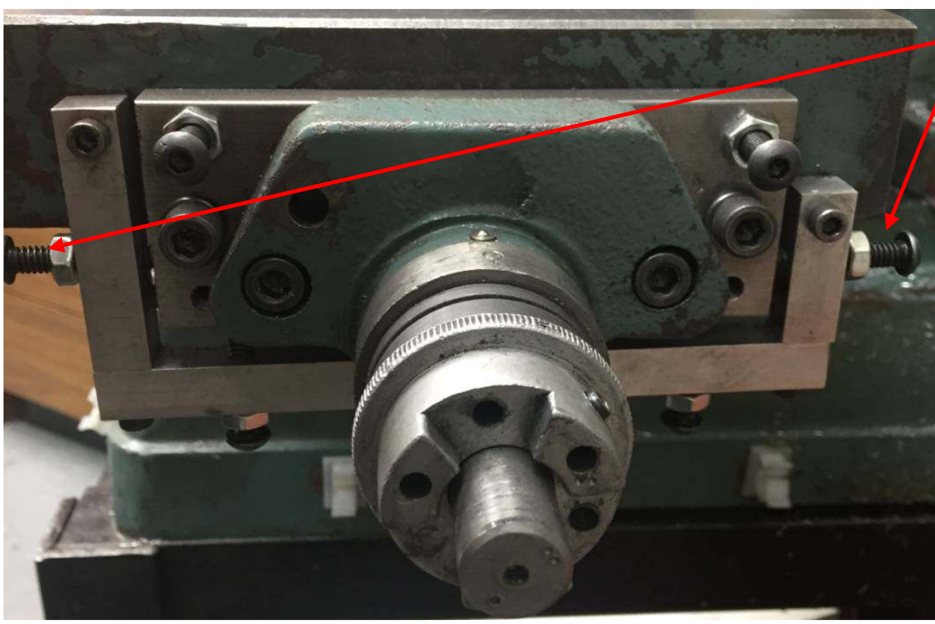
Pitch should now be close to zero.

Zero the Yaw

Near the left bearing, we zero the yaw instrument. Top view:



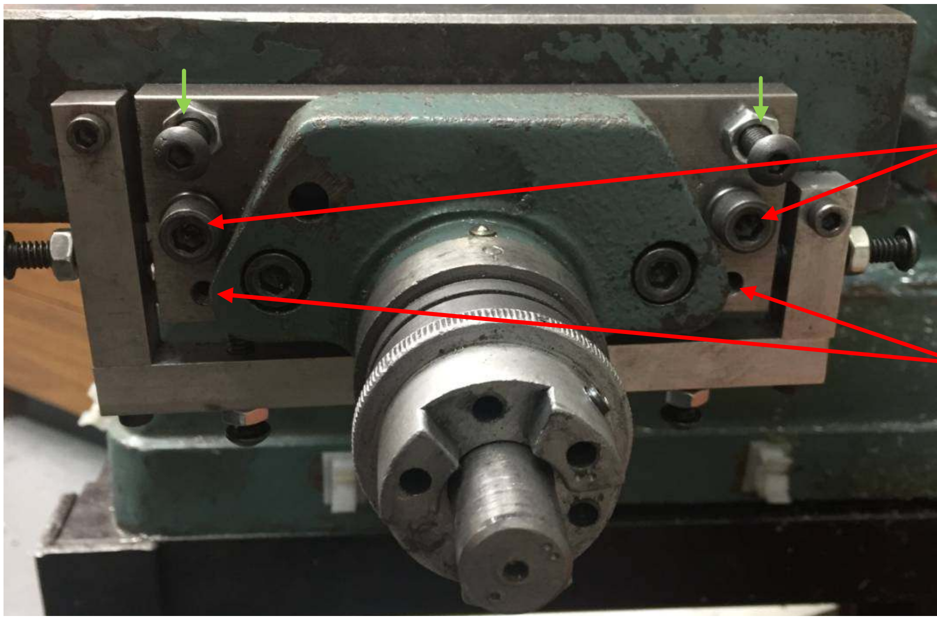
Then we move to near the right bearing and read the difference.



The horizontal jack screws are adjusted until the yaw equals zero. Then the loose horizontal jack screw is tightened to lock this position.

Yaw should now be close to zero.

Right Bearing Block Lock Down



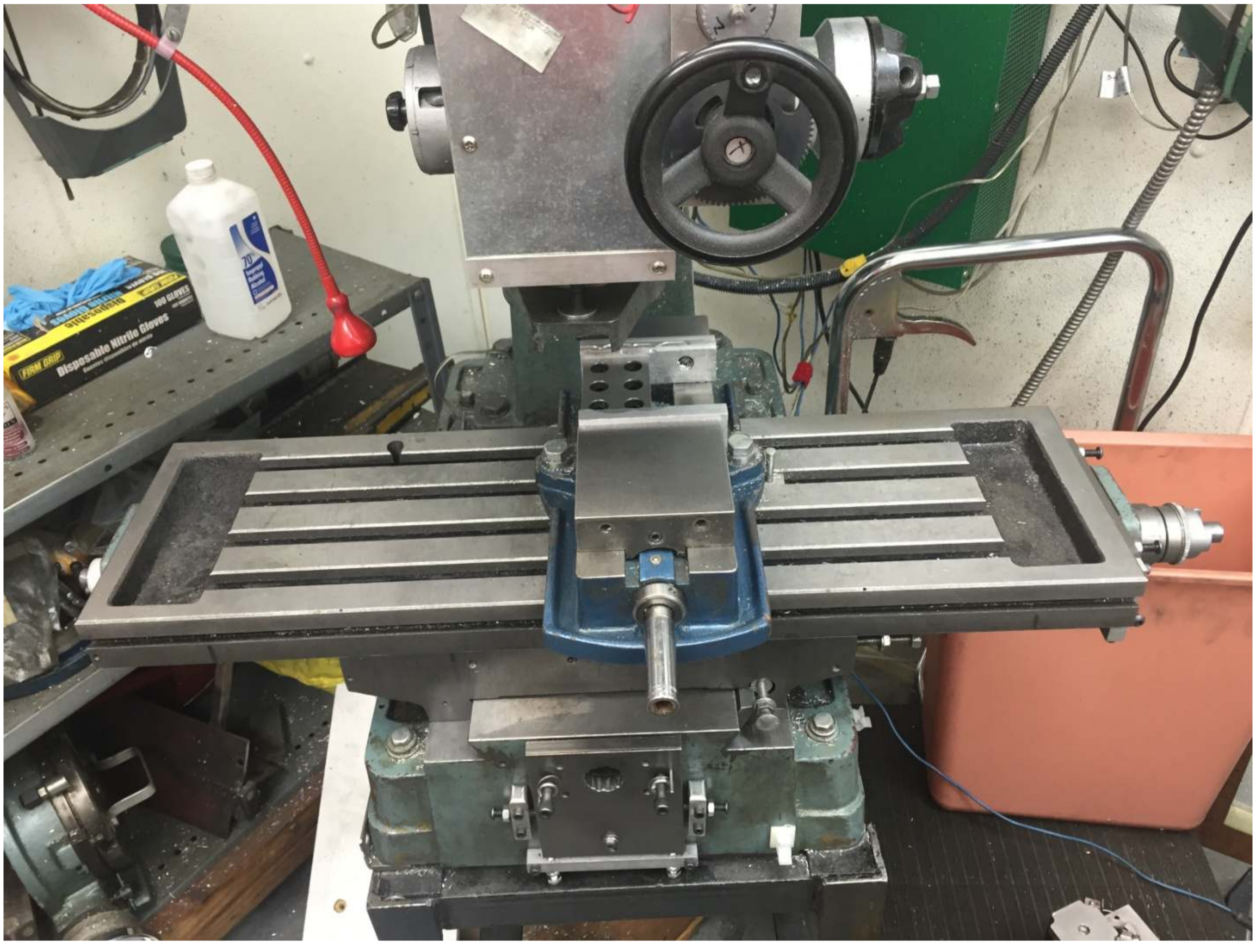
Next we must lock the right bearing plate's position.
The two mounting bolts are turned until barely snug. Then the two top screws (green arrows) are turned until they are snug. Finally the two bottom set screws are turned until snug. Then the two mounting bolts are fully tightened.

And finally, verify pitch and yaw have not changed.

You can then loosen the take up nut just until the leadscrew freely turns. An extension will be needed to reach the adjustment screw.

Run the table along the X leadscrew to verify there is no binding. If you want the minimum possible backlash, run the table until it does bind and then loosen the take up nut a little. Repeat until there is no binding.

Measured Backlash



I was able to set the backlash to 0.002 inches at the left side of my vise. It rose, without binding, by 0.0004 inches after moving 4 inches away to the right side of the vise. About 0.0002 inches of this is radial leadscrew error which is cyclic as the leadscrew turns a full revolution.

The ultimate test is to machine coupons and see how close the actual measurements compare to what the g-code specifies. That task comes next.

Acknowledgments

Thanks to John Herrmann for collaborating with me on the adventure.

I welcome your comments and questions.

If you wish to be contacted each time I publish an article, email me with just "Article Alias" in the subject line.

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