A Few Basic Tests to Perform on your Mill

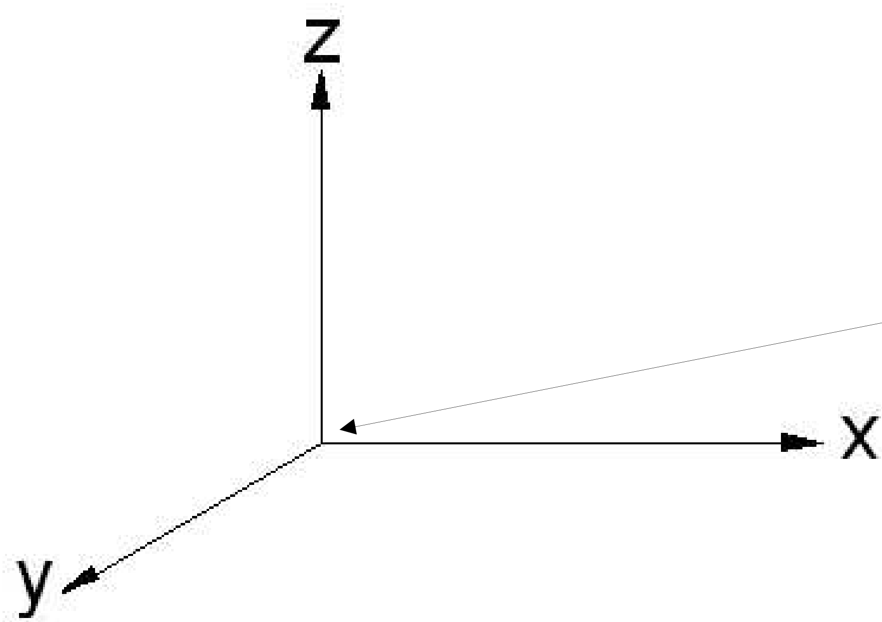
Version 3

By R. G. Sparber

Copyleft protects this article[1].

Mills come in many sizes and weights yet they all can be boiled down to the same simple model. All mills have a table that moves left and right along what is called the X axis. The table can also move front and back along the Y axis. Filling out the set we have the ability to change the distance between table and cutter along the Z axis. This distance can be changed by moving the quill and, on some mills, the knee.

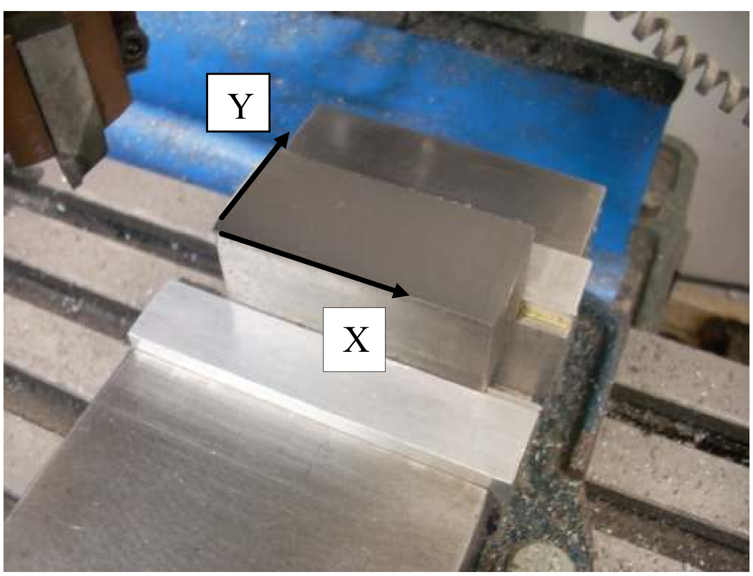
[1] You are free to copy and distribute this article but not change it.



A point can be defined within the working volume of the mill by defining an X,Y, and Z value.

We first define (0,0,0) or origin and then talk about the distance from this point.

The X and Y arrows show the positive direction that the cutter moves relative to the table as the numbers increase on my crank dials. My Z axis dial is opposite from what I am showing here. However, my Digital Read-Out is configured such that increasing numbers on the Z display are consistent with the Z arrow shown here. With my axes defined this way, my origin can be set to the left end of my vise's fixed jaw.



It is common practice with Computer Numerical Control (CNC) to define the Y axis pointing towards the back of the machine. Often the origin is on the left end of the *movable* jaw. As the Y value increases, we are moving across the part and away from the front of the machine.

See the appendix for 3 more ways to move.

In the ideal mill, we can move along a given axis with no effect on the other axes. If, for example, the X axis ways are loose, then moving along the X axis can cause the table to also shift along the Y axis. This play directly contributes to error in the cut. Rather than cutting a straight line, there can be some wiggle to it.

I propose the following tests to see how far a mill is from my ideal model.

You will need a finger style Dial Test Indicator and a means of connecting it to the spindle and to other surfaces near the axes. You will also need a way to stop the spindle from rotating. I just use a small wedge of wood that jams between the front of the belt cover and the pulley. Just remember to remove it before starting up the motor.

My DTI has tick marks every 0.0005".

The Lock and Backlash Test

This test will verify that my X and Y axis locks hold solidly. I will be relying on these locks as I test the individual axis so any failures found in this test must be corrected before proceeding. This is also a good time to test backlash at the ends and middle of the X and Y travel.

First I locked my X axis and turned my X axis feed handle unit I ran out of backlash. It is hard to explain, but it should be difficult to turn the handle further but you also don't want to force it *REAL* hard. If a "reasonable" amount of force causes the lock to slip, you may have a problem.

Assuming your lock holds, turn the dial all the way clockwise and zero the collar. Then turn it counterclockwise and note how much you can turn before you again hit the lock. This is your backlash at this position of the X axis. Run this backlash test with the table all the way to the right, in the middle, and all the way to the left. If the numbers are close to each other, then the wear is either even or small. On my mill I found 0.040" of backlash on the right end, 0.044" in the center, and 0.043" at the left end. That is OK. If the center had been twice what I read at the ends, there would be excessive wear.

I repeated the lock and backlash test on the Y axis and the Z axis. I found my Y axis backlash was 0.069" with the table at the front, 0.075" in the middle, and

0.075” with the table at the back. My Z axis showed 0.023” at the top, 0.024” in the middle, and 0.023” at the bottom. This seems reasonable all the way around even though my Y axis backlash is much larger than what I found for my X and Z axes.

Just for grins, I decided to compare my dials to my DRO. I turned my X axis crank 10 turns to give me 1” of travel. The DRO read 0.9985”. Past experience has shown me that my DRO is far better than this so I suspect my dials are not that accurate. I repeated the test on the Y axis and saw the exact same result. Then I ran the test on my Z axis and found the DRO read 0.9880”. Now, that is really bad so I decided to test further.

I attached my DTI to the spindle and brought it down on the end face of a spacer block. I then zeroed my DTI and DRO.

I then stacked a 1.0000” +/- 0.0002” spacer block on top and brought my DTI down until it again read zero. The DRO flickered between 0.9995” and 1.0000”. So the error in the Z axis is most likely in the dial and not the DRO.

Since I do have a DRO on my mill, I don’t look at the dials anyway. But if you are relying on the dials, it sure is good to know if they are off.

Play in the Ways

Assuming all locks held, it is time to check for play in each ways relative to the mill's base. My base is solidly bolted to my column so it is equally valid to measure relative to the column.

This test will tell you if your gibs need to be adjusted rather than if the ways are excessively worn.

I moved the table so it is centered over the apron. Then I locked the Y axis. Any motion will be due to play in my X axis ways.

I mounted the DTI far from the spindle such that its finger is able to better sense table movement along the X and Y axes. I have used a large C-clamp and a piece of angle iron to provide a place for my magnetic base to attach. This puts my DTI 9.5" from the center of rotation of the spindle.

Now I slowly but firmly apply pressure to the front left and back right corners of the table in an effort to rotate it about its center. I first push and then pull in order to sweep through any play in the X axis ways.

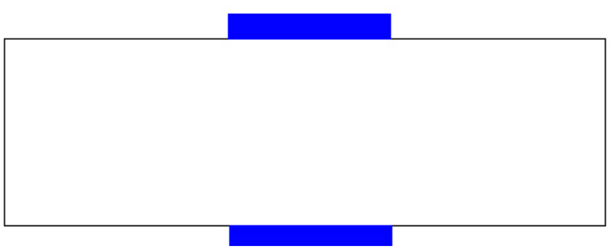
Any motion of the DTI indicates that the X axis ways has play. This play directly effects how close to a straight line an end mill can cut along the X axis. I saw a motion of about 0.001”. I then finger tightened the X axis gib screw and ran the test again. This time the DTI did not move at all. I did verify that the table was still reasonably easy to move with the crank and power feed. There is a tradeoff between minimum play in the ways and the ability to actually move the table along the axis.

The test was repeated for the Y axis. I simply locked my X axis and unlock my Y axis. The DTI again told me if the table moves relative to the column. On my first try, my DTI showed a movement of about 0.001”. I then slightly tightened my Y axis ways. I then saw less than 0.0005” of shift. My Y feed felt a bit stiff so I didn’t want to tighten the ways further.

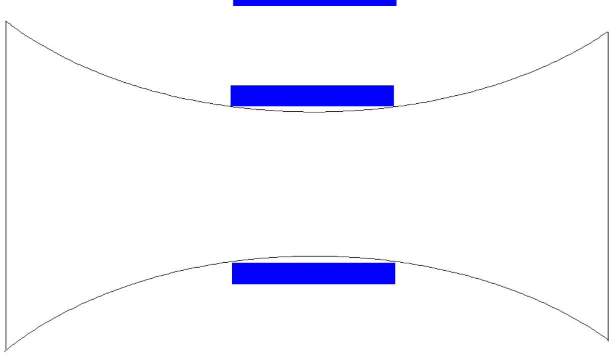
So what has been tested? I found that the play in my X axis ways was excessive and I was able to improve it. My pushing on the table was similar to cutting forces but certainly not equal. A final test must be to make a cut along each axis and measure the results. If the cut along the X axis is straight and the cut along the Y axis is also straight, then all is well. This will require a surface plate, machinist square, and DTI support. Lacking these instruments, be satisfied with the just completed static test. It will certainly find really bad slop in the ways.

Wear in the Ways

This simple test will tell you if the ways have excessive wear. Correcting this wear means scraping and/or grinding the ways. That is not something that should be attempted by a novice.



Here is a simplified picture of a ways. The blue boxes are pressed up against the large black box. I can move the black box left and right because everything is square.



It is often true that the center of the ways travel has the most wear. Here is an exaggerated view. If I snug the lock on an axis with the table centered, I will be able to move along the axis over a short distance. But the more I move towards the ends, the more binding I will encounter. That might indicate wear in the ways. But it could also indicate a misalignment between the lead screw nut that bolts to the table and the lead screw supports. To rule that out, release the ways lock all the way and run from end to end. If you still feel binding, it is misalignment. That doesn't mean it couldn't also be ways wear but there is no way to tell until the lead screw supports are adjusted. It could also be a loose center nut.

On my mill, I ran this test on each axis and felt no wear.

Play in the Spindle

The spindle in my mill is held in position with an upper and lower tapered bearing. Everything is supposed to be snug. This test verified that the spindle cannot be moved by a force pressing on its side.

This first test looks at movement between the spindle and the quill. My DTI has been fitted into the drill chuck. I then rigged up some scrap aluminum that clamps to the lower spindle bearing which clamps to the quill. This aluminum contacts the DTI's finger. Note that the pressure exerted by the finger is tiny so this support is more than strong enough.

I then pressed and pulled on the spindle which is just above the drill chuck. I saw no movement on my DTI. That shows that my spindle bearings are snug.

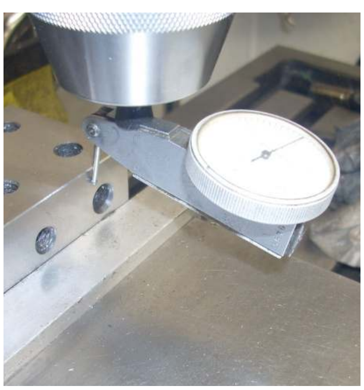
Next I moved my scrap aluminum so it was supported by the head. I am using a very strong magnet that was dug out of an old hard drive. In order to make it easier to pull off of the head, I have put down an old rag to separate them.

As I push and pull on the spindle, I am testing the total play in the spindle/quill and quill/head interfaces. Since I know that my spindle/quill interface is solid, any movement would be due to the quill/head fit.

Perform this test with the Z axis locked. This result will tell you the error when the quill is not moving up and down[2]. Repeat the test with the Z axis unlocked. This result will tell you the error during plunge milling and drilling operations.

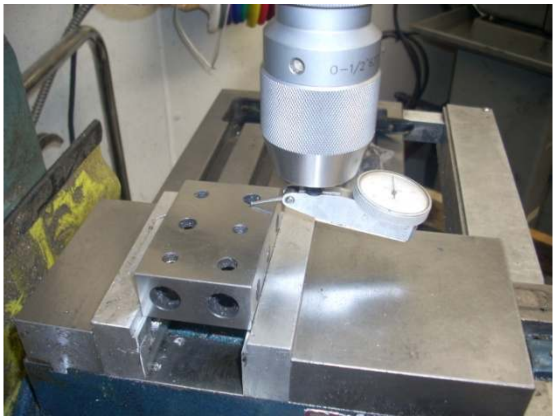
I am happy to report that the DTI needle did not move more than +/- 0.0001" with the Z axis locked. I forgot to run the test with it unlocked.

This final test includes the flexure in the column and base. This is the most important test because this error is what will occur as the end mill is cutting a part that has been clamped to the table. You might think that with all that massive iron, there can't be any bending. Prepare to be surprised.



I have the DTI in the drill chuck with the Z axis locked. I then zeroed the DTI needle with the finger pressing on my block. I pressed on the front of the spindle and noted how much the DTI's needle moves. I then pulled on the spindle while monitoring the DTI to finish this part of the test. You should see movement if you push/pull hard enough. But light pressure should not cause any movement of the DTI's needle.

[2] It should go without saying that any axis not moving should be locked.

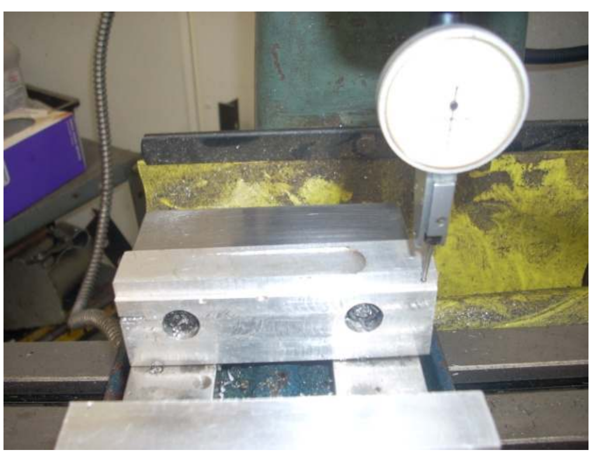


Next, position the DTI's finger so it is referencing the top of the block. With just finger pressure, lift up on the spindle and see if the DTI needle moves. Then push down and see if the DTI needle moves. Any motion could indicate that the spindle bearings has excessive play.

Before I broke down the test set up, I wanted to show you just how non-rigid my massive mill can be. I gently press down on the top of the belt cover and see the DTI move about 0.001". Apply more pressure and see more error. The lesson here is ***never*** rest your hand on the mill's head when making precision cuts.

X Y Axes Perpendicular

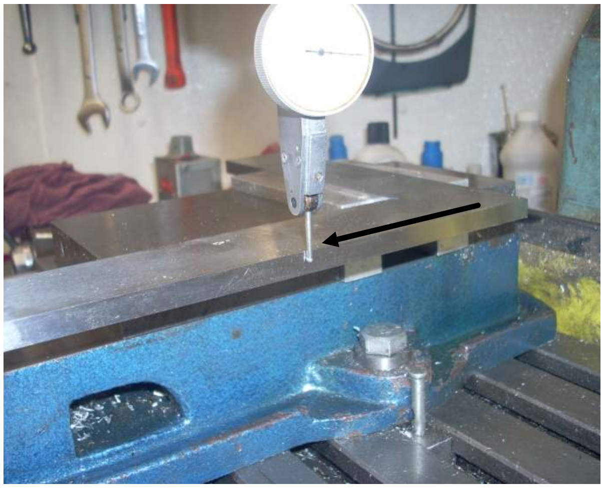
An ideal mill has the X and Y ways exactly perpendicular. This is set during manufacture and cannot be easily changed. Yet it is good to know how much error to expect.



The first thing I did was check my fix softjaw[3] with a DTI attached to the spindle. Since it is cut in place and not moved, any error is due to play in my X axis ways and spindle. The DTI showed less than +/- 0.00025" of variation across the surface. No complaint there. This face was side milled so I do expect some variation.

[3] See http://rick.sparber.org/Articles/sj/sj6.pdf for details on soft jaws.

Then I carefully unboxed my prize Class 2 reference square. I use this square to check my other squares. I believe it is square to within +/- 0.002” over 11.75” or about +/- 0.0002” per inch. I ran my DTI across the edge held by my fixed soft jaw and the needle varied by less than +/- 0.0001” over 2”.



I then ran the DTI along the edge parallel to my Y axis. I saw less than +/- 0.0001” of needle movement over 4”.

I have to admit, I didn’t expect my X and Y axes to be this close to perfect.

The obvious question here is “What do I do if my X axis is not perpendicular to my Y axis?” Bob, of the Yahoo group mill_drill offers some suggestions:

“1.You can get another XY table that you can set on top of your milling table and adjust it so the top X travel table lines up more perpendicular with the bottom Y travel. Then only use the top XY -table for X travel and the bottom XY table for the y travel.

2. You can regrind or scrape the dovetail that is the main slider (the one without the gib strip) so it is more perpendicular. (This is a lot more work but eventually more stable).”

Tram

The word "tram" means the act of measuring how close to perpendicular the Z axis is to the XY plane. Much has been written on how to test for tram and how to adjust the machine so it is closer to idea. I won't duplicate that discussion here[4].

You can also test if the quill's up and down motion is perpendicular to the XY plane. The head must be trammed first. Then you can mount a DTI in the drill chuck and have its finger press on a known accurate square which is sitting on the mill table.

Acknowledgements

Thanks to Brian of the Yahoo group valleymetal for providing many corrections to version 1. Thanks to Bob of Yahoo group mill_drill for suggesting a way to overcome problems with the X and Y axes not being perpendicular. Thanks to Martin of mill_drill for finding a number of "gifts" from the autocorrect function of my word processor plus explaining the topic found in the appendix. Thanks to Jim of mill_drill for suggesting the tests on the spindle, quill, and head.

Disclaimer

This is not an exhaustive set of tests but should help you to identify major problems with the mill. It might help you avoid buying a mill that is beyond fixing or convince you to buy a mill that looks bad yet performs well.

I trust that my friends on the various Yahoo sites will correct and add to my tests and subsequent versions will become better.

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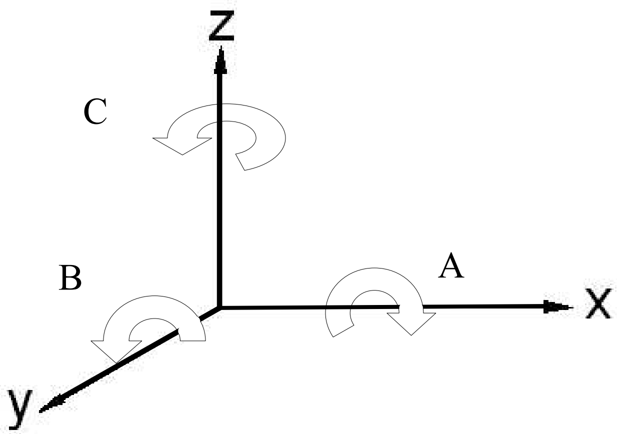
[4] See, for example: http://rick.sparber.org/TM.pdf

Appendix: The Full Set of Movements



I have talked about how all mills enable you to locate a point within the working volume by specifying XYZ coordinates. But there are 3 more degrees of freedom that are commonly found. These deal with rotation around a given axis.

Rotation around the X axis is called “A rotation”. A combination mill and lathe would have it.

Rotation around the Y axis is called “B rotation”. A horizontal mill would have such a movement.

Rotations around the Z axis are called “C rotation”. The spindle turning is one example. A second example is that my round column mill permits the head to pivot. And sometimes I have a rotary table mounted and that too would be C rotation.

You can imagine in a top of the line CNC machine that you have X, Y, Z, A, B, and C movements possible.