Seeing With a Dial Test Indicator, Torque Wrench, and Excel Spreadsheet version 2

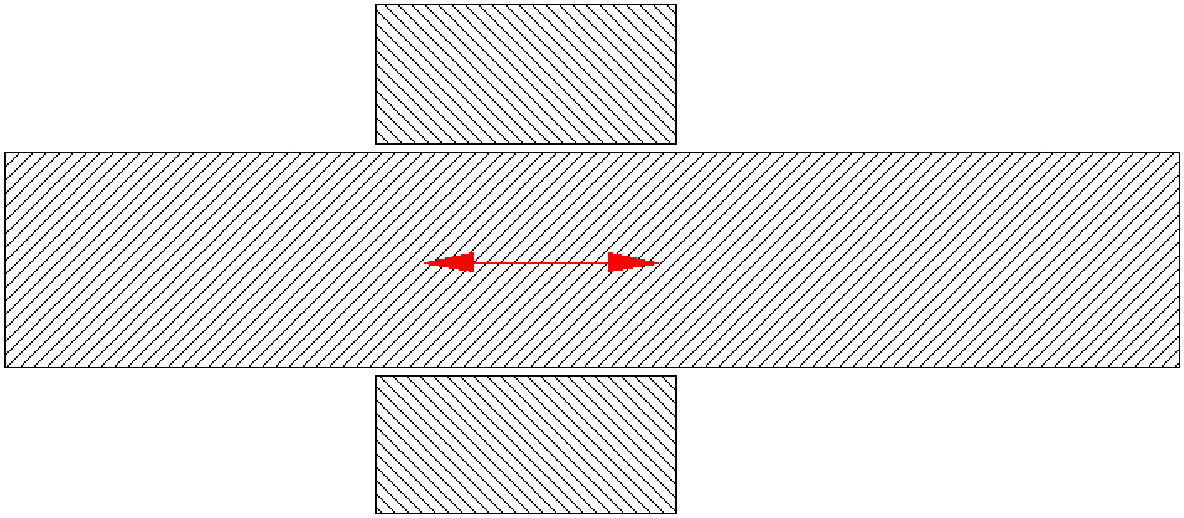
By R. G. Sparber

There are times when I see an error in my machining yet have no idea where it came from. Is some supporting member bending or is it not clamped tight enough? Such was the case recently after re-machining a Harbor Freight XY compound.

The member that might be bending or just not clamped tight enough is the X slider shown above. It is clamped by a set of dove tail ways which I had machined and

[1] You are free to distribute this document but please do not change it in any way.

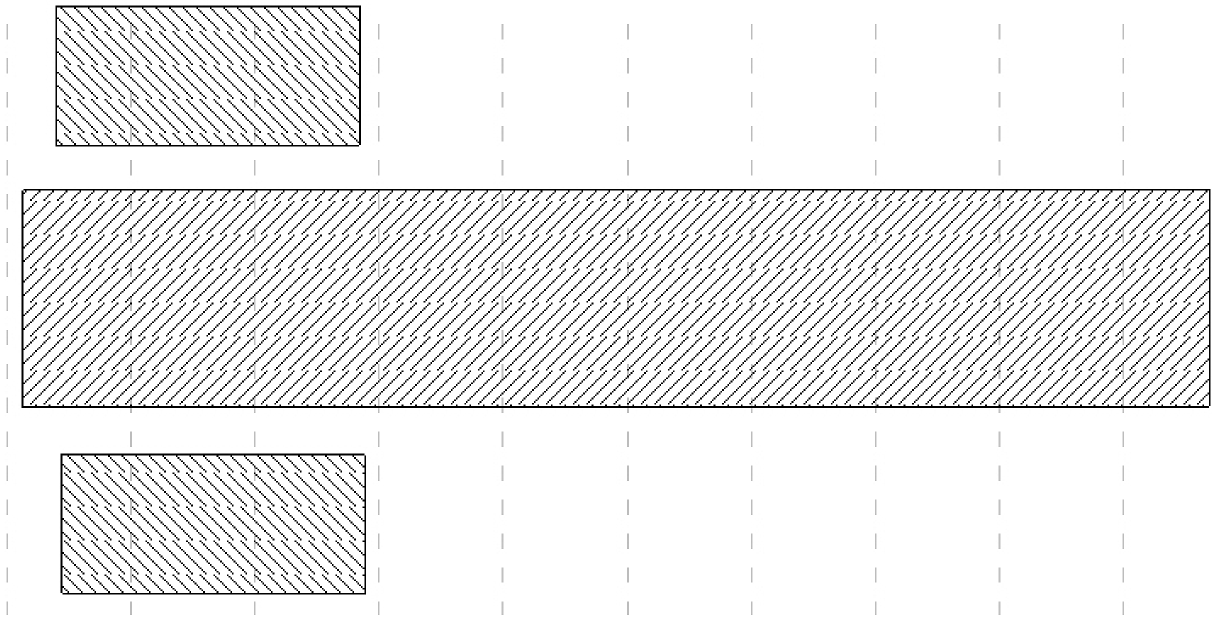
lapped. The fit seemed amazingly good yet when I tried to cut on this slider, I saw an error of many thousandths of an inch. So what is going on here?



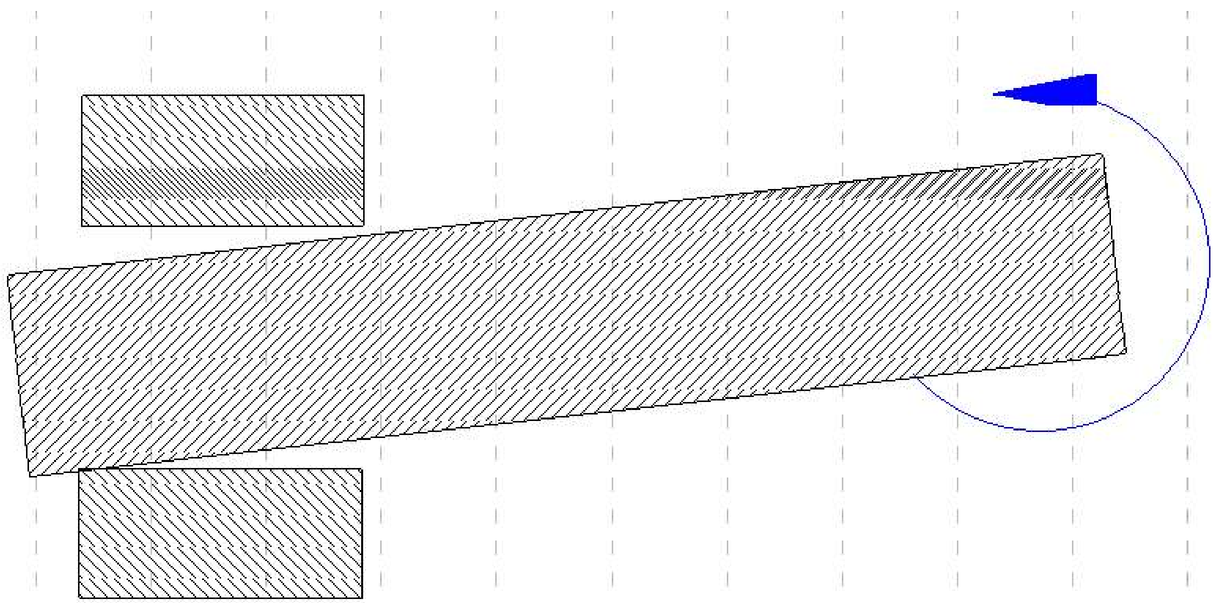
Let's look at a simplified view. The small rectangles represent my dove tail slide ways. The large rectangle is my X slider. Ideally the slider is constrained to only move left and right. But if it is supposed to move, there must be a tiny gap between slide ways and slider.

In the ideal case, the sides of the slider that contact the slide ways are perfectly parallel. If the sides were narrower in the middle than on the ends, then the slider would jam as it moved. Lapping of the contact surfaces can reduce this problem.

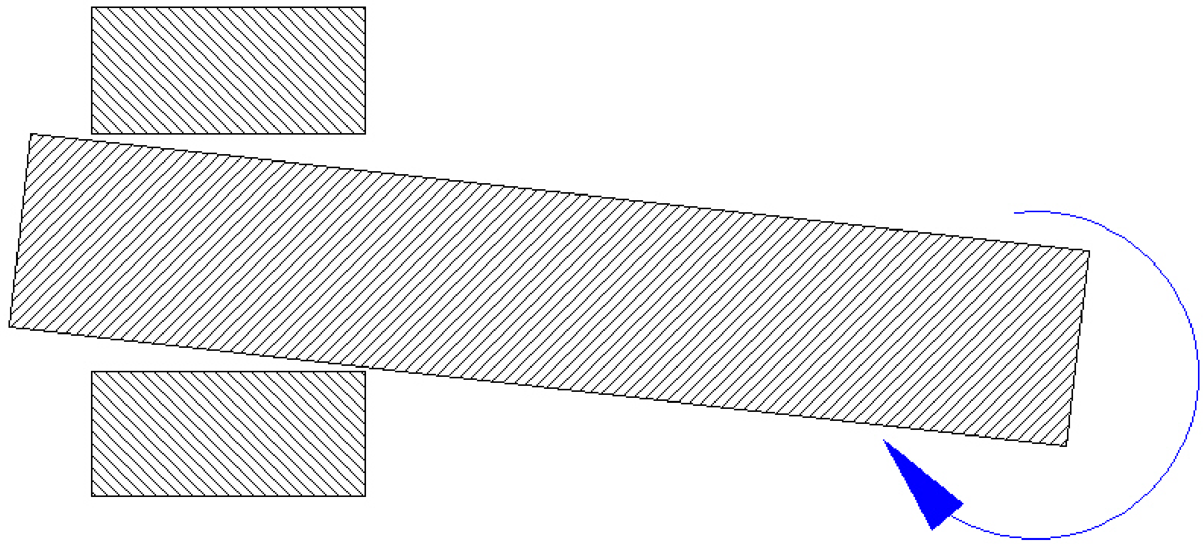
In order to make my point clearer, I will widen the gap between slide way and slider.



With no torque on the slider, it will just lay between the slide ways.



If I apply a negative torque to the slider, you can see that I will contact one slide ways at one edge and the other slide ways at the other edge.



Apply a positive torque and the opposite edges make contact. So in order to flush out the entire amount of play, we apply both a positive and a negative torque.

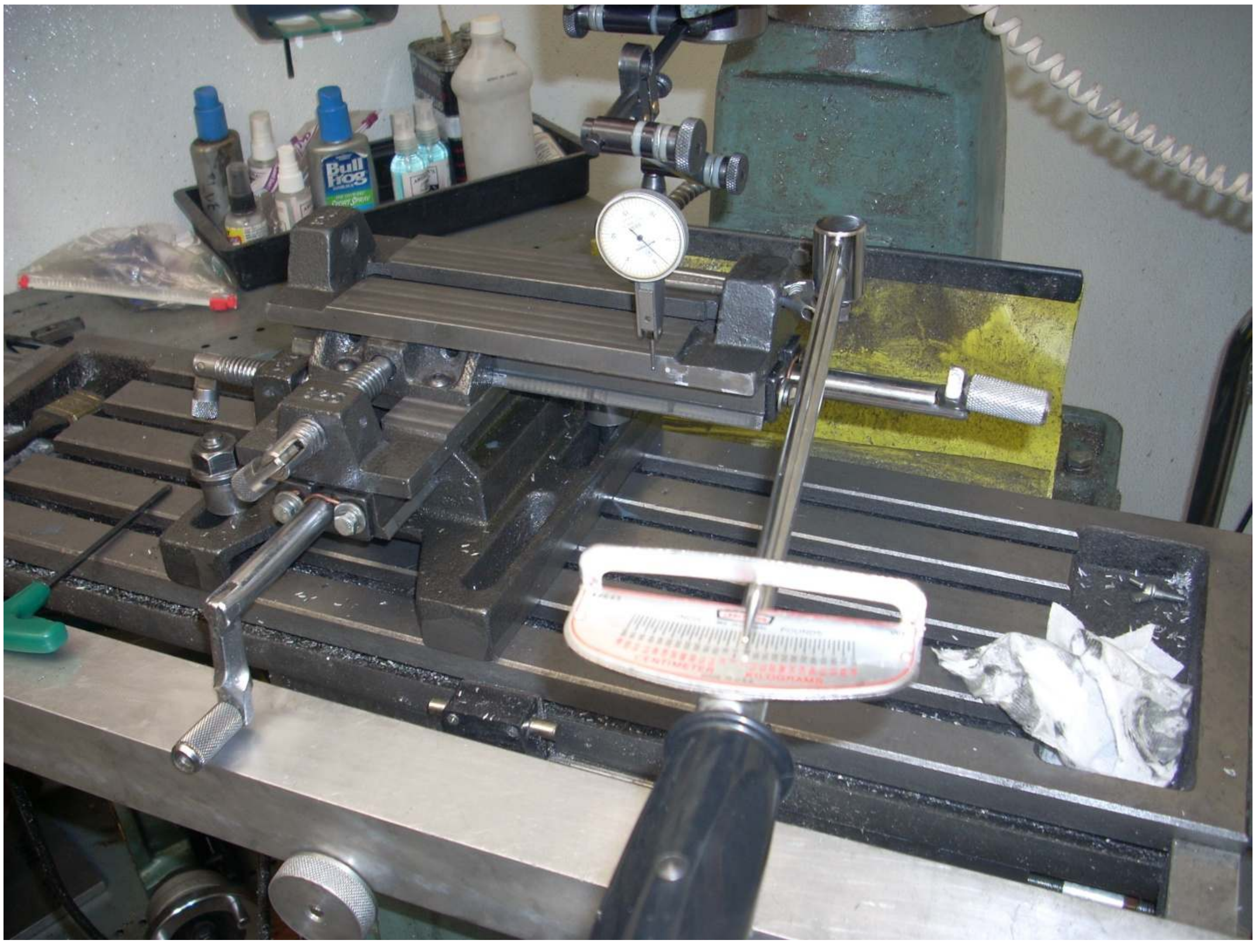
The resulting movement is measure by the Dial Test Indicator. A push rod DTI is best here but I happen to use a finger type which will have more error as the needle moves away from its zero point[2].

Why apply a torque rather than just push on the side of the slider? The short answer is that you can. But note that the movement of the slider might be larger if you push from one side than from the other. So to see the total movement, you need to apply this force on one side and then on the other. Then there is the problem of consistency. The applied force must be known in case you want to apply it again later. If I had a calibrated push rod rather than a torque wrench, I would go with the push rod.

When a torque is applied to a ridged body, it doesn't matter where you apply it. But if the body deforms, then it would make a difference. Picture the slider being made of rubber. Applying the torque between the slide ways would twist the rubber around that point but the part extending from the slide ways would remain straight. Applying the torque out at the end would bend the section from slide ways

[2] See http://rick.sparber.org/Articles/DTI/DTI.htm for details.

out to the end. Given that we don't know if the slide ways is bending or not, it is best to apply the torque out at the end.



The procedure is rather simple. I move the mill table such that the DTI is at the center of the slide ways. Then the mill table is locked and I apply +200 inch pounds and then -200 inch pounds while watching the dial. The torque wrench fits into a small adjustable wrench that slides into a hole in the slider. This arrangement effectively couples my known torque into the table.

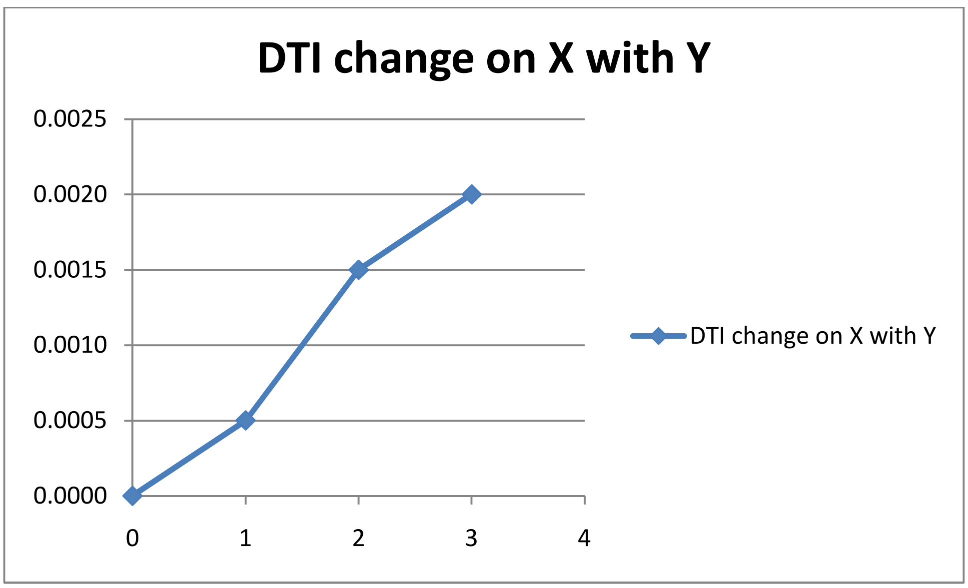
The total swing of the dial is recorded. It should be zero so any non-zero value says something else is moving. In the above case, it was the Y axis slider and slide ways that supports the X axis slide ways.

I then repeated the test using the same torque at a distance of 1", 2", and 3". This is not a lot of data but it is so easy to use an Excel spreadsheet, why not use it?

X on top of Y

location	DTI change on X with Y
0	0.0000
1	0.0005
2	0.0015
3	0.0020

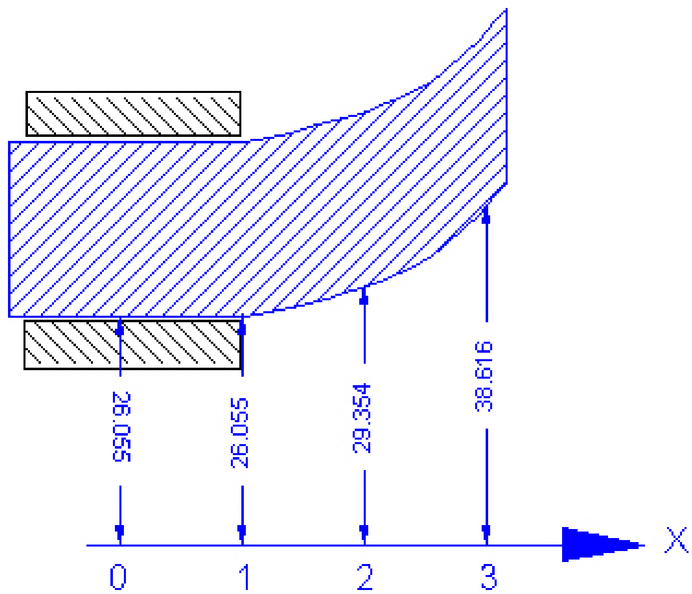
And with a few clicks, the data is plotted:



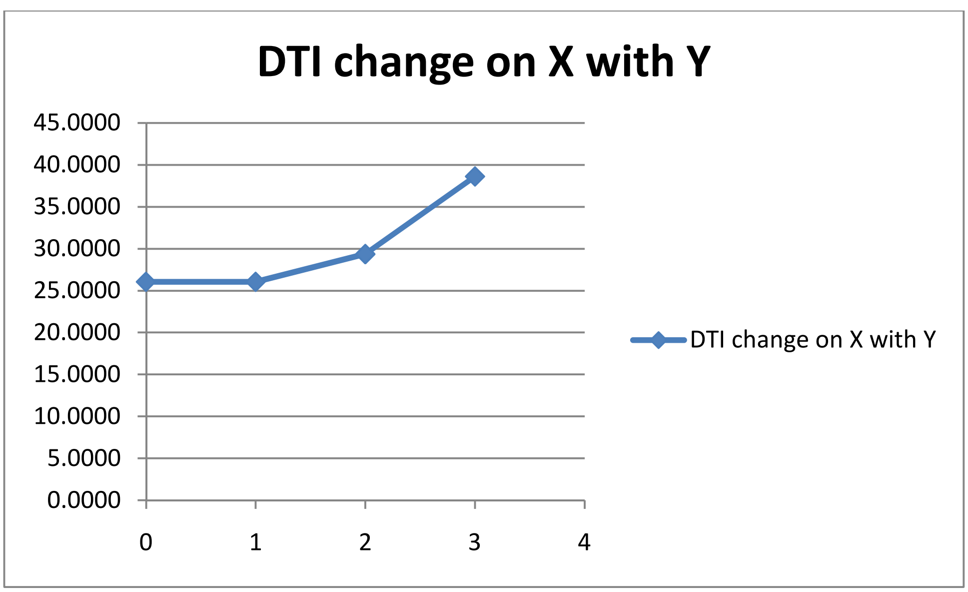
There is a tiny amount of wiggle in this line but it is essentially straight. Recall that I'm applying both positive and negative torque here so this is the total movement at each position along the slider. The average error is about 0.0007" of movement per inch. The fact that the line is essentially straight tells me that we are looking at play in the slide ways and not deflection of the slider.

What if it was bending? It may seem obvious that the graph will look like a magnified version of the bending, but let's run the numbers to be sure.

Consider this situation:



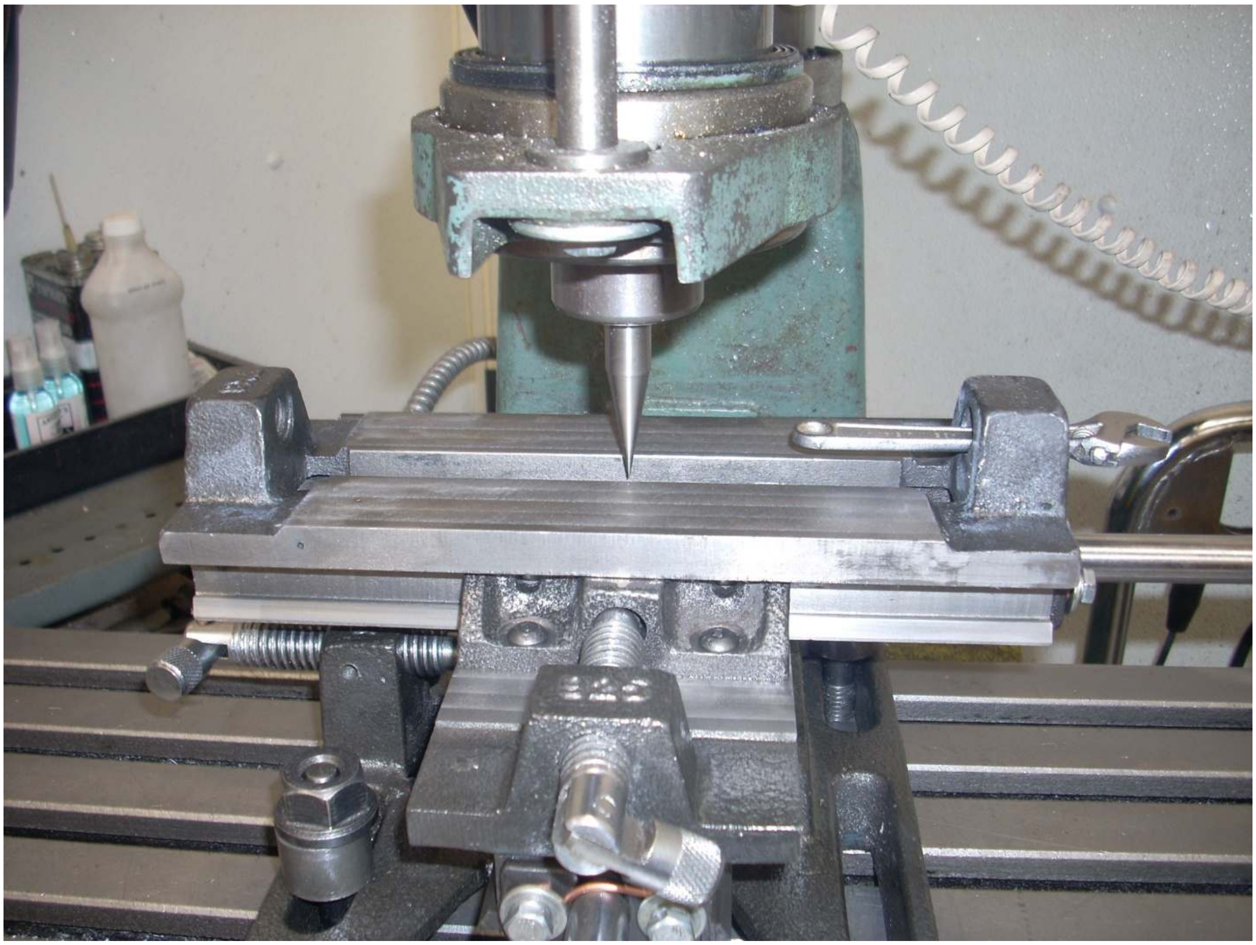
Plug these numbers into Excel and the graph has the exact same shape:



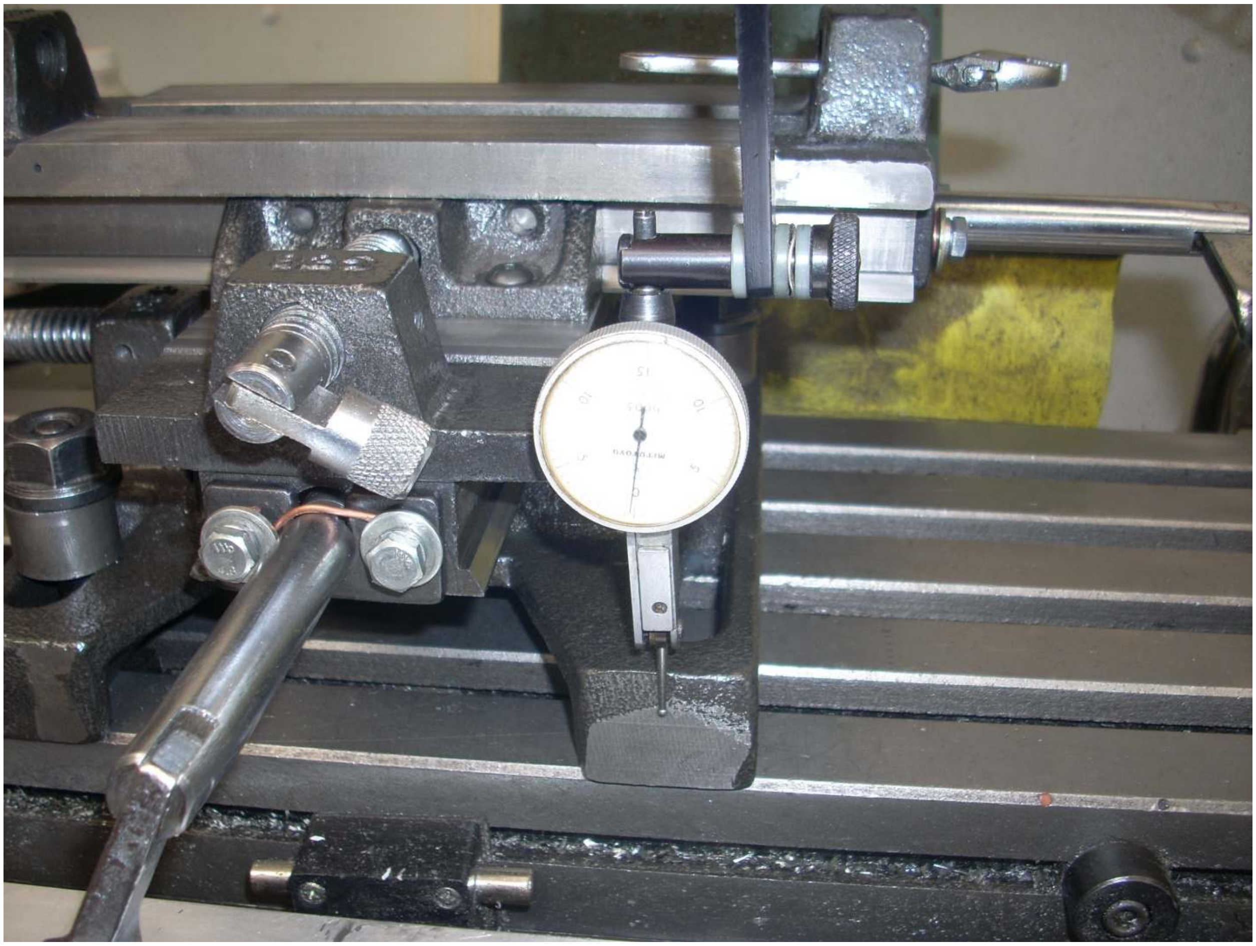
Since my XY compound data was a straight line and not curved as above, I know that my problem is play between slider and slide ways and not the slider bending. I was able to do a bit more lapping of the surfaces and reduce the error a little. Had the error been due to bending of the slider, I might have added a stiffener.

I can look at this error as small rotations about the center of the XY compound. It is important to start at the base and work my way up so nothing is missed.

Using a spud, I eyeballed the center of my XY compound.



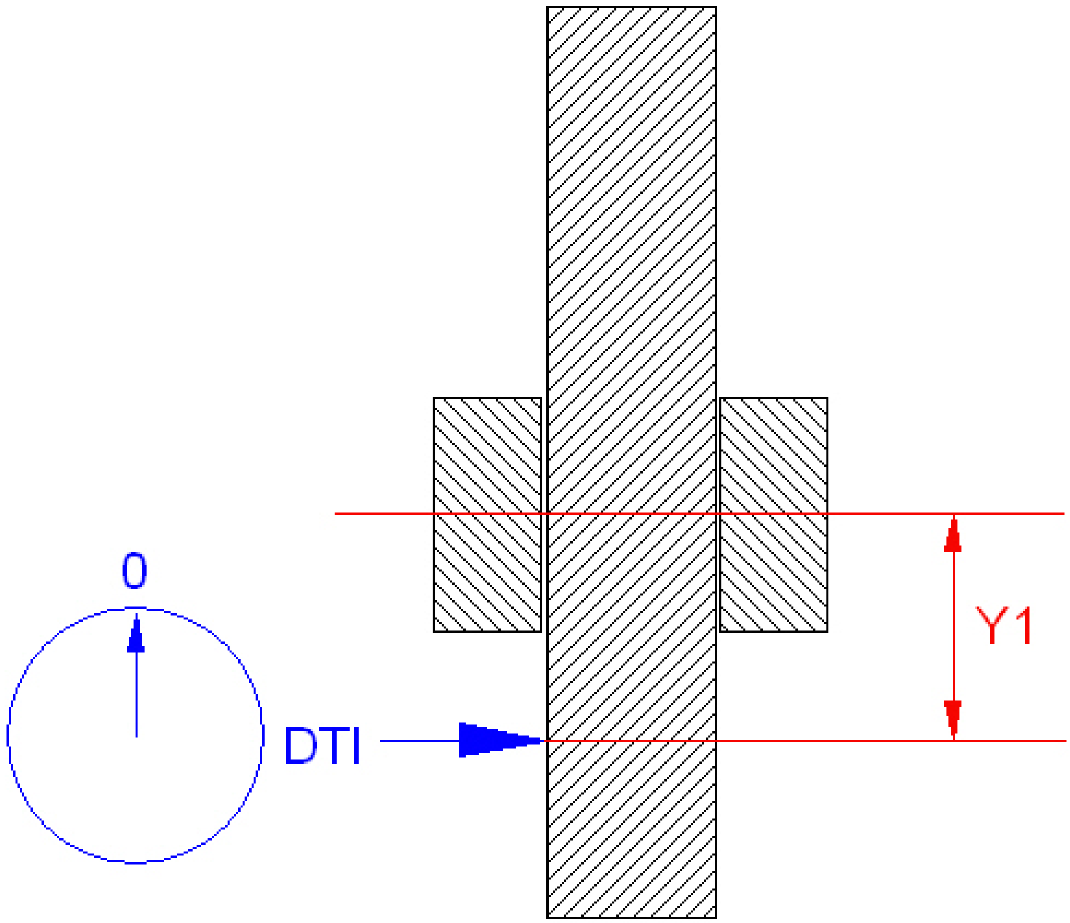
Note my precision torque coupler stuck in the end of the X table casting.



I then moved to a point on the base. The exact X distance is not important because the needle did not move at all as I applied my torque. I have established that the base does not move relative to my DTI support[3]. This was nice to see since it really is a partial measure of the tightness of my mill's X and Y ways.

[3] I am using my spindle as the support because it makes moving around the XY compound easy.

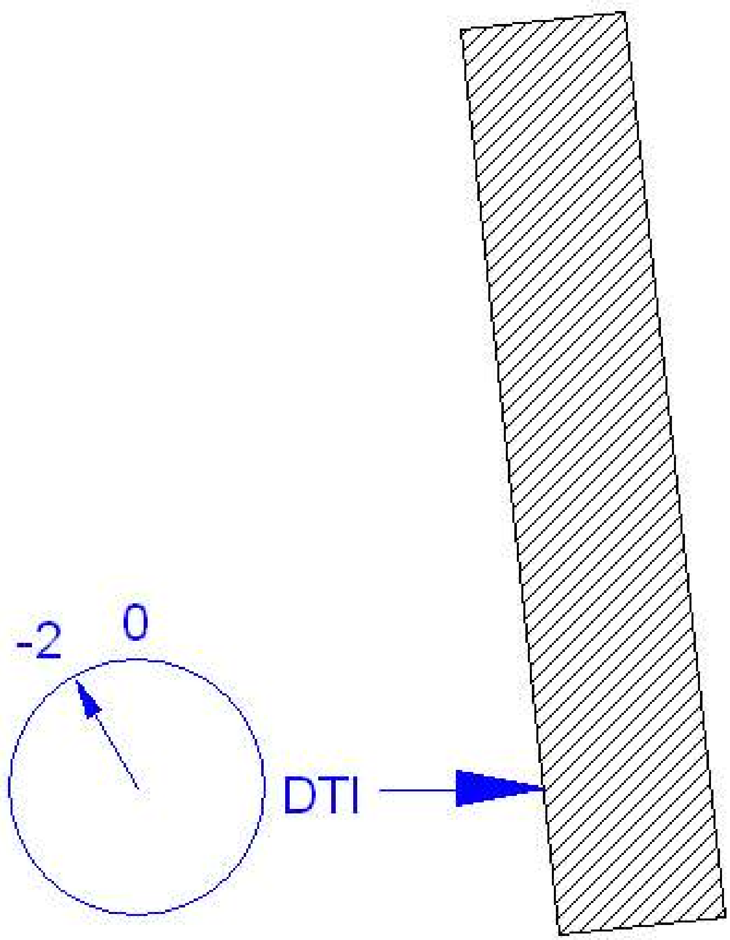
I then raised the DTI and rotated the holder 90 degrees so it was touching the flank of the Y slider. Here is a schematic view.



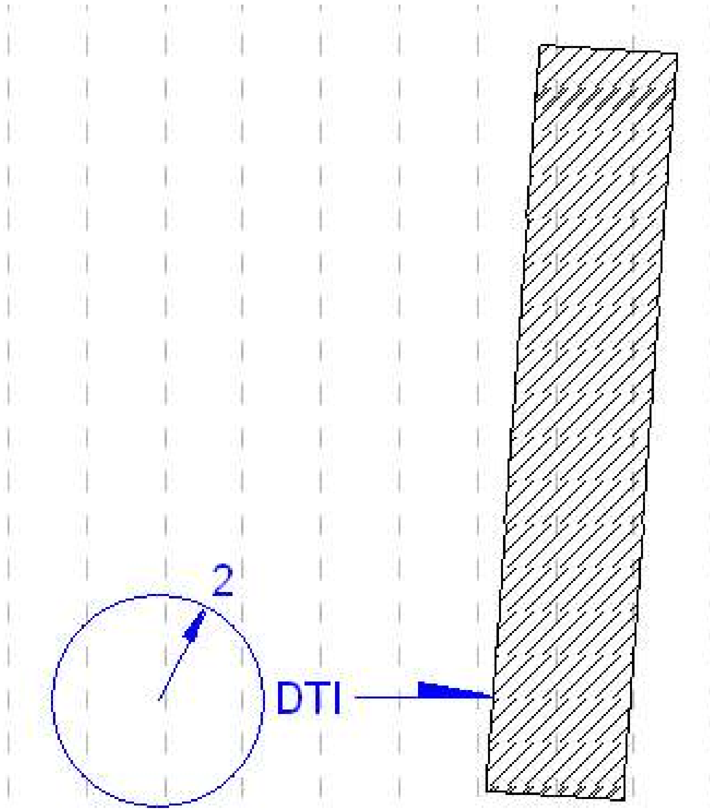
The DTI is at a location Y1 inches from the center of the XY compound.

Y1 = 2.60”.

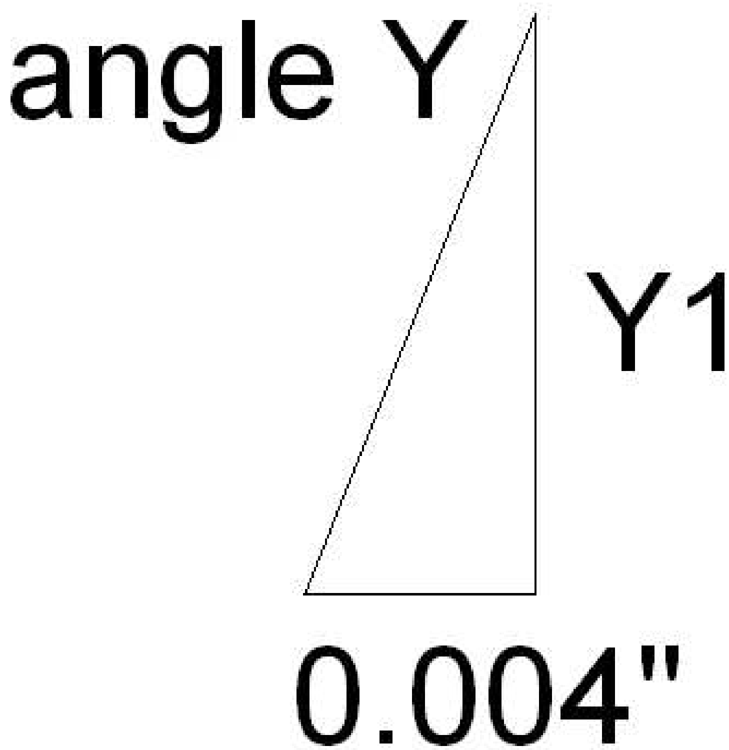
I then applied -200 inch-pounds of torque and saw the DTI read -0.002".



Next I applied +200 inch-pounds of torque and got a reading of 0.002”.



Putting this all together, I can determine how much my Y slider rotated due to my torques. My DTI is at a distance Y1 (2.60”) from the center of rotation and read a total change of 0.004”. I can draw a right triangle:

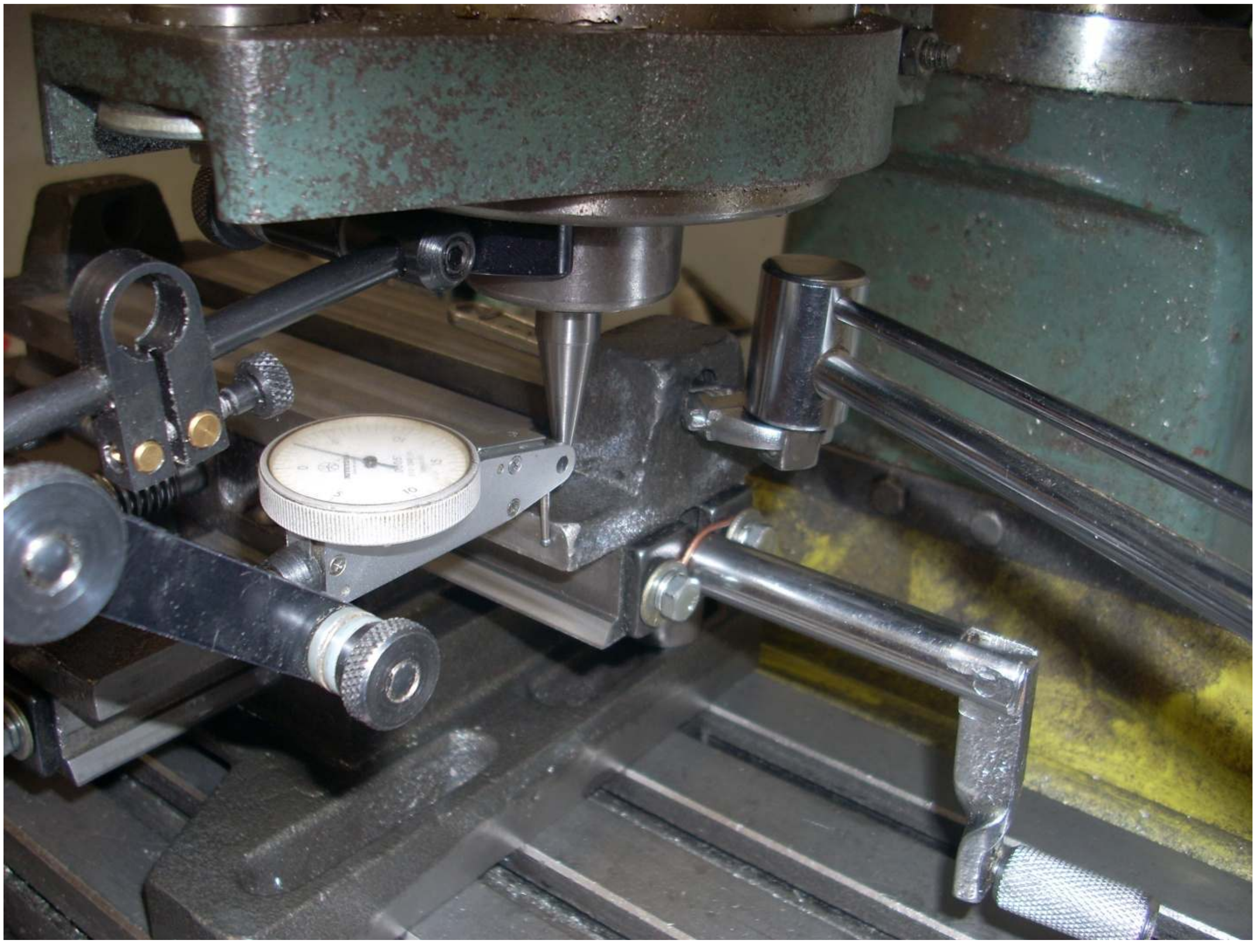


My “angle Y” is the total rotation caused by my applying -200 and then +200 inch-pounds of torque. Since this is a right triangle, I know that

$$\text{angle } Y = \tan^{-1}(0.004''/2.60'') = 0.088^\circ$$

From previous experience, we know that this rotation is due to play in the Y slideway and not bending of the Y slide.

The next stop is the X slider which sits on top of the Y slider. The math is the same but we are now rotated 90°.



I am 1.66” from the center of rotation along the X axis and saw a total DTI movement of 0.0045”.

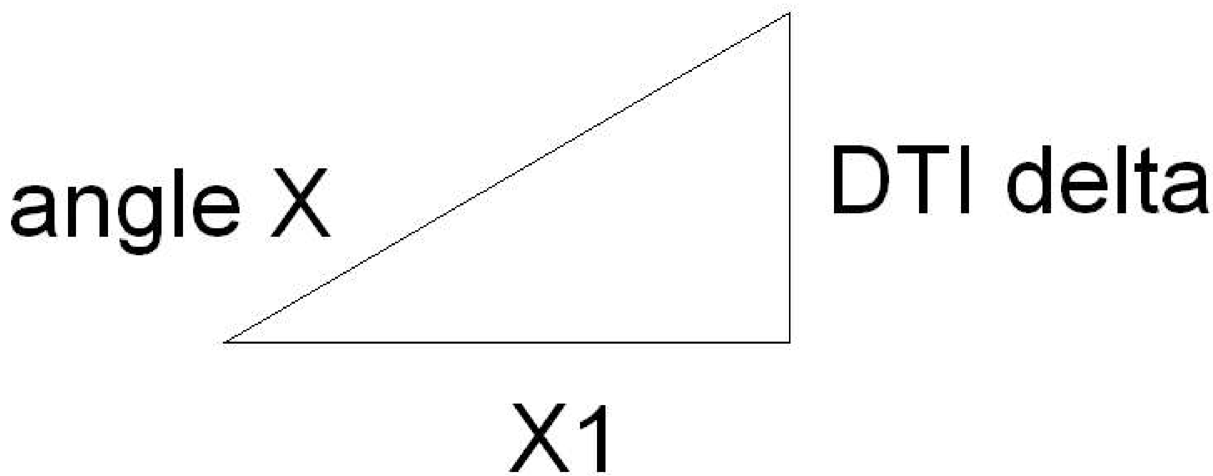
$$\text{angle X} = \tan^{-1}(0.0045''/1.66'') = 0.155°$$

Recall that my X slider sits on my Y slider and that the Y slider is known to rotate 0.088°. So to look at just the rotation of the X slider, I can subtract off the rotation of the Y slider.

Rotation of just X slider = angle X – angle Y = 0.155° - 0.088° = 0.067°

To recap, my Y slider rotated 0.088° and my X slider (alone) rotated 0.067°. This tells me that my Y slider is slightly looser than my Y. If one had been much worse than the other, I would do more lapping of its contact surfaces.

As a sanity test on my total rotation angle of 0.155°, let's estimate how much the X table's end will rotate as I apply my torque.



Angle X is my 0.155°, a distance, X1, of 4.5" puts me near the right end of the X slider. This is again a right triangle so I can say

DTI delta = (4.5") x tan (angle X)

= (4.5") x tan (0.155°)

= 0.012"

Such a delta is far beyond the accurate range of my finger DTI so I used a different approach for measuring the delta. The DTI is employed as a very accurate touchdown sensor. Displacement was handled using my Digital Read Out.

(Note: the above picture is similar to what I did below but not the event.)

With -200 inch-pounds applied to the X slider, I moved the Y axis of my mill table until the DTI read 0 and also zeroed my Digital Read Out's Y display. Then I applied 200 inch-pounds and moved the Y axis of my mill until the DTI again read 0. The DRO read a change of 0.013".

The agreement of the predicted and actual numbers demonstrates the validity of dealing with rotational error.

Your questions and comments are welcome. All of us are smarter than anyone of us.

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