Tramming a Mill/Drill, version 4

By R. G. Sparber

October 22, 2009

Conclusion

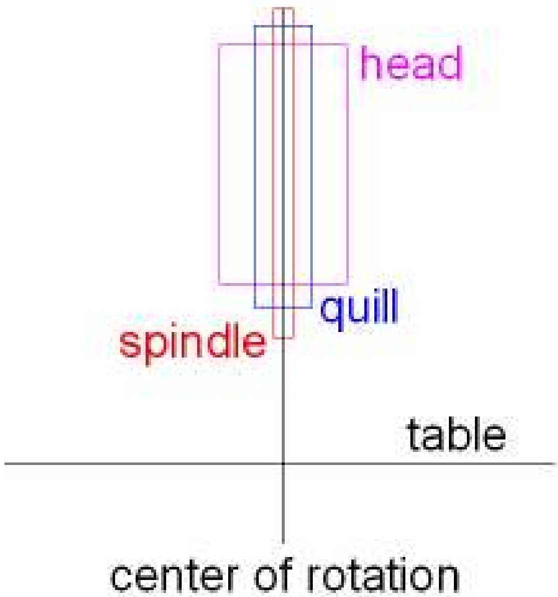
My goal was to find a single iteration process for perfectly tramming my mill/drill. I was unable to do that. However, I was able to get good results with a two iteration process. The first step was to cut shims that mirror what was found by tramming the head with no shims in place. The tram radius was 5". After these shims were installed, a second tramming reveals the thickness of a final set of shims. I started out with a maximum error of about 0.02" and ended up with a maximum error of 0.0005". The joy did not last. After moving the table and head around, I measured a maximum error of 0.003". This is still usable but certainly a disappointment after achieving 0.0005". The 0.003" error is about what I got with my first iteration so maybe that is all the accuracy I am entitled to after all.

Contents

Under all of these modifications is a RF30 mill/drill. Almost 20 years ago, when it first came home with me, I learned that the head was poorly aligned with the table. This is a very common problem. The standard fix is to loosen the bolts that hold the column to the base and add a few shims[2]. That has served me well for all of these years. But recently there was some interesting discussion about tramming on the Yahoo Mill_Drill BBS. It got me thinking about this process all over again.

[2] You can see the base surface at http://rick.sparber.org/Articles/MoveMill/MoveMill.htm.

Tramming



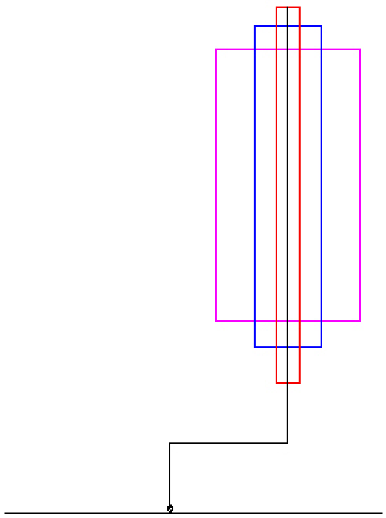
We can't have a conversation about tramming until we all agree what it means.

First let me define the players. We have the head of the mill which provides the solid support for what moves. The head is supported by the column which is supported by the base. You can see the column and base in the picture on page 2. Inside the head is the quill. The quill can move up and down. Inside the quill is the spindle. It is turned by a motor via either gears or belts. This turning motion in combination with the up and down motion lets a mill feed a cutter down while it removes material.

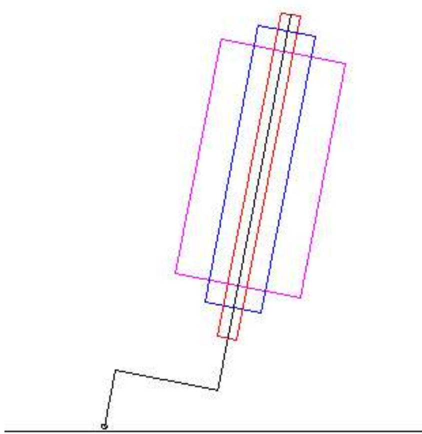
I can draw a line through the spindle that defines its center of rotation. Ideally, as the quill is moved up and down, the center of rotation does not move "very much". The amount it moves can be measured with a Dial Test Indicator (DTI) and result in a figure of merit called Total Indicator Run-out (TIR)[3]. I will assume that the TIR is acceptably small.

Below the head is our table. In this two dimensional drawing, the table is represented by a line. This line is ideally perpendicular to the center of rotation of the spindle. Adjusting the center of rotation such that it is perpendicular to the table's plane is the process of tramming.

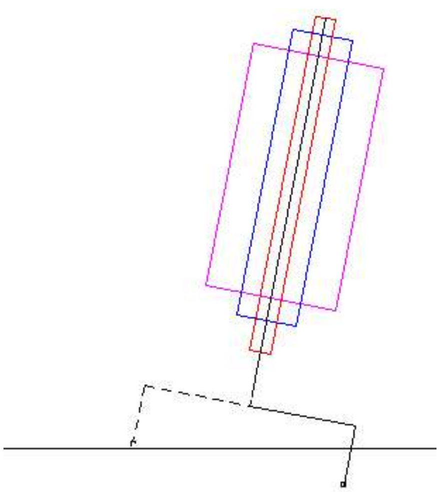
[3] See http://rick.sparber.org/Articles/tir/tir.pdf for more on TIR.



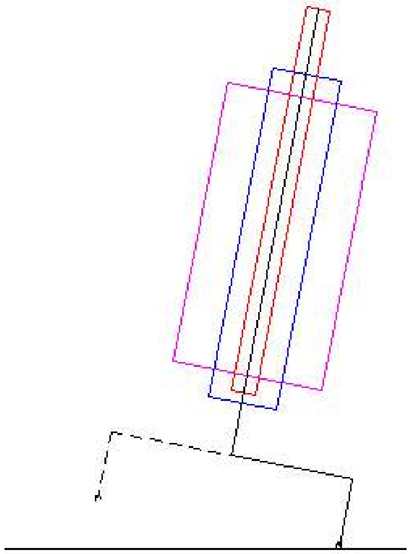
A standard and elegant way to see if the head is trammed is by using a DTI mounted in an arm that is attached to the spindle. The spindle is lowered until the DTI comes in contact with the table. The DTI is then set to 0. Then the DTI is slowly and carefully moved around the table in a circle. If the DTI reads 0 in all positions, the head is perfectly trammed.



Here is an exaggeration of a head way out of tram. I have lowered my spindle until the DTI reads 0.



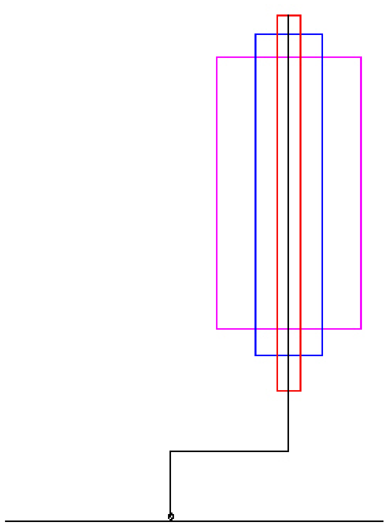
If I tried to just swing the DTI around 180 degrees, it would end up under the table's surface.



Instead, I must raise the spindle, turn it 180 degrees, and then lower it back down.

Consider what just happened with the spindle's vertical position. The 180 degree rotation forced me to raise the spindle. Now, I have defined positive motion of my spindle as moving away from the table. The right side reading is higher than the left side reading. This might lead you to think that the table is sloped but in fact the head is tilted.

Staying with the idea of a two dimensional mill, say that I have two bolts holding the column to the base. These bolts are spaced at a distance equal to the distance between the two points contacted by the DTI on the table. I find a shim with a thickness equal to the amount that the spindle moved up. Put that shim under the bolt on the right and the column will tilt to the left. The column tilts so the head will tilt too.



The cool bit is that the center of rotation will now be perpendicular to the table.

Another important insight relates to the movement of the DTI's tip. In our three dimensional case, the DTI's tip defines a plane. Any readings not consistent with that plane reflect on the testing method and not the flatness of the column base. More on this later.

Thanks to "dragonflight" for helping me understand these concepts.

The Standard Method of Tramming a Mill

I was taught to tram the head of a mill by swinging a Dial Test Indicator (DTI) over the table. Readings are taken at the front, left, back, and right sides (6:00, 3:00, 12:00, and 9:00). By doing this you are limited to the width of the table. A more difficult problem when applied to a mill/drill is that there is no direct correlation between DTI readings and how much to shim.

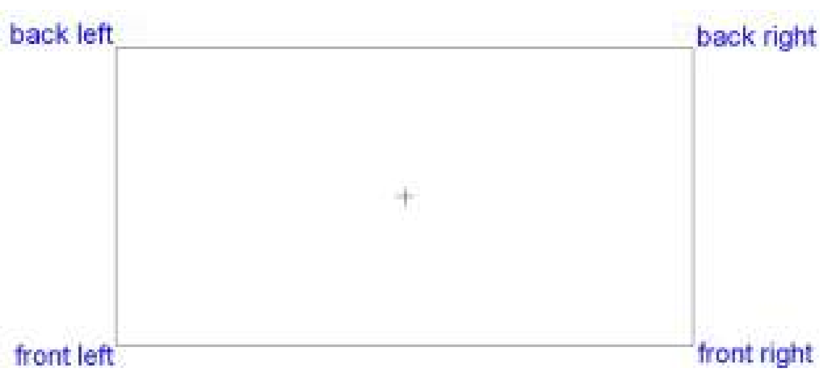
It is not that this standard method is poorly thought out. It is meant to be used on a Bridgeport Mill where the head pivots front to back and side to side. On this machine, the readings are just what you need to get the spindle perpendicular to the table.

The problem comes when you apply this method to a mill/drill. The head's position is changed by adding shims under the 4 bolts that hold the column in place.

Tramming a Mill/Drill

Although the solution is simple, it sure took me a long time to see it with help from a few insightful comments from the BBS.

We want DTI readings that directly correlate to the shim thickness under each bolt. OK, then center the mill/drill table under the spindle and place a dot with a marker at the relative location of each bolt. My bolts are spaced about 4 ½" front to back and 8 ¾" side to side. This pattern is reproduced on the mill table.



All old shims have been removed and all bolts re-tightened to 400 inch pounds. I'll talk more about using a torque wrench on page 6.

The distance from the center to each data point is about 5” so this is already an improvement since the larger the diameter traced out by the DTI, the better the accuracy in determining the tilt of the center of rotation.

My DTI is attached to my spindle and free to move to the 4 points. Since the vertical distances are far beyond what a DTI can handle, I used the DTI in conjunction with my Digital Read-Out (DRO). The DTI is first set to be 0.002” away from zero. The spindle is then lowered until the DTI swings over to 0. In this way I have minimal force on the DTI support and an accurate way to tell when I am at touchdown.

Starting at back left, I lowered the DTI until it read 0 and then zeroed my DRO. I sweep the DTI back and forth over a small arc to verify that I’m not on a low or high spot.

The spindle is then raised about 0.05”. Moving to front left I lowered the spindle until the DTI reads 0. The DRO now reads -0.0026”. The spindle is raised and the DTI is moved to front right. Here I read +0.0183”. At back right I read +0.0180”. So we have:

0	+0.0180”
-0.0026”	+0.0183”

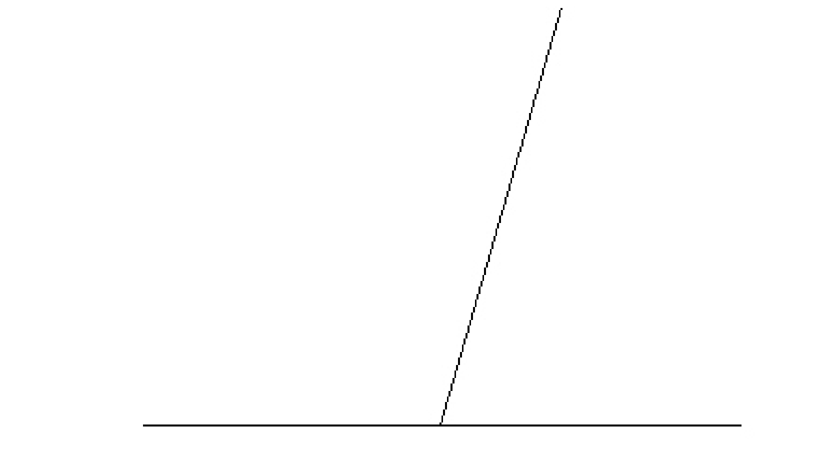
In hindsight, I see that the above data is flawed. As the DTI is swung around to the 4 points it is defining a plane. Pick any 3 data points and I fully defined my plane. That 4th point must line up on this plane but it doesn’t.

Looking at the above data you can see that along the back I have a rise from left to right of 0.0180”. Along the front this rise is 0.0209”. They should be equal. We also have a rise from front to back of 0.0026” on the left side but a fall of 0.0003” on the right side. Some of this error might be slop in my measurement system and or spindle. Ideally, the DTI should trace out a plane.

If you have difficulty seeing this relationship, find a flat object like a book. Put the left end down on the table and raise the right end. You will see that the slope defined by the front right corner with respect to the front left corner is the same as the slope defined by the back right corner with respect to the back left corner.

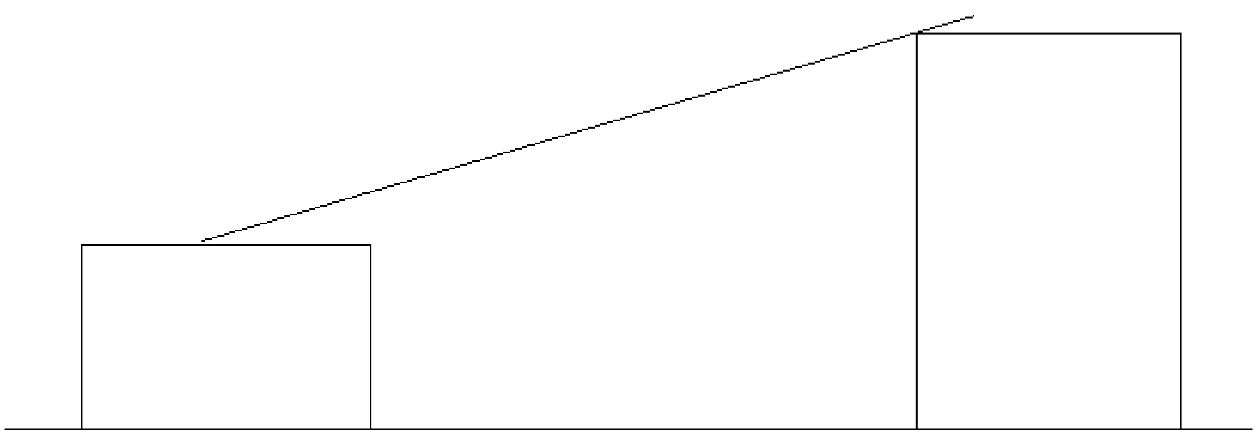
Next, add a spacer under the front left end. This will cause the book to pivot around the back left corner. Because the book defines a plane, you will again find that the slope left to right in the back equals that of the front. You will also find the slope front to back on the left side equals that on the right. Unless you bend the book, you will always have only one slope left to right and one slope front to back. You will see this concept again when the shims are placed under the column bottom.

Let's return to the tramming process.

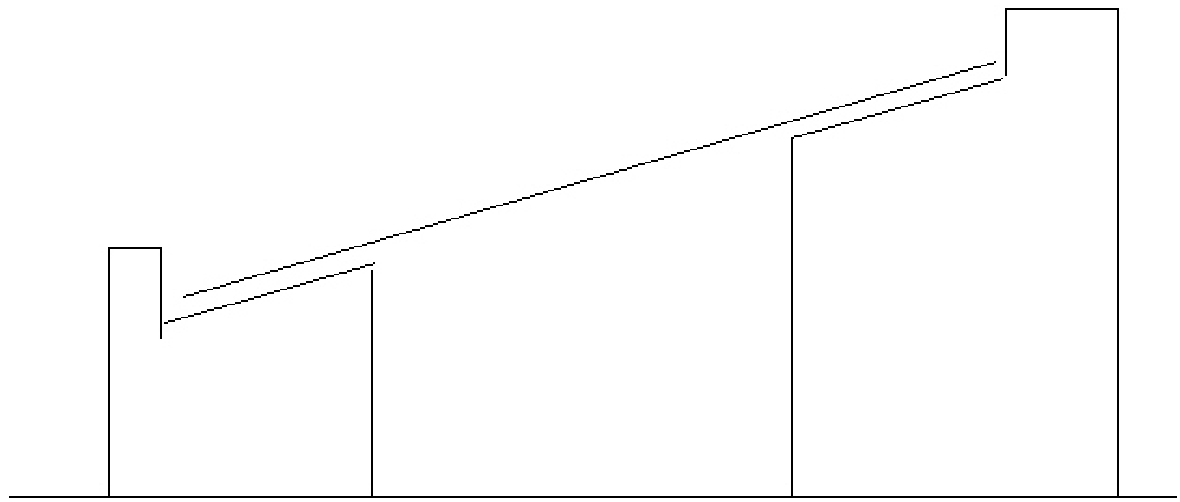


Here is a simple line drawing of my mill base and the column. With no shims in place and the column bolted onto the base, the base will be parallel to the bottom of the column. I have greatly exaggerated the column not being square with its bottom.

By adding shims, I can raise the right side of the column's bottom and get the column to be perpendicular to the base.



In this greatly exaggerated picture you can see that flat topped shims will contact the column's bottom at single points. This concentrates a lot of force over a very small area so will tend to distort the shims. It is also not supporting the column casting very well.



A modification to this approach is to use shims that are cut with the same slope as the column's bottom. The force is distributed over a much larger area. This is still a far cry from the support I would get without shims but I do want my mill head trammed.

It was suggested that once the head has been trammed to the owner's satisfaction, epoxy can be worked into the gap to provide more support.

Note that the height of all shims should be measured at the center of the bolt's location to be consistent with the DTI's positions. The slope I need is about 0.018" in 8.75" or about 0.002" per inch.

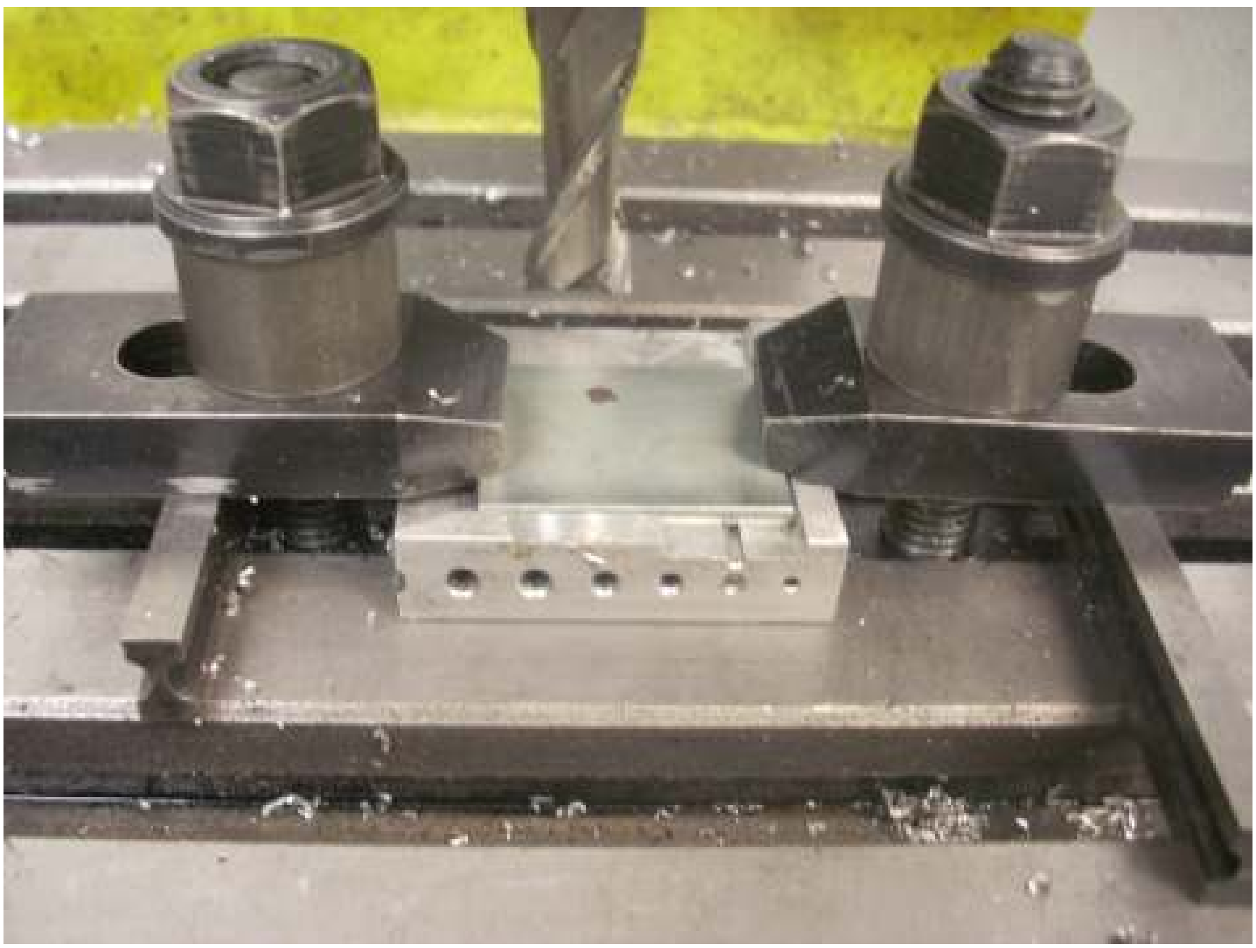
Let's assume that the base and bottom of the column are both planes. A plane is completely defined by 3 points. If more points are involved, they must be set onto the now defined plane. As I put shims between these planes, their thicknesses must be consistent with a plane. My machining will not be perfect so I'm sure that my four shims will not define a single plane.

If the base and/or column bottom are not planes, then my 3 contact points with the 3 shims defines a plane that is not parallel to the cut surfaces. In this case the 4th shim would have to align with the cut surface and not with the defined plane. In either case, this 4th shim can be either too tall or too short. That can't be true for the first 3 shims.

Think about how a 3 legged stool will never wobble no matter how rough the floor. Put down a 4 legged chair and it will almost always rock back and forth. Jam a shim under the short leg and you can get the rocking to stop.

This error in shim heights means that my column bottom and/or base are bent slightly in order to come in contact with all 4 shims. The closer the fit, the less bending we must do. I will return to this subject when we go over the shop experience.

Shop Work



Using a piece of scrap 6011 aluminum ½” x 2” x 2”, I milled a pocket to align each shim. One end of this scrap was raised with 0.004” shims to give me the needed slope of 0.002” per inch. I want to end up with 1.25” long shims but need some metal for clamping so the blanks are 1.5” long. My maximum height difference is about 0.02” so I start by touching the surface with my end mill, setting zero, and then feeding down to -0.025”. I then re-set zero. By doing this I can cut all 4 shims at the proper relative heights.

In my case most of the slope is left to right so the angle is simple. If it was also sloped front to back, a second set of shims would be used to cut the fixture to a compound angle.

I have cut and stamped the 4 shims. The far ends were sawed off and all edges deburred.

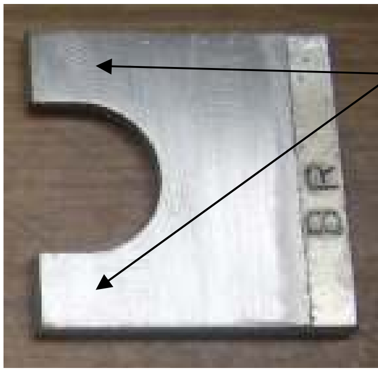
Using my 5/8” end mill I have cut slots to accept the ½” bolts.

There is a lot of surface area here so a lot of friction. The slope of these shims is only 0.002” per inch so it is unlikely that they would slide out due to downward pressure as the bolts are tightened.

In theory, I can move these shims in and out and vary the space they make between the mating surfaces. In practice, note that the cut slot is only 1/8” larger than the bolt’s diameter. When I install each shim, I slide it in until I hit the bolt and then back it out enough for the raised back end of the shim to clear the castings. This is about 1/16”. At 0.002” of slope per inch, 1/16” is a change of only 0.000125”. You will later see that my variations are much larger than this.

Here are the right two shims.

In hindsight, there is a potential problem with the design of these shims. If they are pushed in too far, the raised bar with the stampings on them might get between the mating surfaces. It would be better to cut this area so it is below the rest of the shim.



I took measurements at the two narrow parts of each shim and took the average in order to estimate the thickness at the center of where the bolt will go.

The left side shims are around 0.075" thick and the right side shims are around 0.1" thick.

Here are the *differences* between the shims:

Back left – my reference Back right +0.0191"

Front left +0.0023". Front right +0.0201"

Or in compact form[4]:

0	+0.0191"
+0.0023"	+0.0201"

From page 7 we have the tram values with no shims present:

Back left – my reference Back right +0.0180"

Front left -0.0026". Front right +0.0183"

Or in compact form:

0	+0.0180"
-0.0026"	+0.0183"

[4] I mark my reference as "0". If a reading turns out to be zero, I will show it as "0.0".

Next I will attempt to predict what will happen to the tram when these shims are added. I am taking the tram value and subtracting the shim value.

Back left - my reference Back right -0.0011”

Front left -0.0003” Front right -0.0018”

0	-0.0011”
-0.0003”	-0.0018”

The four shims are installed and all bolts torqued to 400 inch pounds. The DTI is set so before touchdown it reads -5 thou. The spindle is lower to the back left reference point and locked when the DTI reads 0.

Back left - my reference Back right -0.0020”

Front left +0.0015” Front right 0.0”

0	-0.0020”
+0.0015”	0.0”

I can’t say that my predictions were very good but at least I’m a lot closer to tram that I was before adding the cut shims.

I will redefine my back right location as my reference so that all numbers are positive.

Back left +0.0020” Back right - my reference

Front left +0.0035” Front right +0.0020”

+0.0020”	0
+0.0035”	+0.0020”

I’m now on my second iteration of shims. I want to put a 2.0 thou shim under the back left bolt, a 3.5 thou shim under the front left bolt, and a 2.0 thou shim under the front right bolt. Ideally, this should perfectly tram my spindle. I just happen to have shims very close to these values so installed them. I now see

Back left - my reference Back right 0.0”

Front left 0.0” Front right +0.0005”

0	0.0”
0.0”	+0.0005”

After waiting 45 minutes I took another set of data just to be sure there wasn’t any drift due to the metal settling in. I saw the front left point change from 0.0” to +0.0001”. All other points remained the same.

A few days later I moved my mill table back and forth plus unbolted the head and ran it up and down. Then I put the head back approximately at the same height as before and cut some scrap 6011 aluminum with my 5/8” end mill. The table was cleaned and the tram rechecked:

Back left - my reference Back right +0.0014”

Front left +0.001” Front right +0.0030”

0	+0.0014”
+0.001”	+0.0030”

My worst case error went from 0.0005” to 0.0030”. This shift gives me some hint of how stable the mill/drill is over time and use. I was able to get almost perfect alignment of the head but it did not stay there. Still, an error of 0.003” over a 10” diameter circle means an error of about 0.0002” over the diameter of my 5/8” end mill.

Other Insights Along The Way

After much discussion on the BBS, a number of key points were presented. The first is that it is best to put in only 3 of the 4 shims. In this way I avoid bending the column base at all. It appears that my shims are close enough to ideal that I did not run into this problem.

In order to test if the column bottom fully contacts the tops of these shims, I put a sheet of kitchen aluminum foil on top of each of the 3 shim. Then I tighten down the bolts to 400 inch pounds. Then all bolts were loosened and the foil carefully removed. All foils showed the imprint of the column bottom. This demonstrates that the sloped shims do support the column casting over their entire face.

An interesting test was suggested to reveal what is bending when I pull down on the top of my mill head. With the DTI attached to the spindle and zeroed on the mill table, I can easily get a deflection of 0.001”. What is bending? Is it the head and column or the column and base? The answer came from swinging the DTI around so it is resting on a bar bolted to the bottom of the column. If the head and/or column is what bends, the DTI should move as I pull down on the top of my mill head. It did not move at all. This tells me that the flexure I see in the head as I push down on it is due to the column moving relative to the base. I have 4 massive bolts torqued to 400 inch pounds each at this joint yet I can still stretch them enough to see a 0.001” deflection between spindle and table. This is not really a problem as much as cool insight.

Acknowledgements

I wish to thank the numerous people on the Mill_Drill BBS for their comments and suggestions: Cliff Johnston, Jim S., Curt Wuollet, Dan Mauch, dfischer1947, Dragonflight, garydavison952, Glenn N, lkasdorf, leasingham_connelly, Malcolm Parker-Lisberg, Cecil Strange, and toolingjim . I would also like to thank Larry Gill for improving the clarity, spelling, and grammar of this article.

What Next?

I welcome questions and comments that will improve this article. All of us are smarter than any one of us.

Hopefully others will try this procedure and report back to the BBS on what they find. Only if others can reproduce my success can it be considered valid.

Rick Sparber

rgsparber@AOL.com