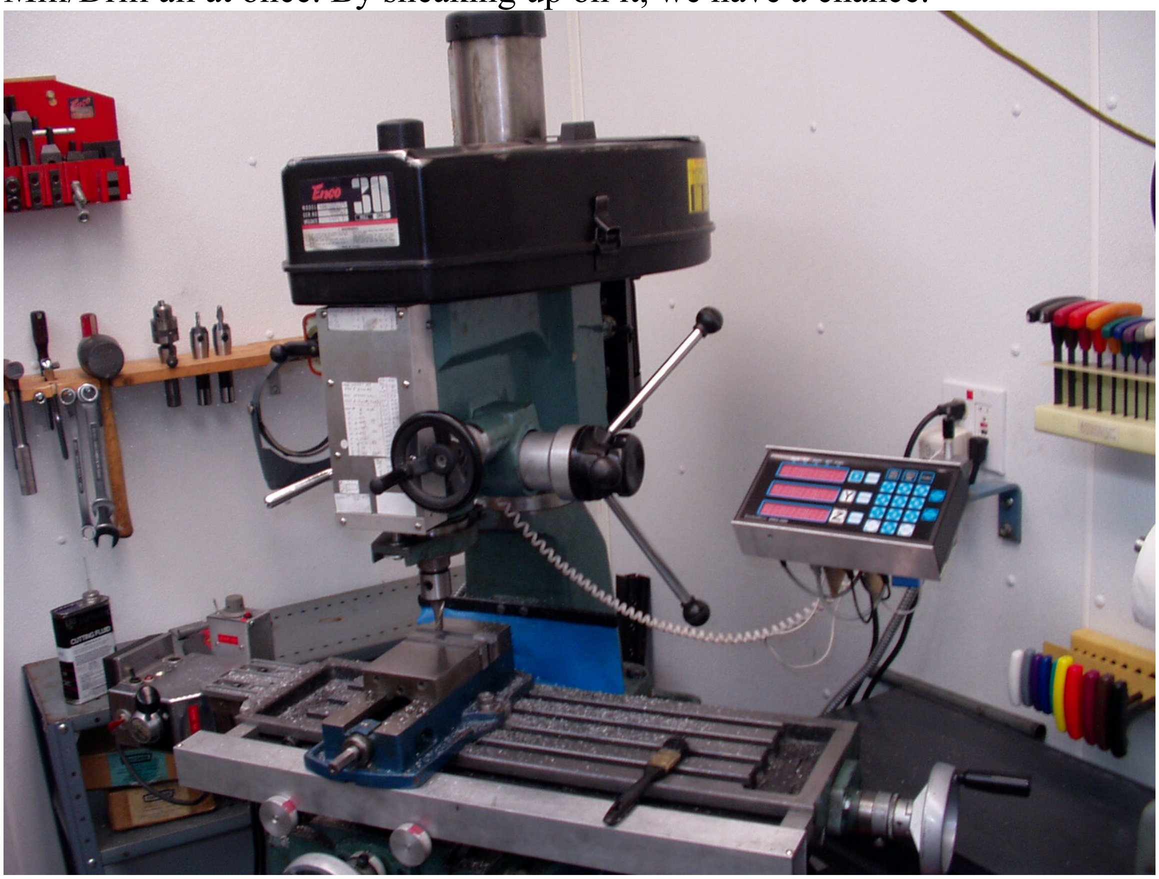
Mill/Drill Error Sources

By R. G. Sparber

March 21, 2007

I find it very difficult to visualize all of the error sources in my RF30 Mill/Drill all at once. By sneaking up on it, we have a chance.



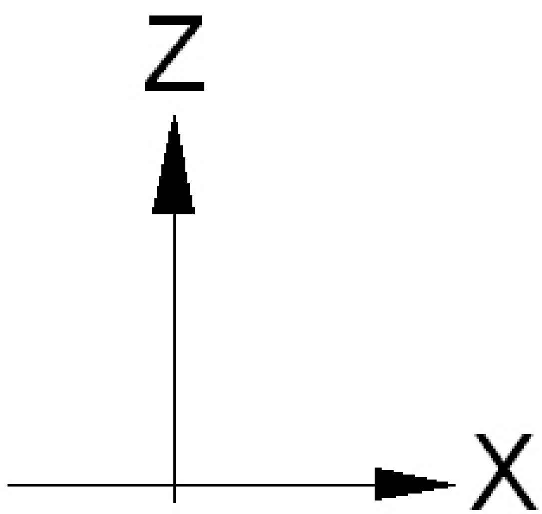
Types of Error Sources

There are two types of error sources. The first I will call "static". Static errors are present even with the machine turned off. One example of a static error is if the column is tilted with respect to the table.

A second type of error source is "dynamic". These are evident only when the mill/drill is running. Some dynamic errors exist whenever the motor is on, others pop up only when the cutter is actually removing material.

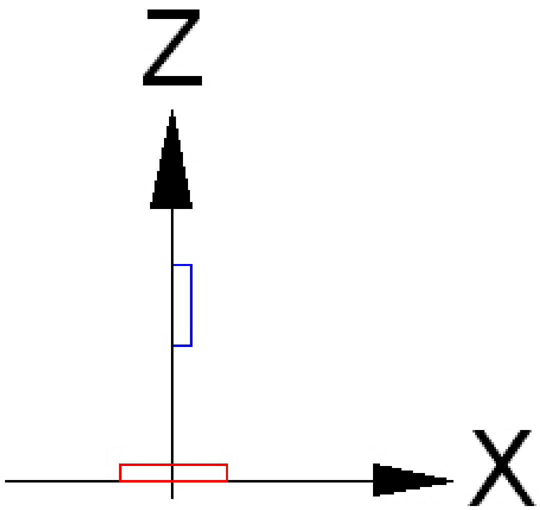
Both static and dynamic errors cause my mill/drill to behave in a non-ideal manner. We will investigate both of them in this article.

Static Error Sources

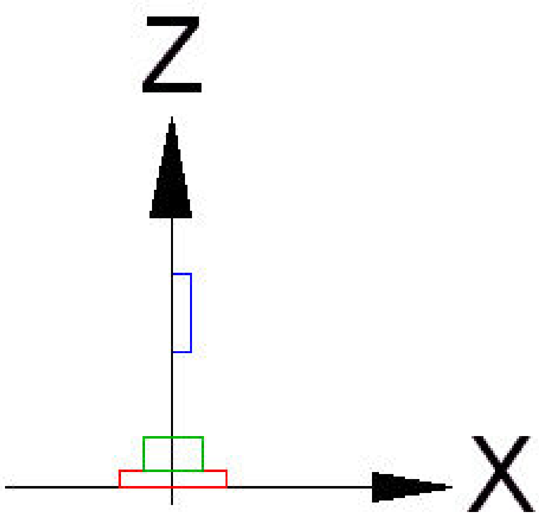


I have never been good at thinking in 3 dimensions. Fortunately, much of this discussion can be accomplished by only thinking in 2 dimensions at a time.

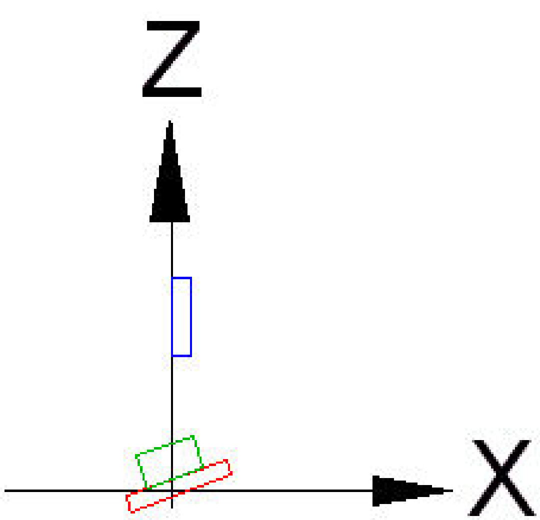
Let's start with the basics. I can represent an ideal mill/drill in 2 dimensions by just talking about the X and Z-axis. The Z-axis is exactly perpendicular to the X-axis.



The table, shown in red, moves along the X-axis. The cutter, in blue, moves along Z-axis.

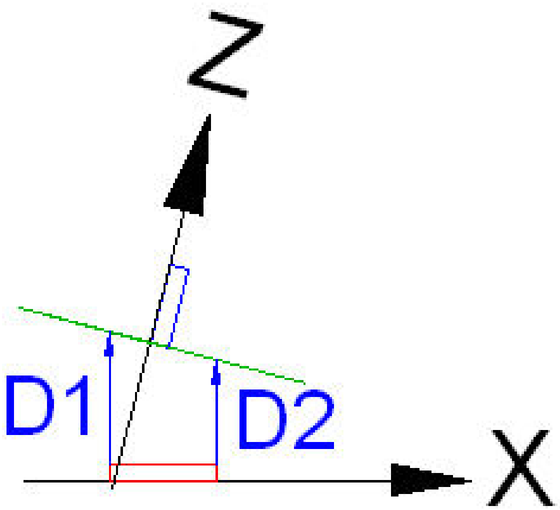


I can clamp a block of metal, shown in green, to the table. The table will precisely move this block along the X-axis. If I move the cutter down into the block, chips will fly. The result will be a cut surface that is exactly parallel to the X-axis. What could be simpler? Well, many things can go wrong when using a non-ideal mill/drill.

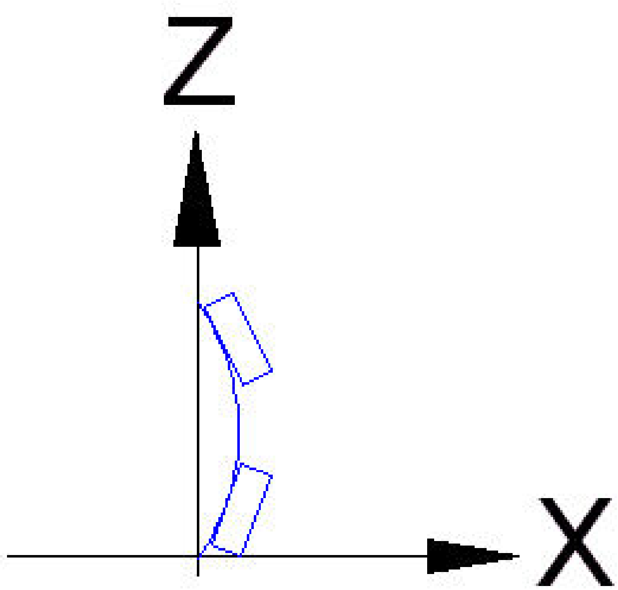


Look at what happens if the block is not aligned with the X-axis. As the cutter moves across the top of the block, we will get a taper. The end of the block that is higher will have more cut off than the lower end. Often this is a problem with the means of holding the block rather than with the table.

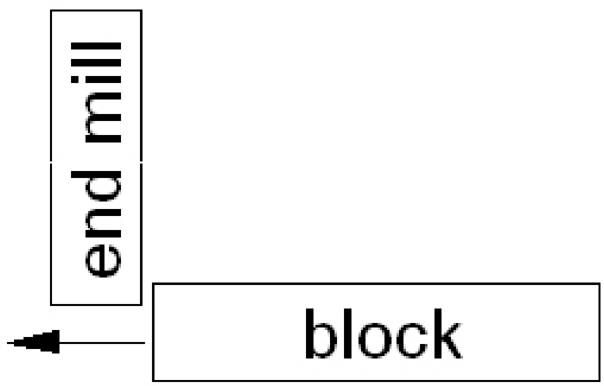
You can detect this error by measuring from a fixed point on the Z-axis to the surface that will support the block to be machined. I have an article that discusses this procedure on my web site.



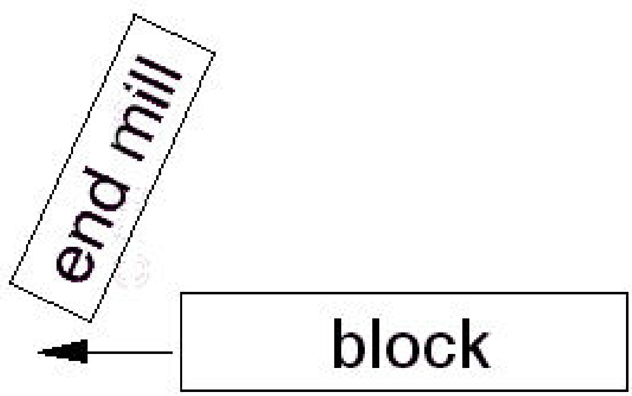
Another static error source comes from not having the Z-axis perpendicular to the X-axis. This error is commonly measured by "tramming the head". Plenty has been written on this subject so I will not add to the pile.



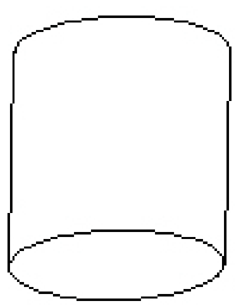
A word of caution is in order. If your column is not straight, you may have to re-tram the head each time you raise or lower it. Note that the blue boxes are aligned with the curve that represents the column. At the bottom the box representing the spindle points one way and at the top it points the opposite way. Shimming the column so the bottom box is aligned with the Z-axis will not work as the head is raised to the top.



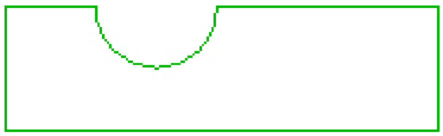
Lets start thinking about Z-axis misalignment by considering the ideal case. The end mill is rotating around a line parallel to the Z-axis and the block is moving parallel to the X-axis.



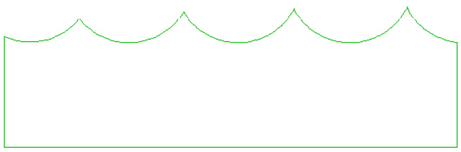
Look what happens if the end mill is not parallel to the Z-axis. Looking in just 2 dimensions, it appears that the block will still be cut flat on top.



Think about how the end mill looks when it is tilted. The bottom appears as an arc. The block sees it the same way.

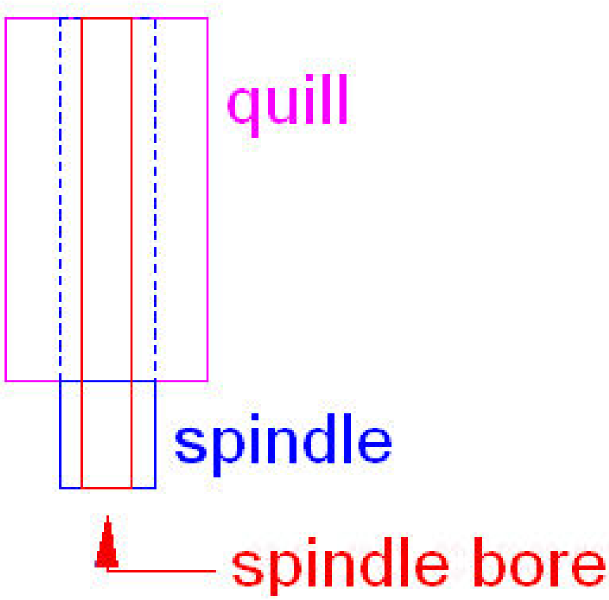


Here we have an end view of the block. As the cutter moves across the block's surface, we get a dished cut.

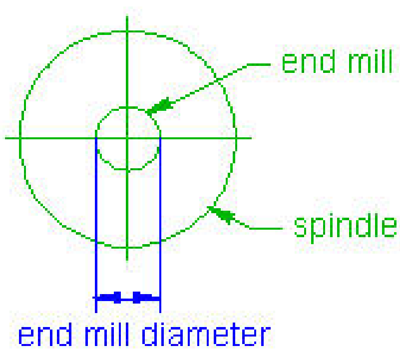


When you make repeated cuts, the surface will take on a scalloped pattern. Even if the distance from peak to trough is only .0005", you can clearly see it.

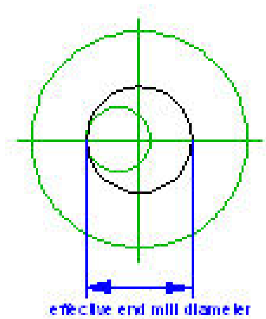
A different crop of static errors can become evident when you cut using the side of the end mill.



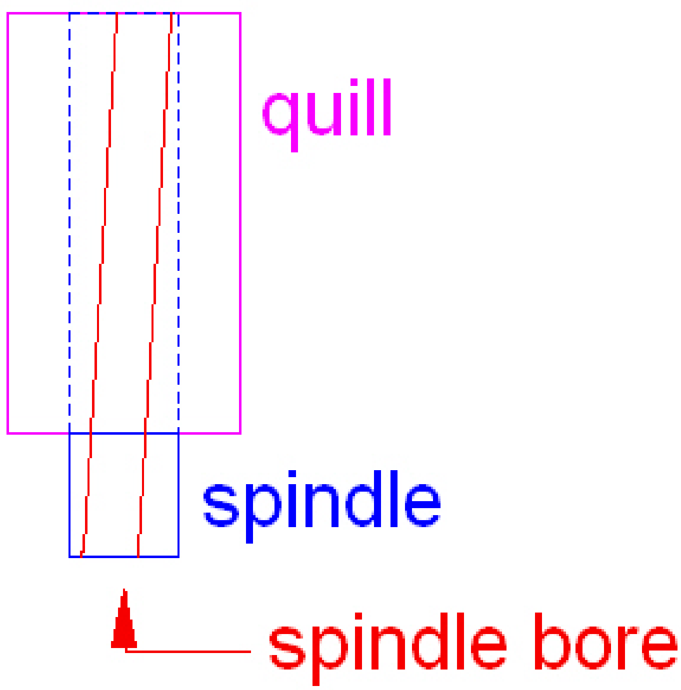
Consider the case of the spindle bore's alignment. Here is the ideal case. The quill moves parallel to the Z-axis. It carries the spindle, which is also aligned with the Z-axis and free to rotate. Inside the spindle is the spindle bore. The center of the spindle bore is ideally aligned with the Z-axis plus is on the center of rotation of the spindle.



Say we lay our head down on the mill's table and sight up at a mounted end mill. It hurts just to think about doing this. Anyway, you would ideally see that the center of the end mill is aligned with the center of rotation of the spindle.

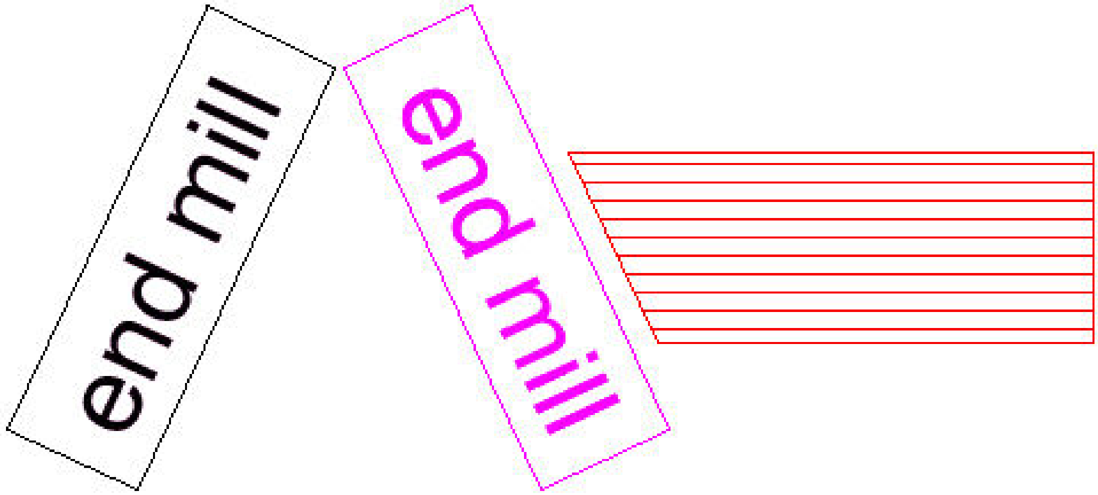


Consider what happens if the end mill's center is not aligned with the center of rotation of the spindle. The cutter pirouettes around and cuts with a diameter larger than that of just the end mill. If you side mill with an end mill with this error, you will discover that it has an "effective diameter" that is larger than you can measure with a micrometer across its shank. For more information about this effect and how to compensate for it, please refer to my article on effective end mill diameter on my web site.



In addition to having the center of the end mill not aligned with the center of spindle rotation, we can also have a spindle bore not aligned with the center of rotation. As the spindle rotates, an end mill fitted into the end will trace out a funnel shape.

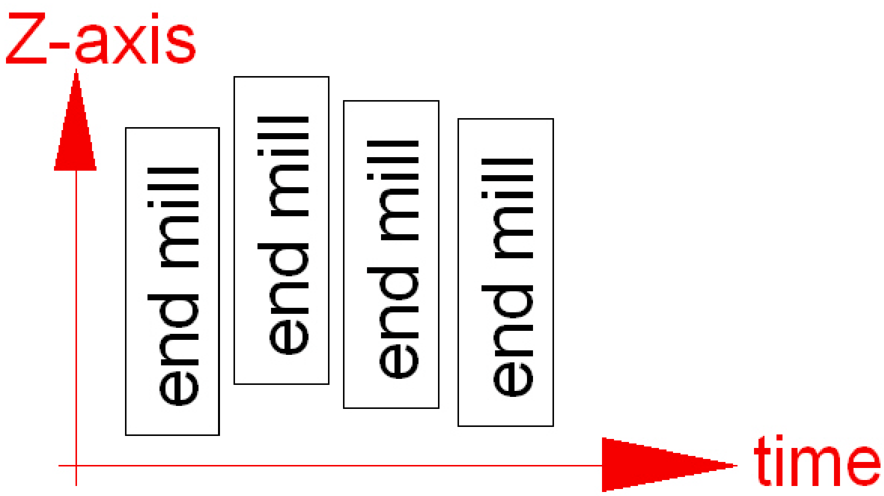
Lets look at what this misalignment does to the end of a block.



When the end mill points to the left (in black), it is far from the block being cut so has no effect. As the spindle swings around to the right (in purple), we see the block being machined by the side of the end mill. The angle cut is the result of the end mill's center not being aligned with the Z-axis. A very wise and generous man, who wishes to remain anonymous, told me how to detect this condition. Select a length of drill rod and hold it in a collet. The drill rod should be long enough to reach almost to the back of the collet so it is uniformly held and still extend out 4 or 5 inches. Snug up the collet with your draw bar. Now place a finger Dial Test Indicator (DTI) on the rod near the collet. Note how much the needle on the DTI moves as you manually turn the spindle a full 360 degrees. This value is called the Total Indicated Runout (TIR). Repeat the test at the bottom of the rod. If these two numbers are equal, then your spindle alignment is accurate to the limitations of your DTI. If the two readings look identical, it just means that the error is too small to be seen with your DTI. If they are not equal, you can at least be aware of this defect. I know of no simple way to compensate. My mill/drill shows a difference of about .0003" in run out between the two measurements.

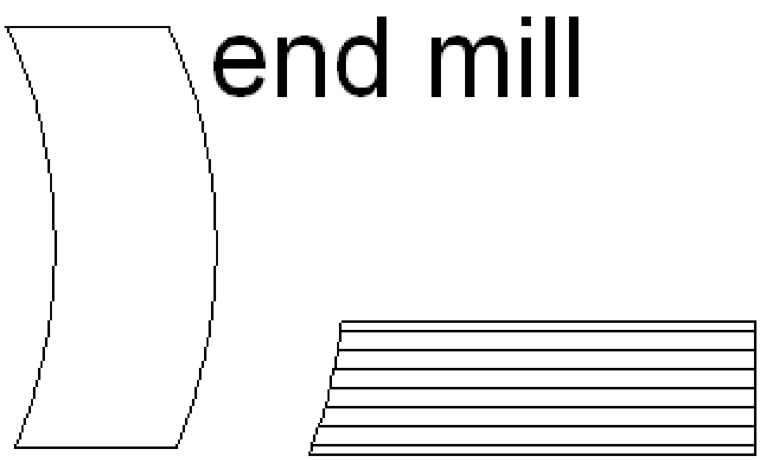
Dynamic Error Sources

It is helpful to think of my mill/drill as being made entirely of cooked pasta. The motor, belts or gears, and spindle all rotate and therefore generate vibration. This vibration has a field day with the mill head. It will flop around in every dimension.

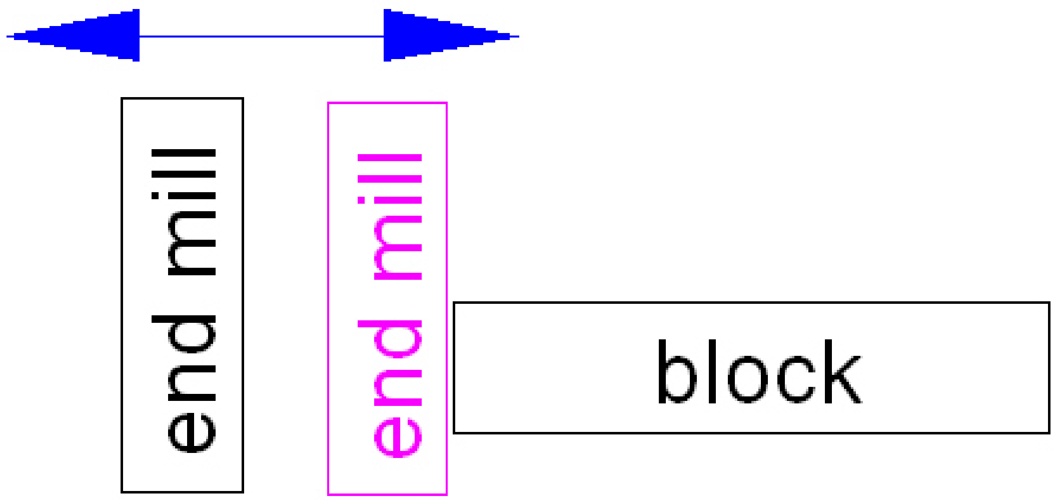


This graph attempts to show you how, over time, the end mill moves up and down due to vibration of the head. This vibration is typically occurring at a rate much higher than the feed rate of the block being cut. You therefore do not see the up and down motion on the cut surface. This error is most obvious when you are working with a Digital Read-Out with its Z-axis reference set with the motor off. I discuss this at length in an article on my web site related to precision Z-axis milling.

I will next describe two dynamic error sources that are evident during side milling.



There is a lot of force on the side of an end mill while it cuts. This is particularly true since our mill is made from cooked pasta. During deep cuts, the end mill deflects away from the block. This deflection reduces as the cuts become lighter. It is common practice to take a light finish cut followed by one or more passes without advancing the end mill into the block. When the end mill is no longer removing metal, there is no more deflection.



The second dynamic error source relates to the mill head flopping around due to vibration. Not only does the head bounce up and down, it can also flop side to side. Early studies of my mill indicate that this error is much smaller than the up and down problem described earlier. It makes sense to me that my column is more likely to bend than twist. So if you do have noticeable side vibration, it will cause the end mill too cut too deep during side cutting. The vibration will cause the end mill to bounce to the left (in black) and then to the right (in purple). The end mill can only cut when the right most position. This error may only be evident when using a DRO that has had zero set with the motor off.

What more could go wrong?

As with all of my articles, I rely on readers to help me improve the text. As I learn more, this article will become better.

All of us are smarter than any one of us.

Peace,

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