Accumulated Error When Squaring a Block

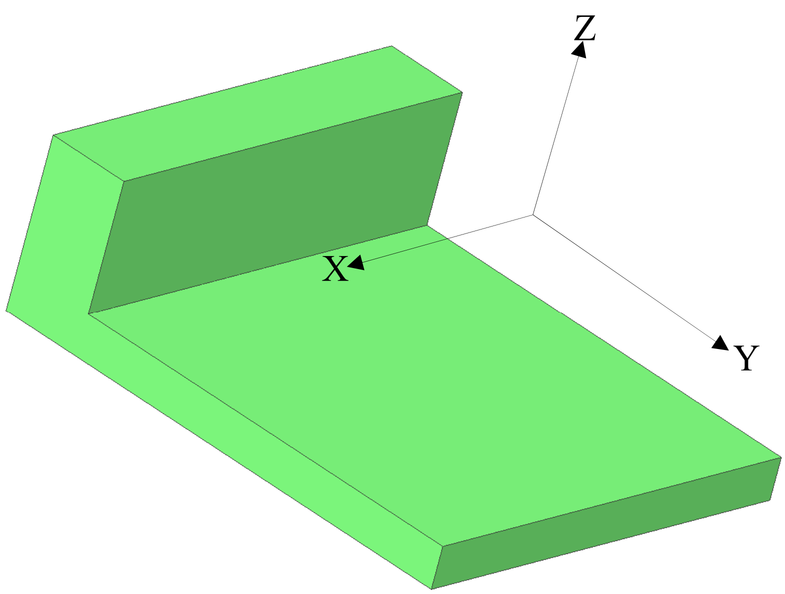
By R. G. Sparber

Error in the vise directly affects the squareness of the machined work piece. This article attempts to explain this relationship and what can be done about it.

In theory, machining is very simple and all resulting parts are perfect. That's nice.

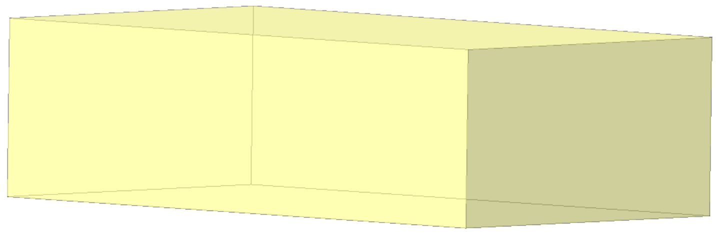
My shop contains machines that are less than perfect. Toss on my less than perfect skill level, and I quickly leave the world of theory. This article deals with how small errors are multiplied during the relatively simple procedure of cutting four faces of a block in hopes of making them perpendicular to each other.

I will start by looking at the theory so we will have a basis for seeing non-ideal conditions.

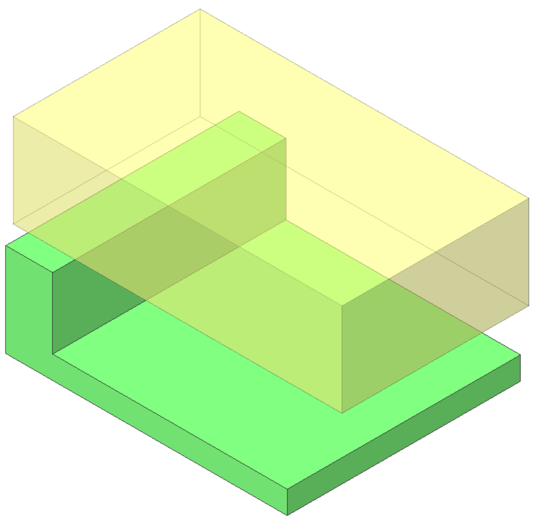


My ideal vise includes a vertical face and a horizontal face. It can be clamped to an ideal milling machine such that the vertical face is parallel to the XZ plane and the horizontal face is parallel to the XY plane.

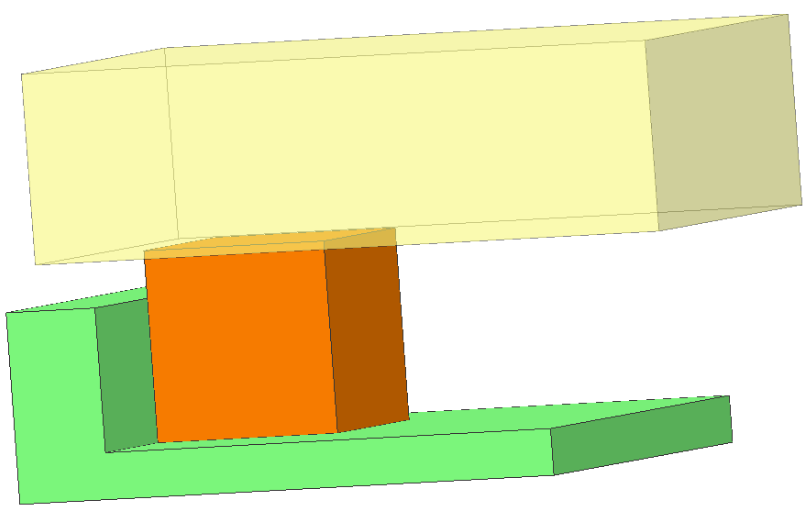
The movable jaw is not shown because it just applies pressure to hold the work piece in place.



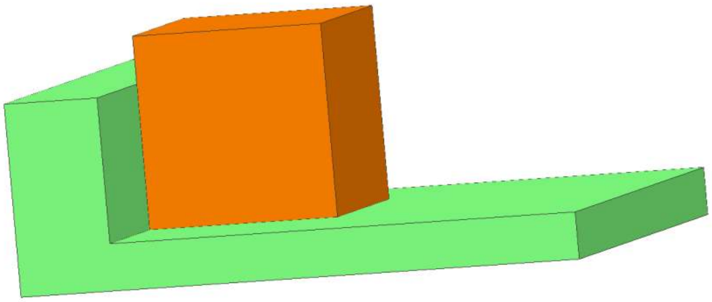
I have an end mill that cuts a volume represented by this translucent yellow box. The box is also perfectly aligned to the XYZ axes.



Putting the two together we get the essence of an ideal milling machine.

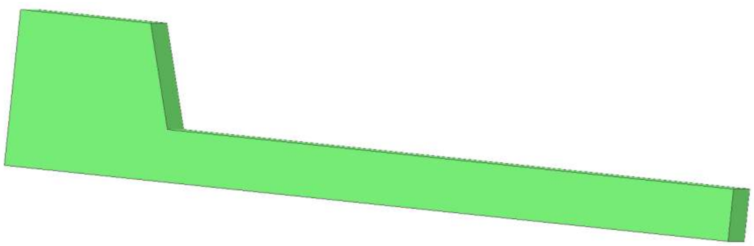


I have added a work piece that is perfectly flat and square on two sides. These sides are in contact with the fixed jaw's vertical surface and the vise way's horizontal surface. A tiny bit of this work piece is within the yellow space. When the end mill is moved over the top of the work piece, the top surface will be cut exactly perpendicular to the vertical jaw and parallel to the vise ways.

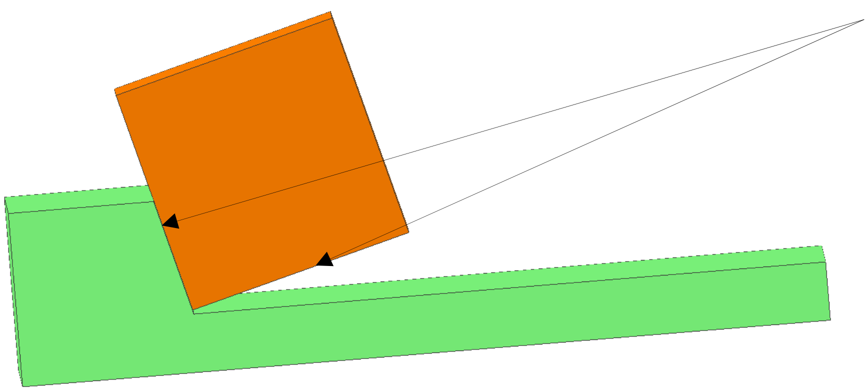


My freshly machined work piece now has three adjacent faces that are perpendicular. I rotate the block so the top face is against my fixed jaw. With another pass of the end mill, all four faces will be perpendicular to each other.

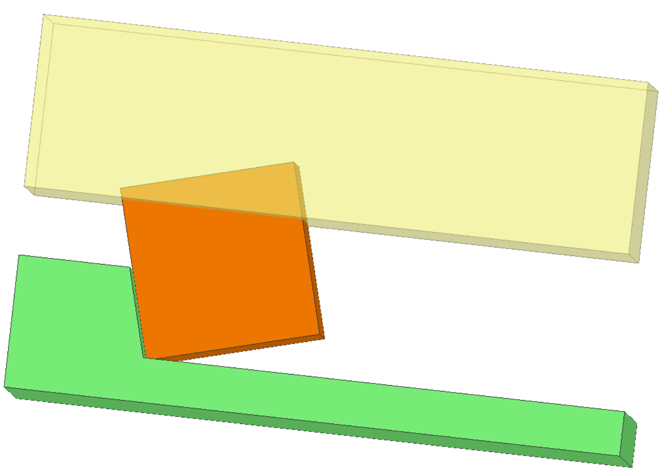
So starting with an ideal vise and an ideal mill, I can cut my work piece to have 4 adjacent faces that are perfectly perpendicular.



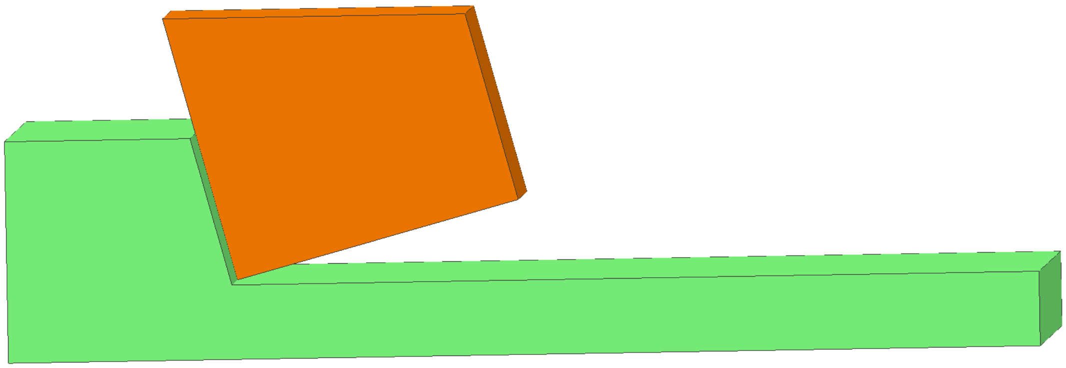
Next I will discuss a non-ideal fixed jaw. In order to make it clear, my fixed jaw will be off true by 15°. However, both the fixed jaw and vise ways will be dead flat.



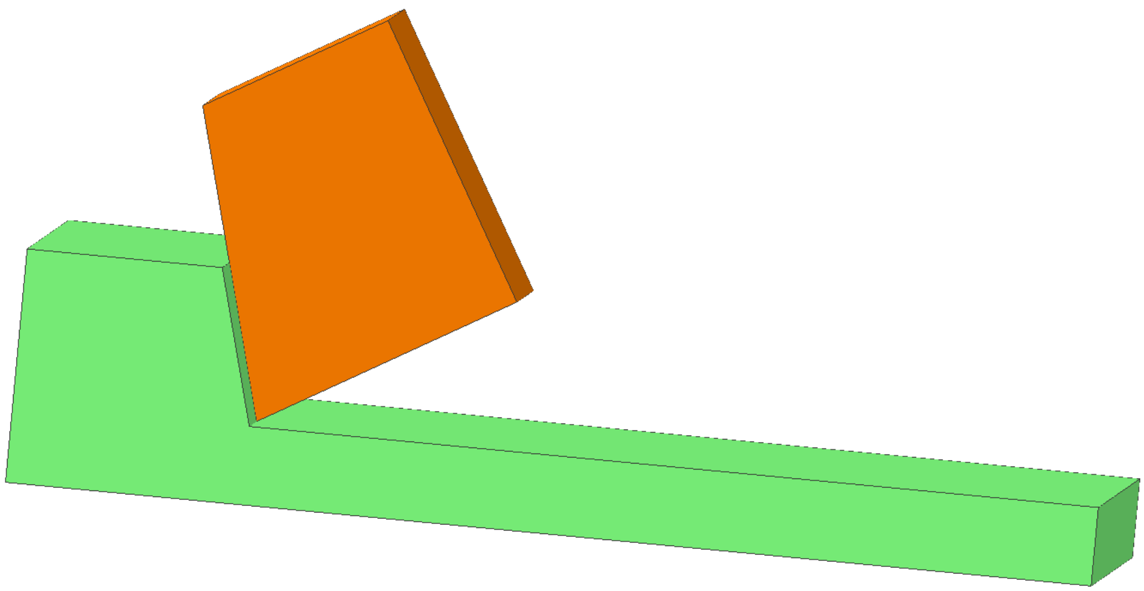
My work piece has two faces that are flat and perpendicular. But when I put one of these faces against my fixed jaw, the other face does not touch the vise ways.



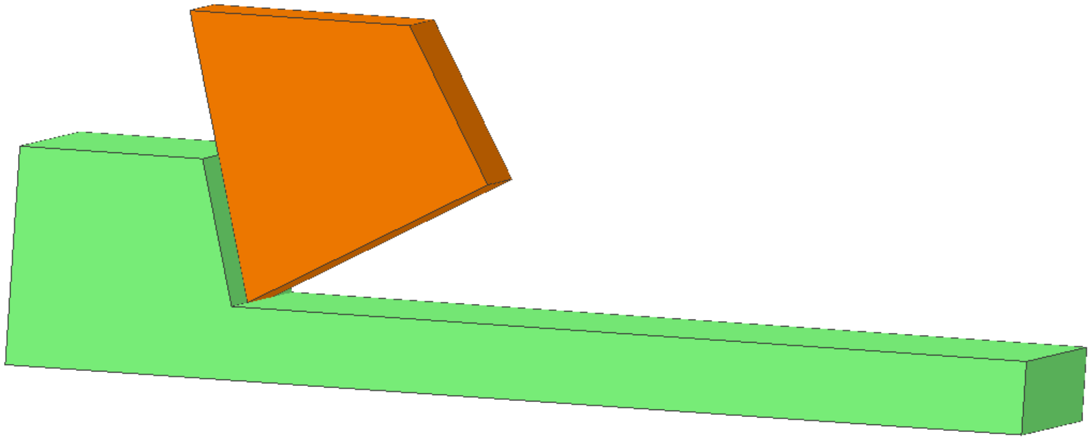
The translucent yellow box shows what will be removed by my ideal end mill.



The face I just cut forms an angle with the face against the fixed jaw that is 15° less than 90° (= 75°).

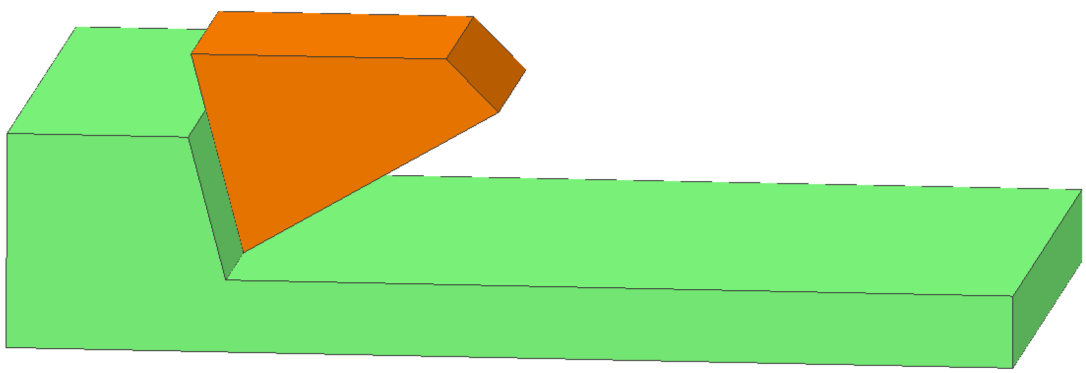


I rotat the work piece in preparation for cutting the second face.

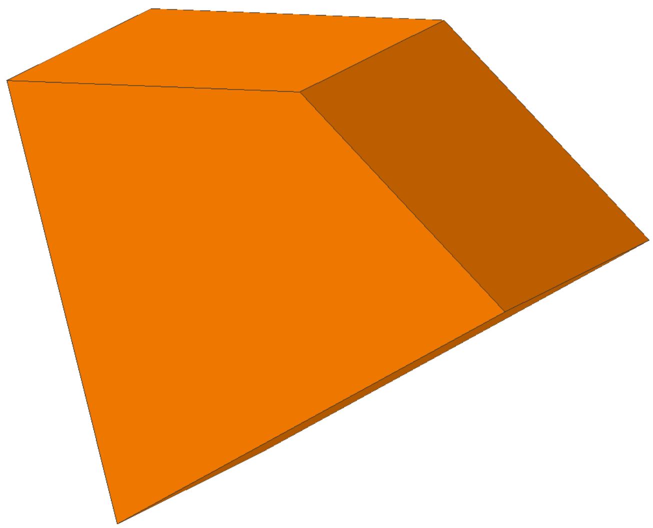


The resulting work piece looks rather sorry. I made two cuts which are both out of square. The top face forms a 75° angle with the face against the fixed jaw. Comparing this freshly cut face with the one nearest the vise ways, I see an angle of 30° rather than being parallel.

In other words, the error in the fixed jaw in injected into each set of adjacent faces. The error accumulates such that faces that should be parallel end up forming an angle equal to twice the fixed jaw error.



The freshly cut face is then rotated so it is against my fixed jaw. I use my end mill to cut the top true to the XY plane.

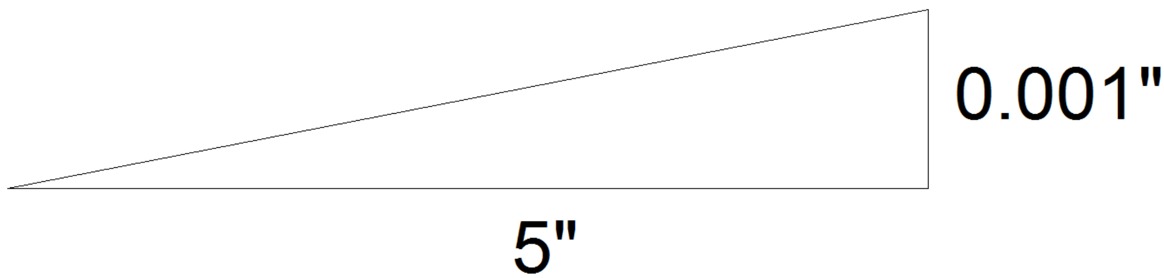


The work piece is now complete. Given an error in my fixed jaw of 15° over 90° (= 105°), adjacent faces are at either 15° under (= 75°) or over 90° (= 105°). Opposite faces are at 30°.

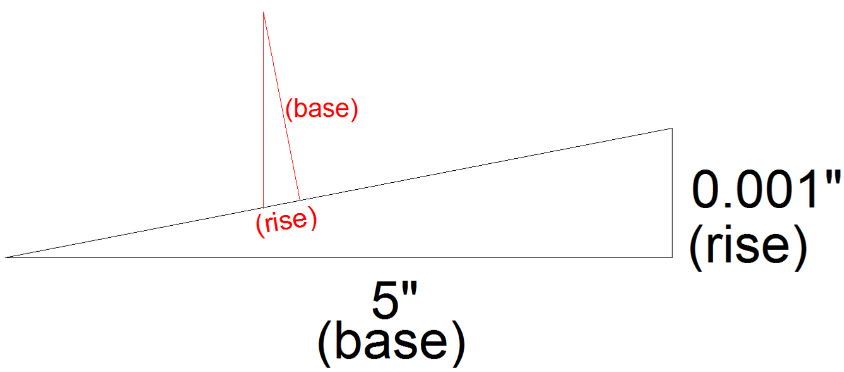
The bottom line is that the block will reflect error in the fixed jaw for all cut faces.

What if the fixed jaw is side milled to true it up? Such is the case when using soft jaws[2].

I first verify my head is reasonably true to the mill ways. Say I measure a variation of 0.002" across a 10" circle along the Y axis during the tramming process[3].



This means my cutter is tilted in the YZ plane by a slope of $\frac{0.001"}{5"}$ which is an angle of $\tan^{-1}\left(\frac{0.001"}{5"}\right) = 0.011°$



The line marked "base" on my red right triangle represents what the end mill will cut. Note that its rise and base will be proportional to what was measured during tramming.

This means that my fixed jaw will also have an angle of 0.011° from true.

[2]See http://rick.sparber.org/Articles/sj/sj6.pdf
[3] See http://rick.sparber.org/TM.pdf

In my extreme example, the fixed jaw was off by 15° and we ended up with adjacent faces off by plus or minus this error.

So if my fixed jaw was off by 0.011°, then adjacent faces would be off by plus or minus 0.011°. On a 5" cube, we are talking about a 0.001" error. On a cube 5 times smaller, the error would be 5 times smaller: a 1"cube would be off on an edge by $\frac{0.001''}{5} = 0.0002''$. On my little RF30 mill/drill, lack of rigidity gives me that much error.

The work piece can be assessed by using a surface plate and Dial Test Indicator to detect variations in thickness and squareness[4].

Acknowledgements

Thanks to Bruce Rogers for suggesting this topic.

I welcome your comments and questions.

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[4] See http://rick.sparber.org/Articles/DTI/DTI.htm and http://rick.sparber.org/iis.pdf