Thoughts about Precision Milling

By R. G. Sparber

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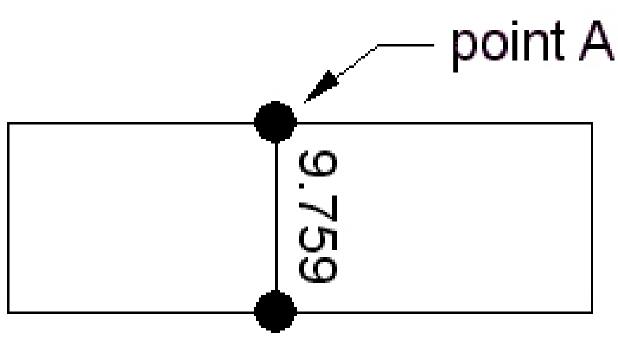
My journey to gaining the highest precision with my RF 30 mill/drill has taught me many lessons. One of those lessons relates to how to think about the measuring and machining of a thickness. These concepts can be introduced with a single dimension and then expanded until we are dealing with the real world of 3 dimensional parts.

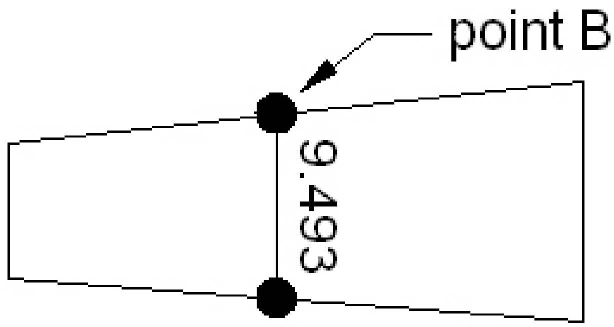
The central concept here is using a single control point to guide your cutting while monitoring the contour of the resulting machined surface.

The One Dimensional Model

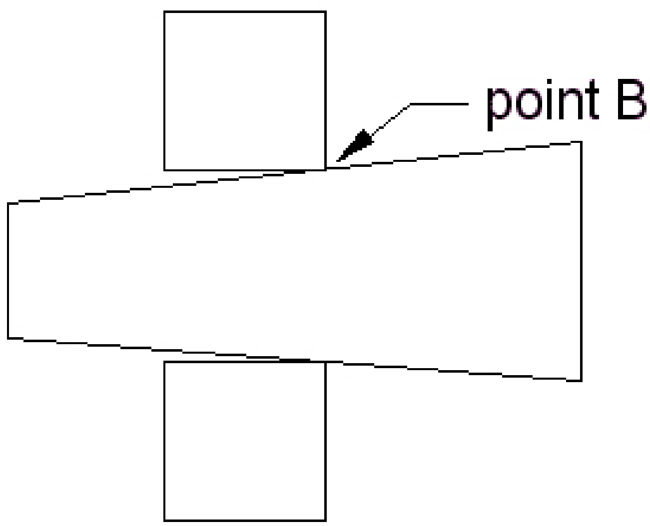
In the world of one dimension, we limit our thoughts to the length of a line. Ideally this line has no thickness. Due to limitations in my measuring instruments, some thickness can't be avoided. More on this later.



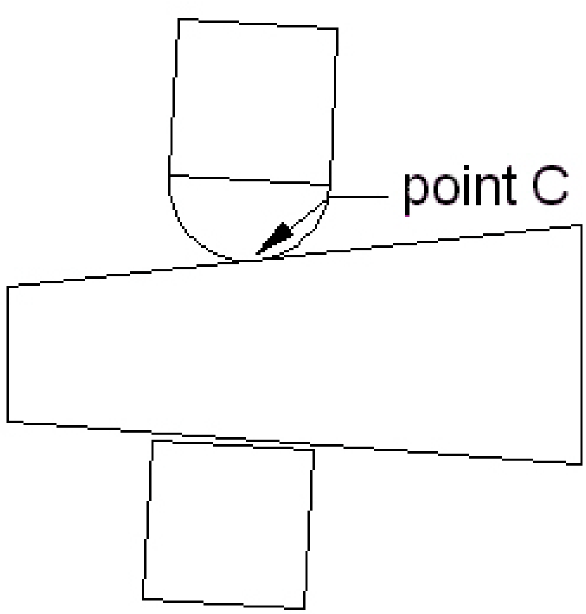
Consider a block of metal that is perfectly square. We can put a mic at "point A" and measure a thickness. Since the block is perfectly square, this measurement accurately represents the thickness of the block from end to end. I will call this measurement my "control point". As I machine the thickness of my block, I want to always measure at this control point. If the measurement at this point says I need to feed in .005", I will advance my cutter by this amount and make my cut. Then I must return to my control point and assess the results. Ideally my thickness at the control pont will now be .005" less than before my cut.



Now consider a block of the type type found in my shop. It is never perfectly square. I can pick a "point B", and put my mic on it. The reading is an accurate measure of a thickness only at this point. If we look a bit closer, we see how hard it is to take a meaningful measurement.



You can see that the mic's anvils only make contact on the up hill side of the block. A small movement of the mic will produce a different reading of the block's thickness.



One solution to the problem of having a poorly defined set of contact points is to put a precision ball on the end of the mic's anvil.

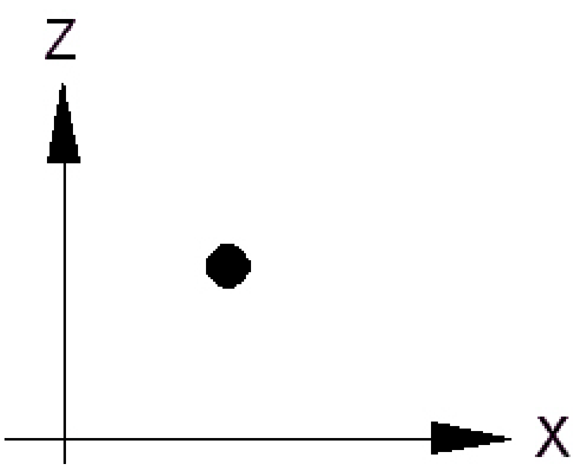
The bottom anvil is now free to make full contact on the bottom surface while the top anvil contacts at essentially a single point. The mic is now solidly on the part. Note that the thickness measured with the ball anvil is slightly different than the one measured with square anvils. The thickness with a square anvil at point B will be larger than the thickness with a ball anvil at point C. Hopefully, after machining, the top surface will be much closer to being parallel with the bottom surface so this effect will become minimal.

The important idea here is that we now have a far more repeatable measurement. The ability to repeatedly measure a given thickness is essential to precision machining. Recall that we are measuring the thickness at our single control point between cuts in order to judge how accurately we are feeding in our cutter and the depth of subsequent cuts. If our measurements are at random points along the line, error will be introduced.

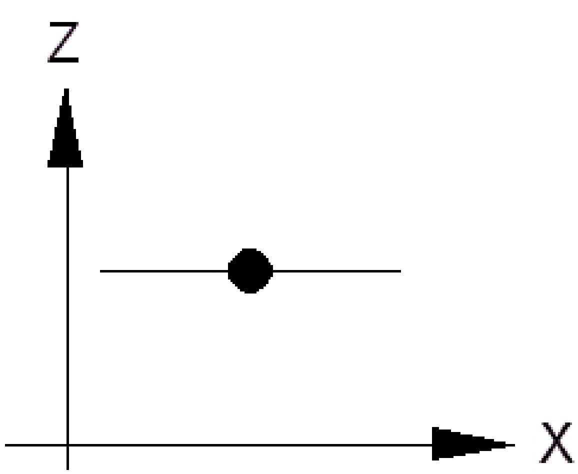
When I first started to improve the accuracy of my machine, I focused on just my control point. It was time well spent, as you will soon see. The concept of having a single control point turns out to be valid right through the three dimensional case.

Once I was able to repeatedly machine a thickness at a given point, it was time to broaden my work. The next step was to machine a plane. Before we launch into all three dimensions, lets look at two dimensions first.

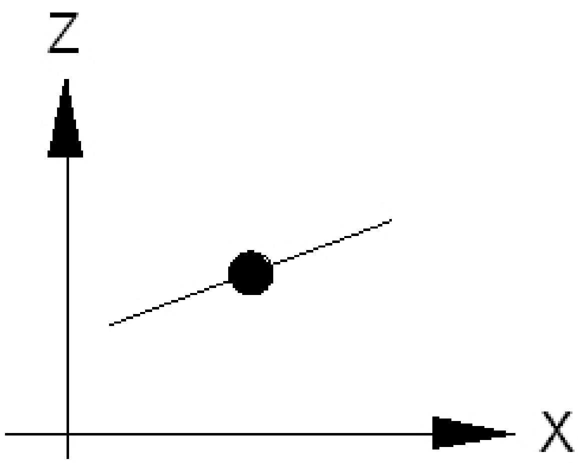
The Two Dimensional Model



When we thought about the one dimensional world, a single number was sufficient to tell us all about our single point. If I look at this case in a two-dimensional world, we have a single point at a distance from the X axis along the Z axis.

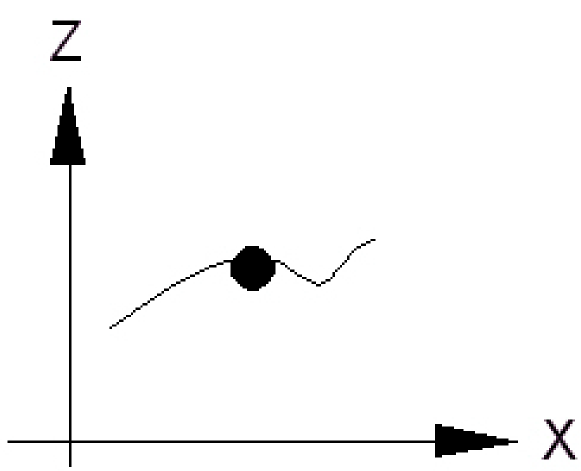


If I now draw a line through this point that is parallel to the X-axis, we have the ideal case of a dead flat line. It is parallel to the X-axis at a distance along the Z-axis.



Consider the case of a line with a slope. At our control point, the distance from the X axis is known. But when we move away from this point, the distance to the X axis will either increase or decrease.

What does this mean when machining? We can use our mic to monitor our control point but can only passively observe how the line behaves. We control the point by measuring only at this point and feeding the end mill down in a precise fashion. The slope of the line depends entirely on our ability to hold the part and the repeatability of our machine. An excelent means to canceling much of the error in a set up is to use soft jaws. Soft jaws are machined in place just before they are used to machine the part. My favorite way to precisely feed my end mill down is to use a sine bar and DTI. See my web site for articles on these topics.



In the general case, the line is not straight. If you use your best measurement instrument and technique, the most you can hope for is that the line is straight and flat to the limits of your equipment. Look close enough and you will always see a line that is not perfect.

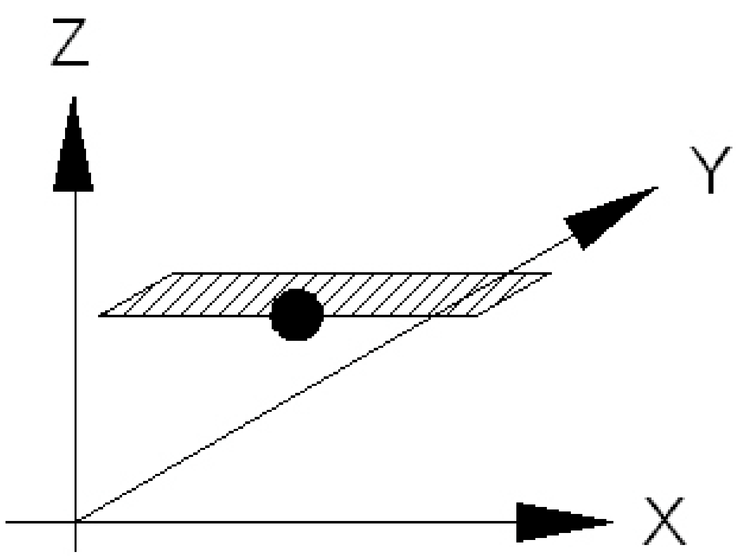
How can we describe our non-ideal line? Well, it turns out there are many ways to do it. Which one to use depends on your applications.

One way to characterize a line is to measure along the line and find the extremes. For example, say at one end of the line you measured a low of 0.818" and part way to the other end you saw a high of 0.822". You can they say that the line is 0.820 ± 0.002". When the + is the same magnitude as the - we call it a "bilaterial" tolerance. This approach is simple to do and does completely specify the worst case limits of the line.

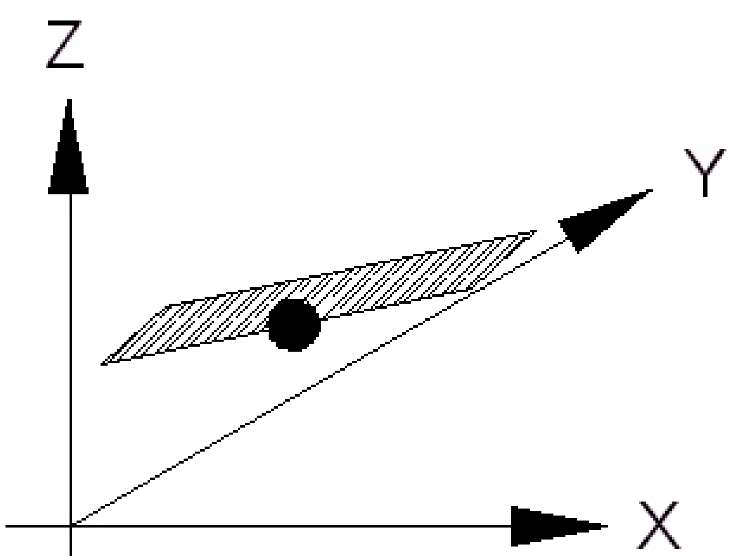
Another method is to take a lot of measurements along the line and take an average. Deviation from this average can be as simple as noting how far the worst case points are from this average. You will probably end up with one value for + and a different value for -. In this case we have a "unilateral" tolerance. If you are trying to get the best possible fit between two machined surfaces, this approach may give a clearer picture of how well you are doing.

Many other statistical methods exist including standard deviation and Root Means Square. I'm sure Google will find plenty to read on these subjects.

The Three Dimensional Model



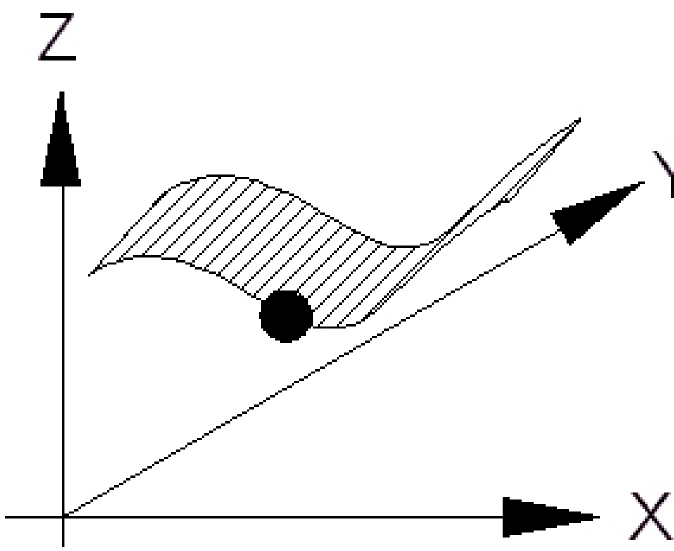
Entering the world of three dimensions means adding the Y-axis to our existing model of X and Z axes. Our line now expands to become a plane. All of our discussion related to two dimensions will apply here. We can define a single control point on our plane and us it to monitor and control the distance this point is from the XY surface. Ideally, our plane is parallel to this XY surface.



Recall in the two-dimensional case that we can have a line that passes through our point with a slope. The same is true in the three dimensional case. Our plane can have areas that are closer to the

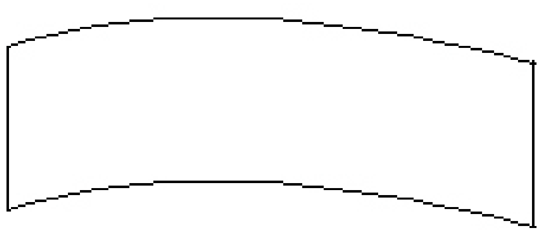
XY surface and other areas that are farther away from this surface. As in the 2D case, we can control the point with careful feeding in of the end mill but the condition of the surface depends on machining technique and your machine's stability.

In the general case, we have our control point on a curved surface. As in the 2D case, there are many ways to describe this surface. One common way is to measure the surface at all 4 corners and also in the middle. This will give



you a good idea of its contour. For a clearer picture of how the surface deviates from ideal, place the part on a surface plate and use a finger Dial Test Indicator to search the top for lows and highs. The finger is typically in contact with a much smaller area than the area of a square ended mic anvil and often is smaller than even the ball attachment to the mic's anvil. See my article on DTIs for more details.

Don't be surprised if the mic shows one thickness and the DTI does not agree. You might be looking at a warped part.



Consider the case of a 2D box that is curved on the top and bottom. You can mic the thickness and find it uniform. Yet if you put it on a surface and measure the height at various points, you will see the bend.

The take home message here is to both mic and use a surface plate to get a complete picture. Do not assume difference between these methods can be blamed on defective instruments. It might just be a shape like this that is driving you crazy. A second lesson here is that when you measure the thickness of a 3D part, be mindfull that non-ideal contours on the hidden underside of the part directly effect your readings as you concentrate on the top side.

I welcome comments and corrections to this article. All of us are smarter than any one of us.

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