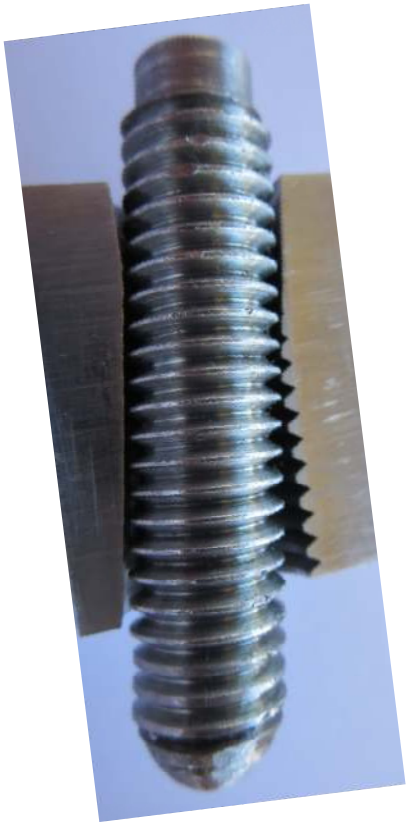
Angled Half Nut, version 3.2

By Larry Rudd and R. G. Sparber

This article was written with those new to the metalworking hobby in mind. More experienced readers will find that few steps are needed to make this part even though there are many pages here.

The Angled Half Nut is easy to slide on, quick to lock.

Cross section views: slide lock



Rod Grantham introduced us to "Smart Nuts" in this YouTube video:

https://www.youtube.com/watch?v=goUmlhPC6H4

A Smart Nut slides on a threaded rod and then with a quick spin of the nut, it is secure. Rod Grantham makes these nuts by the hundreds and sells them as part of his book binding equipment.

Recently we wondered about making Smart Nuts in different sizes. Our first attempt was with a standard ¼-20 nut that was about 0.2" thick. The results were marginal. After working through the math, we now see the bigger picture plus a slight changed in the design which makes it easier to machine. The result is what we call an Angled Half Nut.

We do not recommend using the Angled Half Nut in applications involving safety. It is designed for easy install and remove but does not have the strength of a full nut. In a single test, a 3/8-16 Angled Half Nut machined into 1" thick 6061 failed at a torque of 225 inch pounds. A 3/8-16 regular tapped hole in the same material failed at 400 inch pounds.

Angled Half Nut Machining

Design and Tooling Needs

Select the thread size. This will define the threads per inch (TPI) and diameter of the tap drill. It will also define the maximum internal diameter. A ¼-20 has a maximum internal diameter of 0.250". A 3/8-16 has 0.375" and a ½-13 is 0.500". So nothing complicated here.

You will need the tap and a tap handle, a drill with a diameter equal to the maximum internal diameter, and a end mill of this same diameter.

You will also need a piece of round stock 2" plus or minus 0.5" long and half the diameter of the maximum internal diameter plus or minus 30%. In other words, the exact size is not important. This rod is used for alignment.

Next, determine the needed stock.

$$minimum\ nut\ thickness = \frac{12}{TPI} + .0887C \text{ inches} \qquad (1)$$

where C is the maximum internal diameter.

¼-20	.622"
3/8-16	.783"
½-13	.967"

The maximum thickness will likely be set by the length of your tap.

The minimum outside diameter of the nut is set by where the angled hole emerges out the bottom.

$$\text{Minimum nut diameter} = \text{C} + .361\text{E} - \frac{1.08}{TPI} \qquad (2)$$

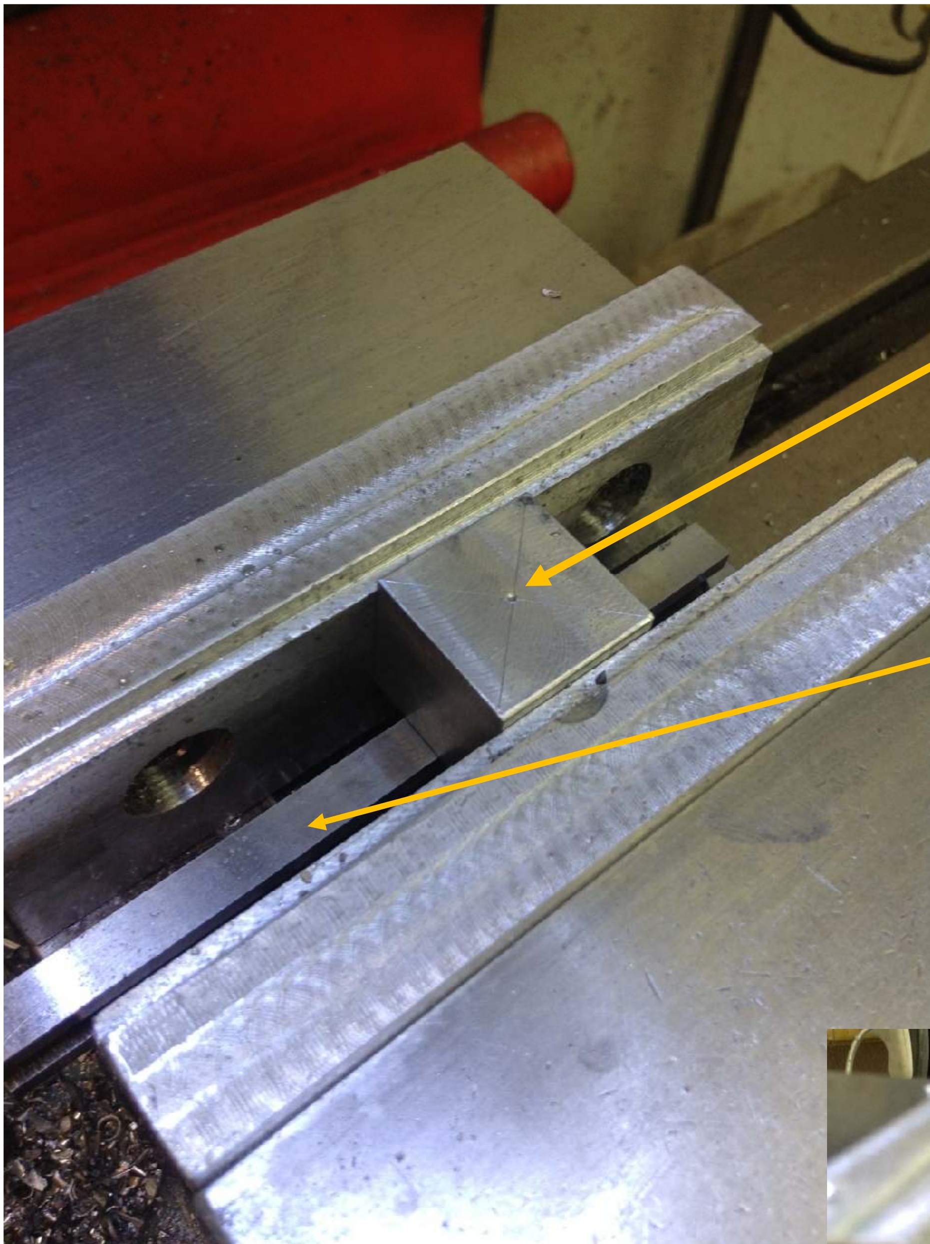
where C is the maximum internal diameter and E is the chosen nut thickness.

Given 1" thick stock:

¼-20	.557"
3/8-16	.669"
½-13	.778"

The angled hole will form a sharp edge with the outside diameter of the nut if you go with the minimum nut diameter. You may want to consider going at least 0.1" larger.

Shop Procedure

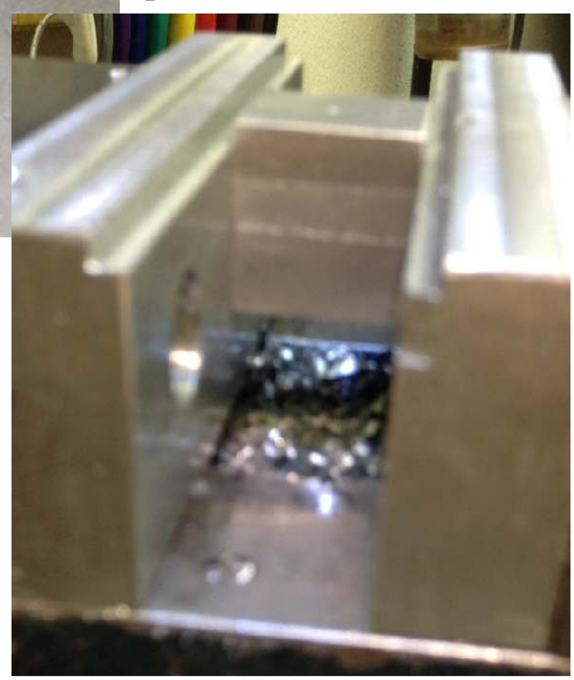


Select your workpiece. For ease of machining, 6061 aluminum is good. For strength, use steel.

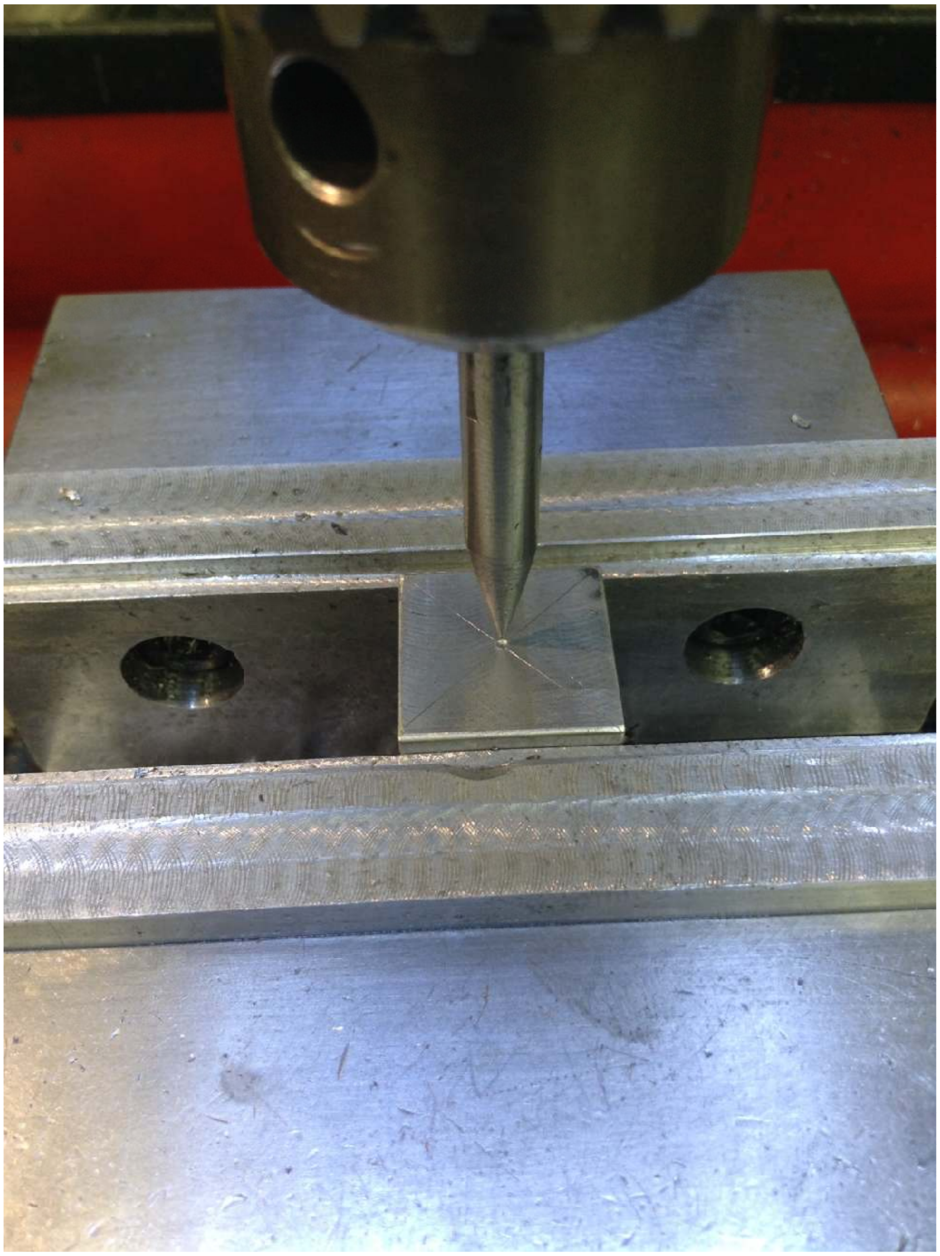
Mark the location of the hole to be machined.

Mount the workpiece in your mill vise supported by a parallel.

Tighten the vise and remove the parallel. We will be drilling through the workpiece and do not want to hit the parallel.

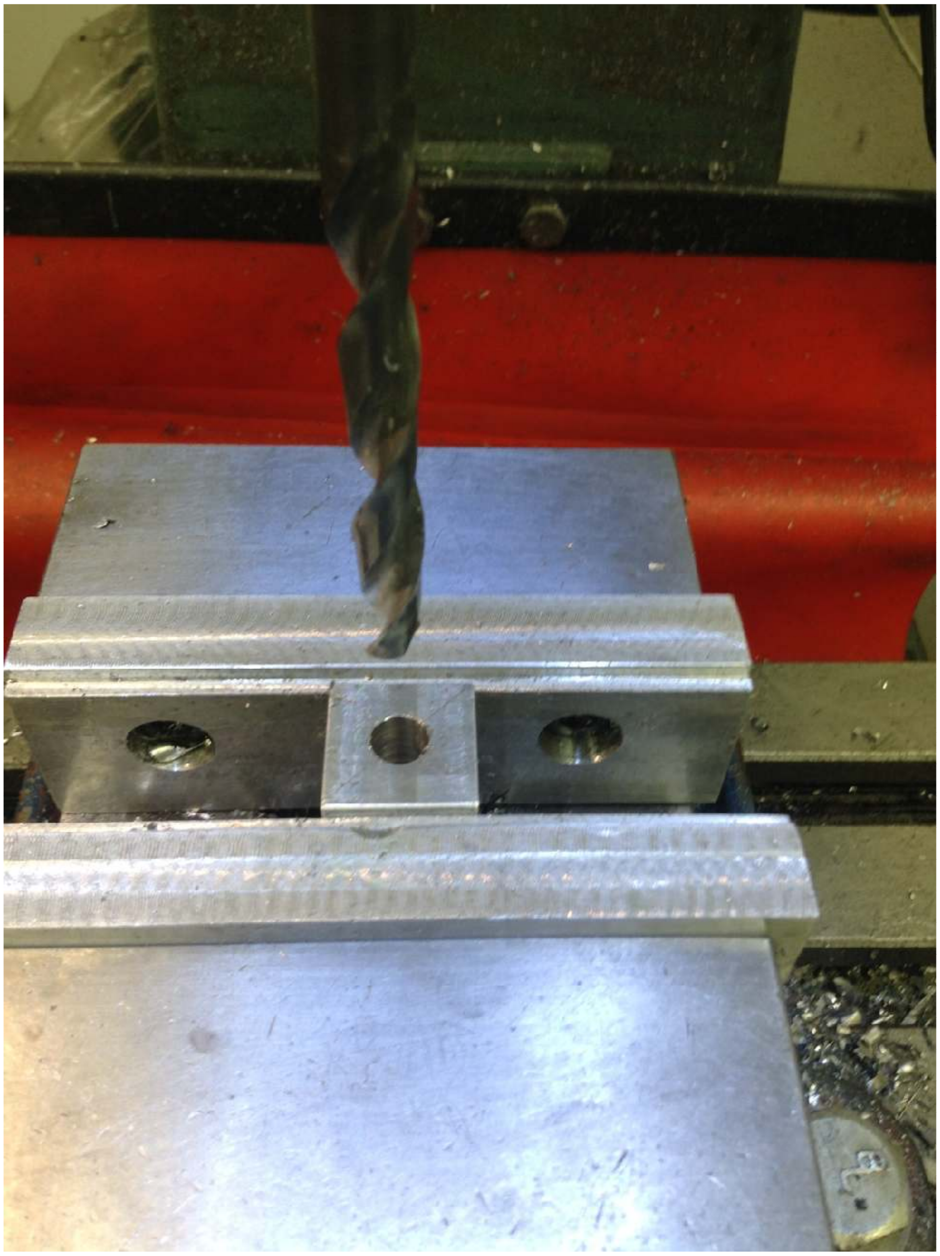


Well, actually, this is not good practice as pointed out by Corey Renner. I should have used two thin parallels to support the workpiece and arranged them so the drill does not hit them.

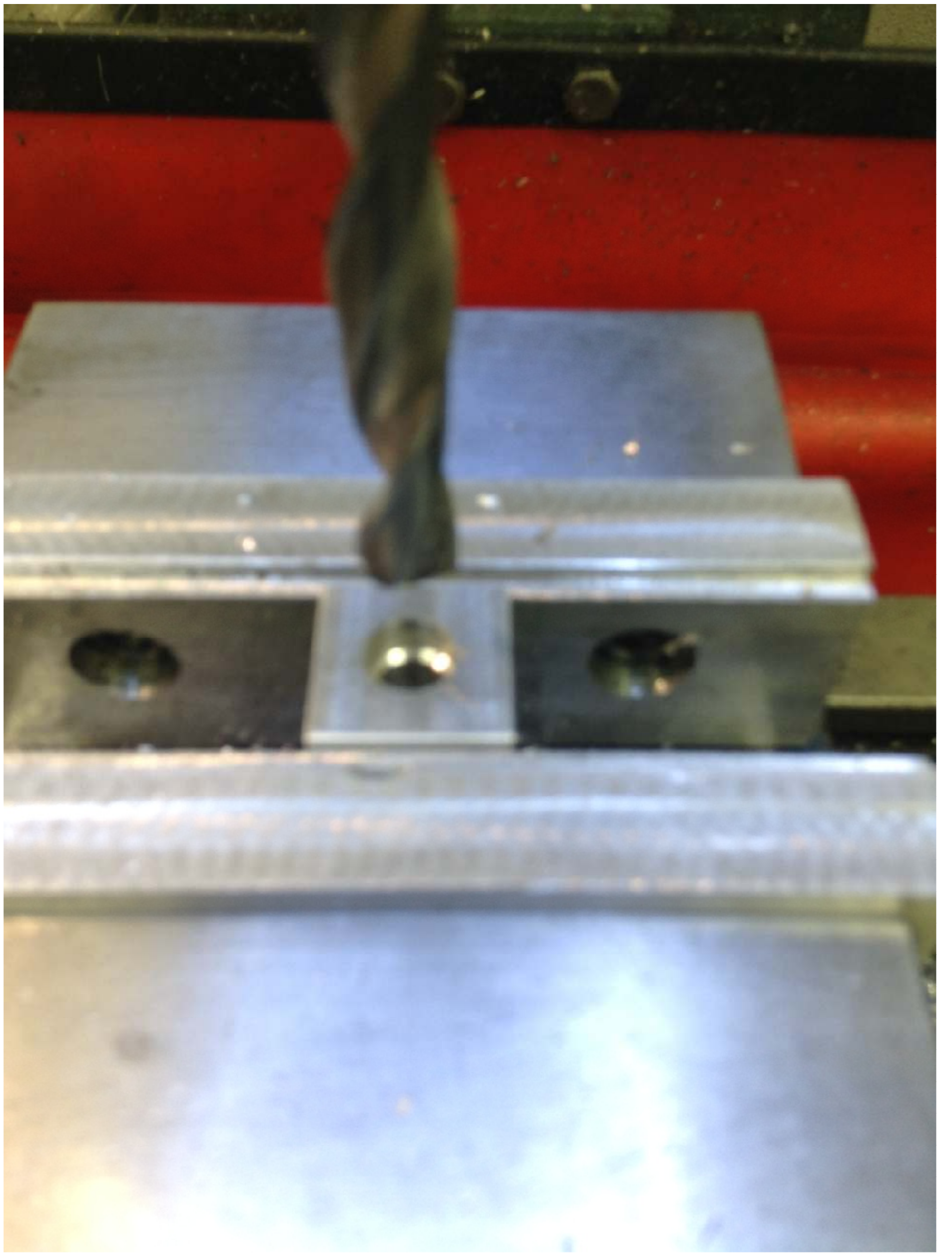


Install a drill chuck in the spindle. Set the height of the head so your drills and end mill will fit without having to change height.

Use a spud to locate the spindle center of rotation over the center of the hole to be machined. Lock the X and Y axes.



Use the tap drill to drill through. When using large drills, I often first drill a hole about half of the final diameter. This makes it easier to run the larger drill.

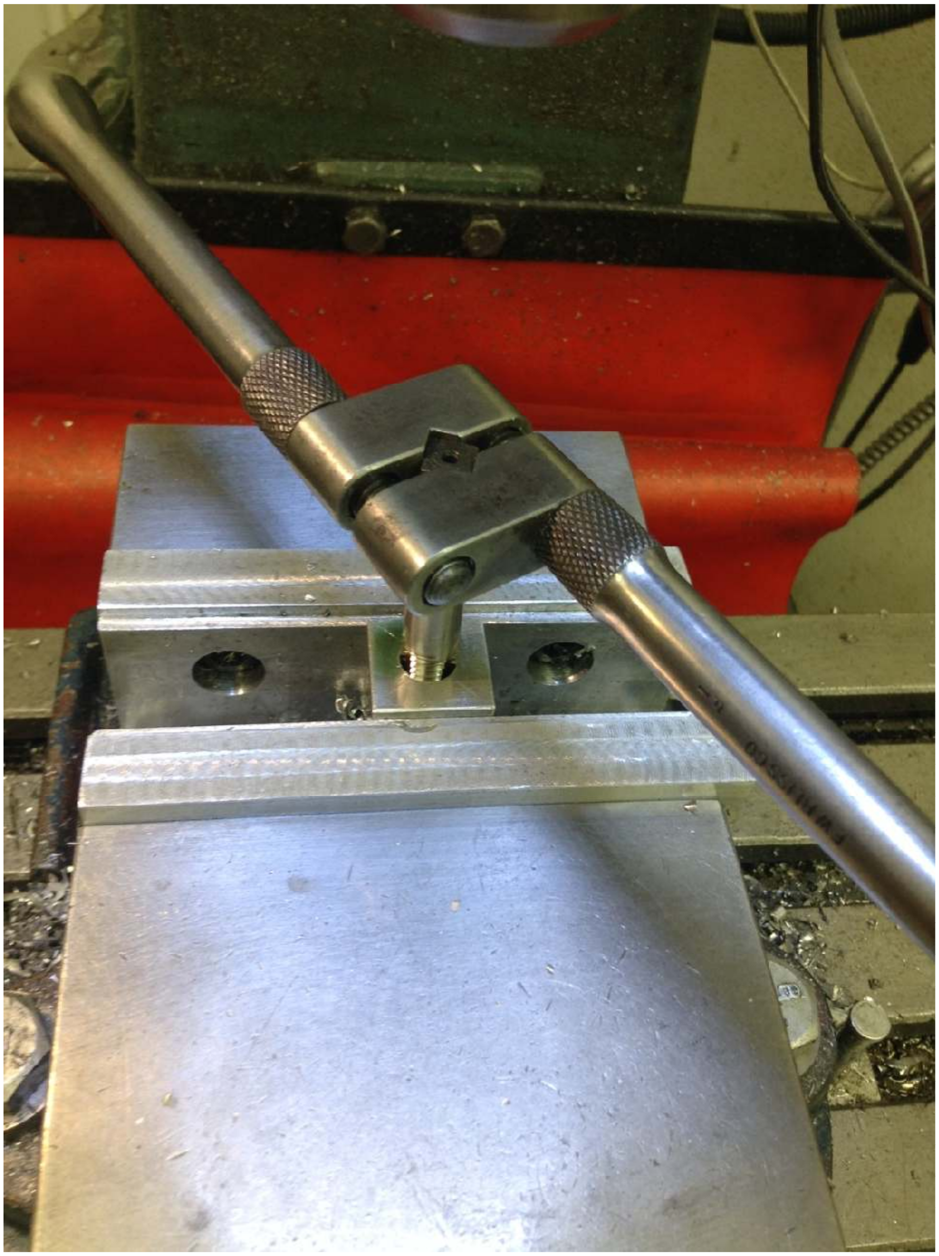


Install the drill with a diameter equal to the maximum internal diameter. Drill down until the entire point of the drill is in the hole. Then feed in and additional depth equal to 3 threads:

$$depth = \frac{3}{TPI} \text{ inches}$$

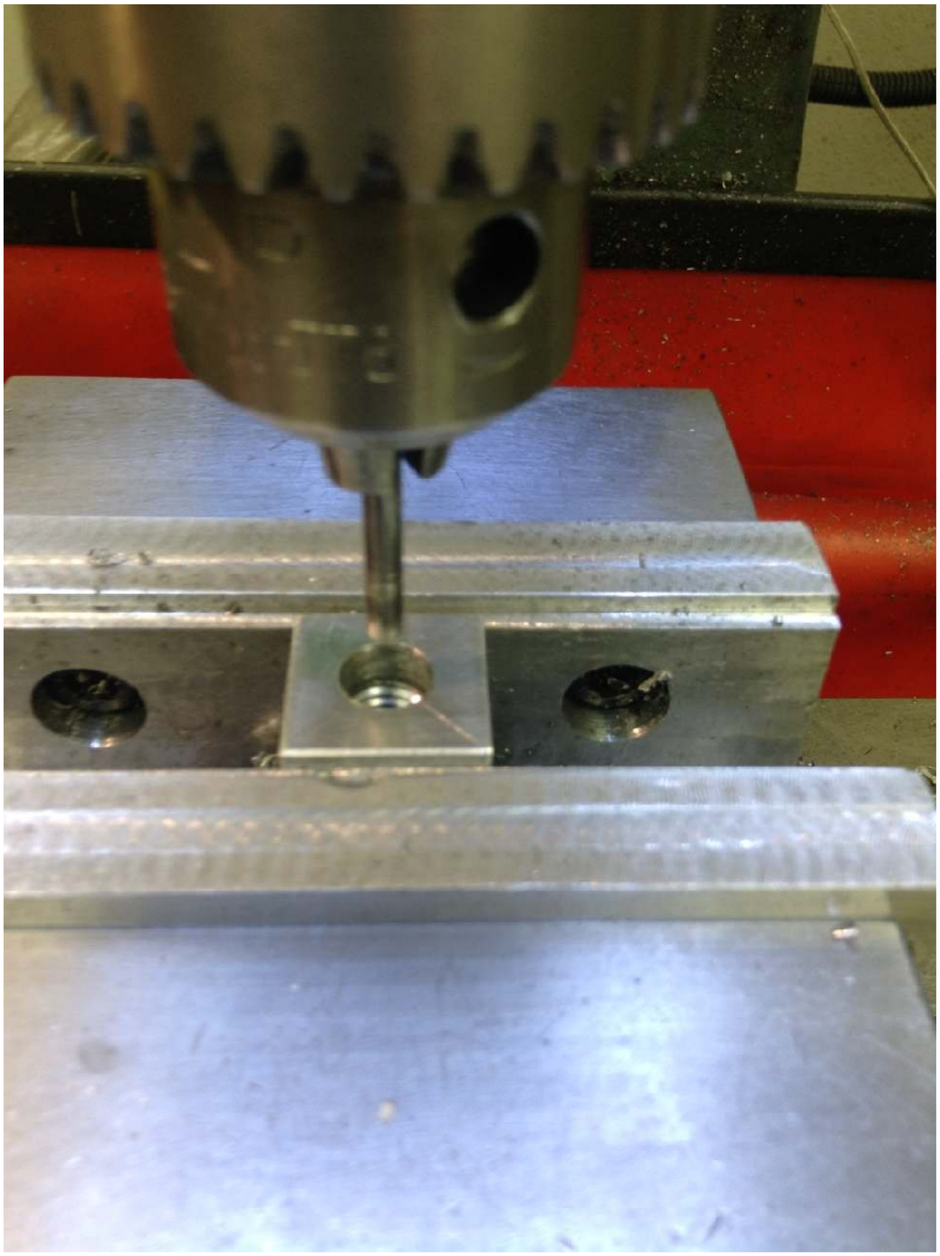
20 TPI	.15"
16 TPI	.19"
13 TPI	.23"

Alternately, you can use the end mill to do this counterboring.

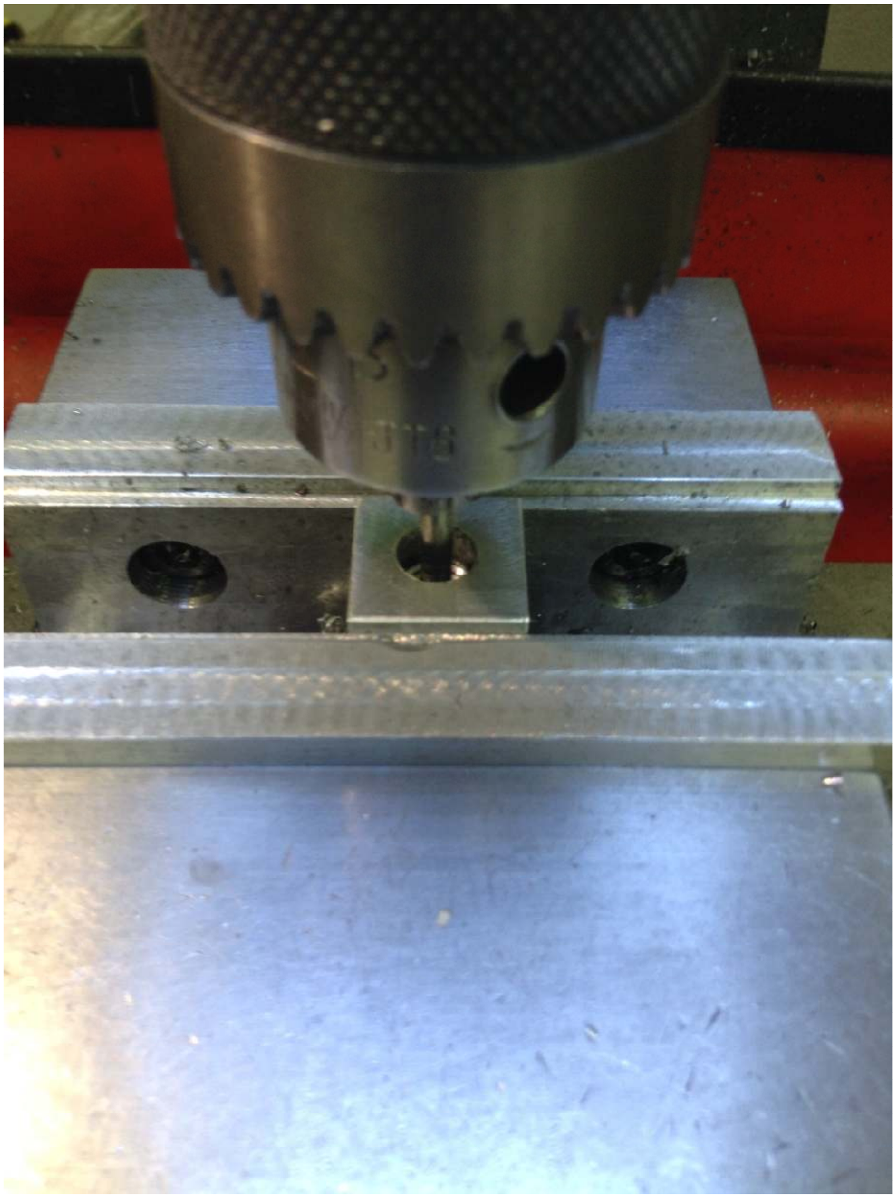


Run your tap through the workpiece without disturbing the position of the vise on the X and Y axes.

Remove all metal chips (commonly called swarf).



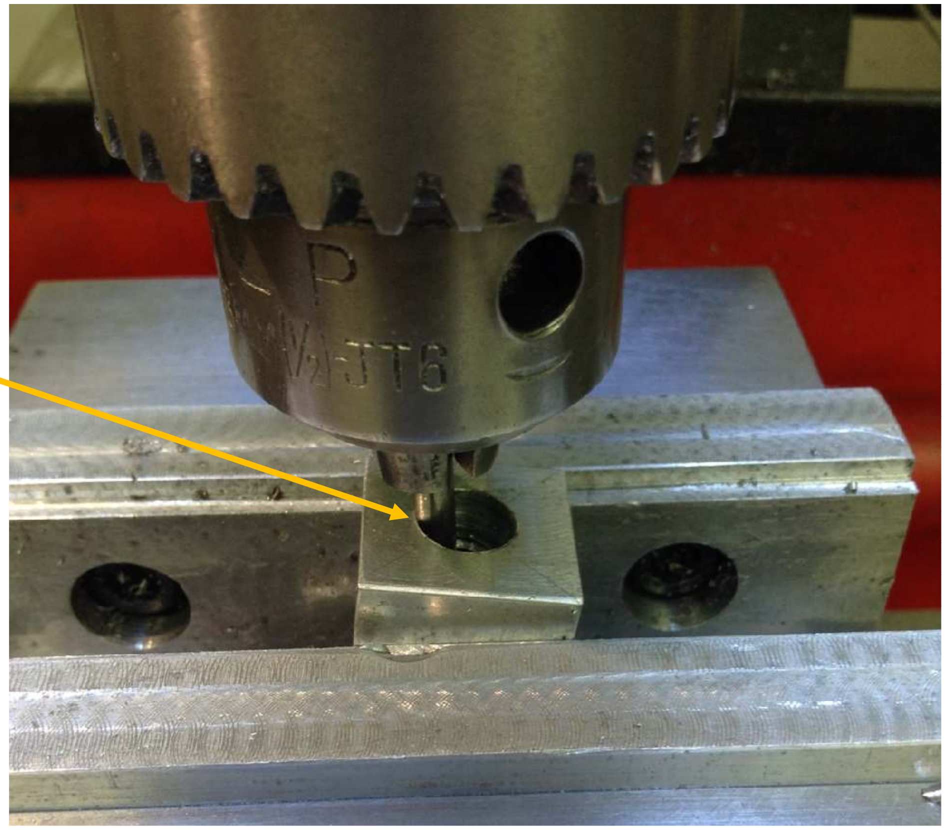
Chuck up the 2" long piece of rod. It should be at the center of the tapped hole.

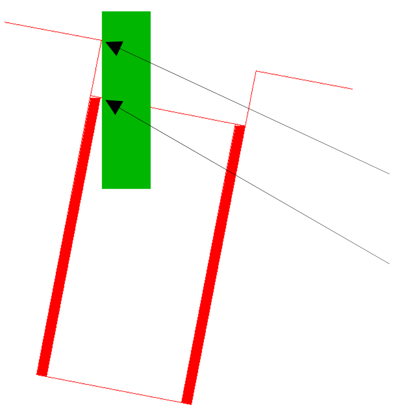


Lower the rod down into the hole so the end of the rod is about $\frac{5}{TPI}$ inches from the surface.

20 TPI	.25"
16 TPI	.31"
13 TPI	.38"

Loosen the vise just enough so the workpiece can slide. Lift the left side of the workpiece up and push to the right. We need to get the top lip of the hole in contact with the rod along with the top of the thread which is down in the hole.





In this cross section view, the green rectangle is our rod. The two red rectangles are the threaded regions. Note that the rod contacts at two points:

the top lip of the hole and

the start of the threads.

Push the block hard enough into the rod to make contact but not enough to bend it.

Tighten the vise.

Remove the rod and drill chuck. Install the end mill.

Carefully measure the diameter of the rod in order to calculate how much to move the mill table.

$$X\ axis\ movement = 0.484C - \frac{K}{2} - \frac{0.54}{TPI} \qquad (3)$$

Where K is the diameter of the guide rod, C is the maximum internal diameter, and TPI is the threads per inch of the nut.

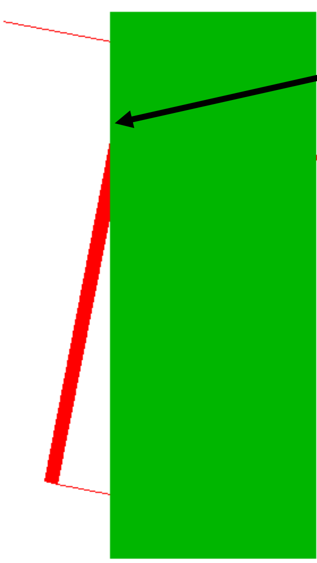
Assuming a guide rod 0.150" in diameter:

¼-20	.019"
3/8-16	.073"
½-13	.125"

Unlock the X axis and move the table to the left by the calculated amount. This moves the right flank of the end mill towards the lower lip of the counterbored hole.

Mill through the workpiece.

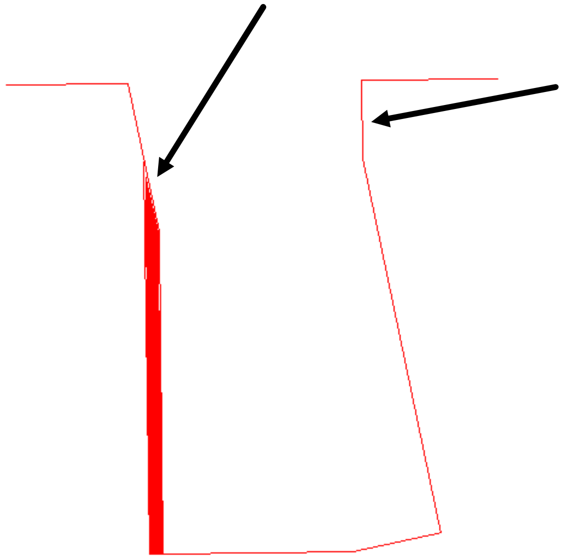
Done!



The green rectangle is the end mill. Some of the threads on the left face has been removed, some are tapered.

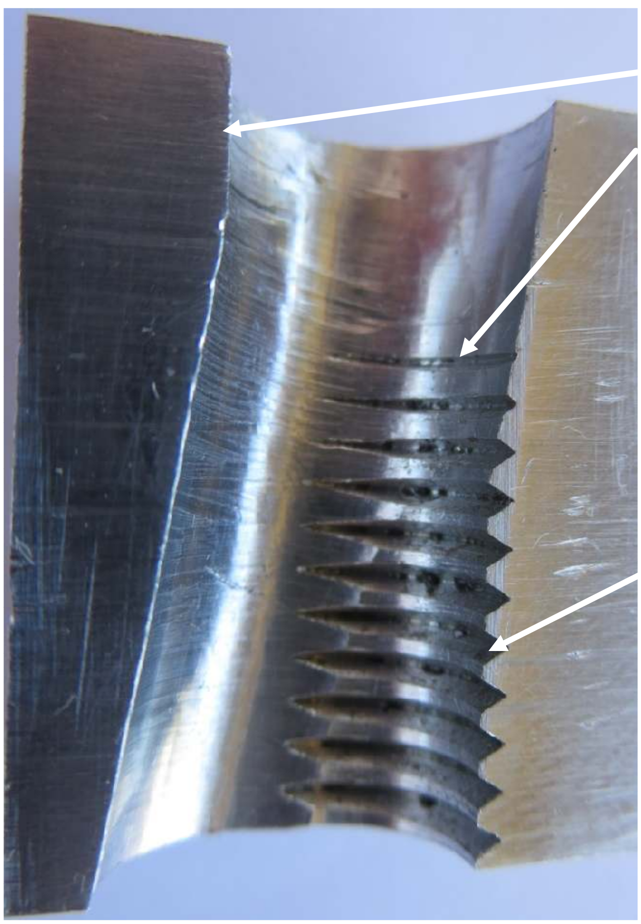
On the right face, we have a smooth section parallel to the threads that was not touched by the end mill.

The resulting cross section has tapered and full threads on the left flank and



a smooth section parallel to the threads on the right flank. Below this section are no threads.

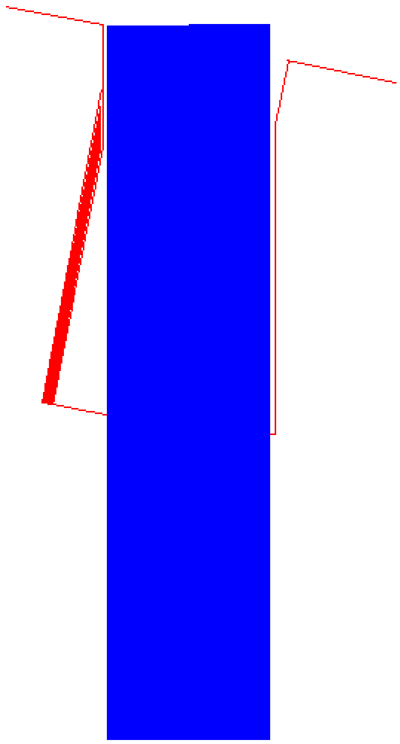
Unless you cut the Angled Half Nut in half along its major axis, it is hard to see these features.



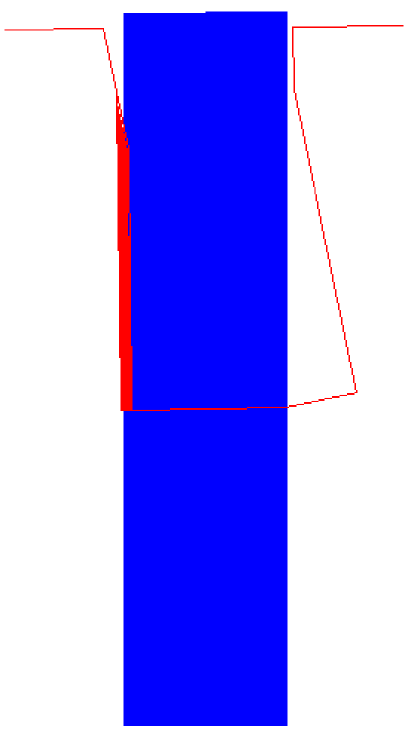
smooth section

tapered thread

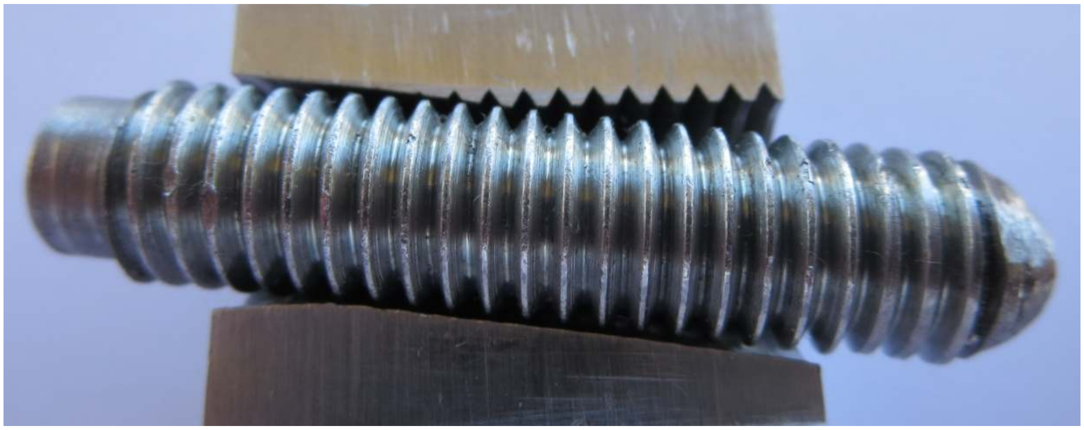
Full depth thread



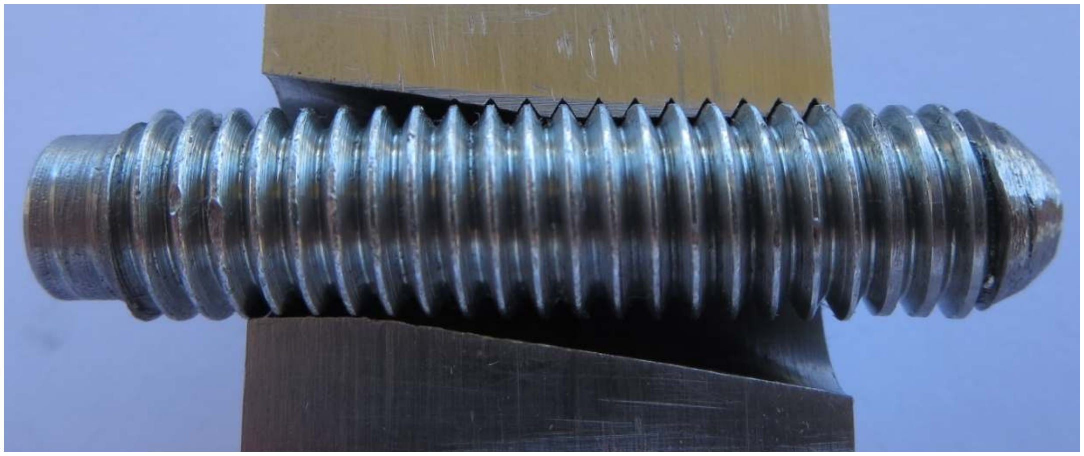
The blue rectangle is our threaded rod. With the nut cocked, it slides down the rod.



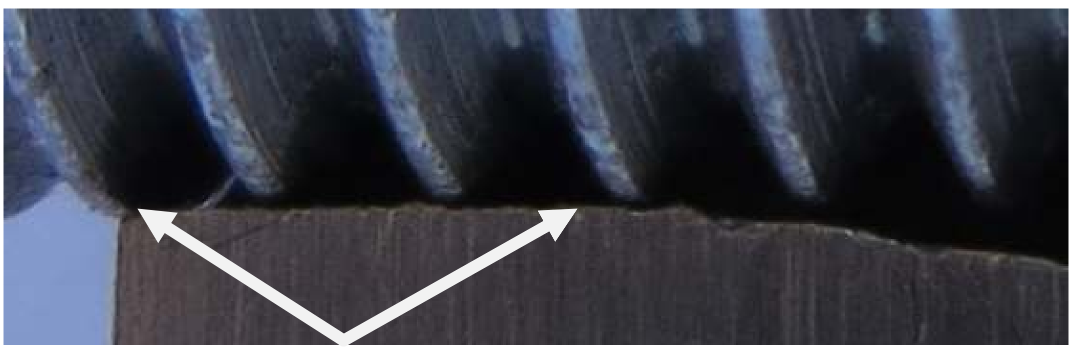
As the Angled Half Nut is tightened, it rotates which causes the threads to engage.



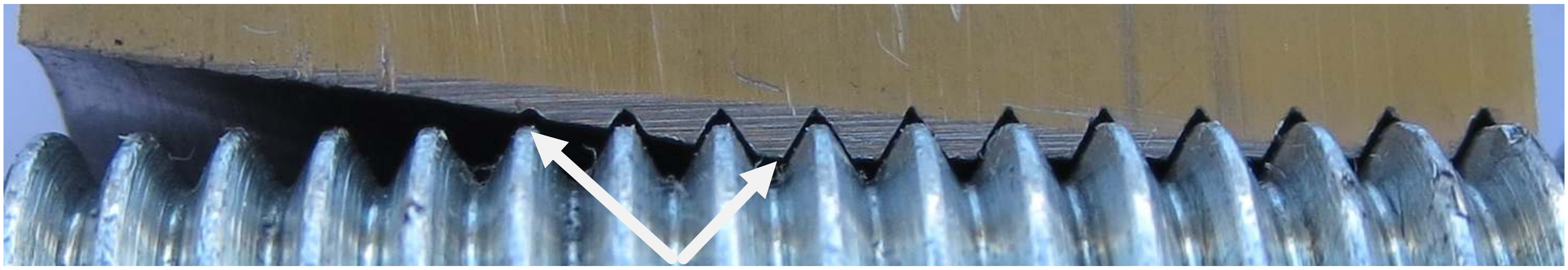
Cross sectioned Angled Half Nut with threaded rod disengaged.



Cross sectioned Angled Half Nut with threaded rod engaged.



Between the arrow heads you can see almost 3 threads in contact with the smooth area of the bore.



Between the arrow heads you can see the tapered thread section. It is 3 threads wide. To the right of this section is full depth threads.

Acknowledgments

Thanks to Rod Grantham for sharing this idea. Thanks to Corey Renner for pointing out that I was using my parallels wrong and how to best drill with large diameter bits. Originally I had written to drill the hole one size under and then go for final.

We welcome your comments and questions.

Larry Rudd and Rick Sparber

If you wish to be contacted each time I publish an article, email me with just "Article Alias" in the subject line.

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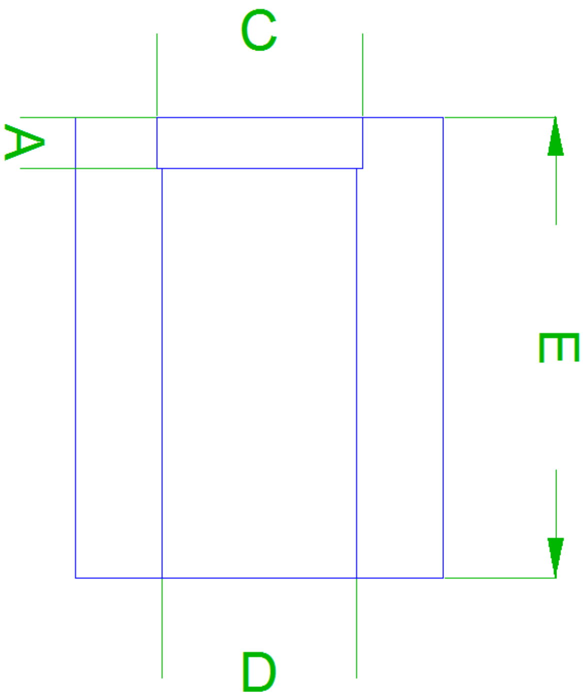
Appendix

We found that making the Angled Half Nut was far easier than figuring out the math behind it. Many iterations were needed before the right answers was found.



We start with the dimensions of the tap hole and counterbored hole.

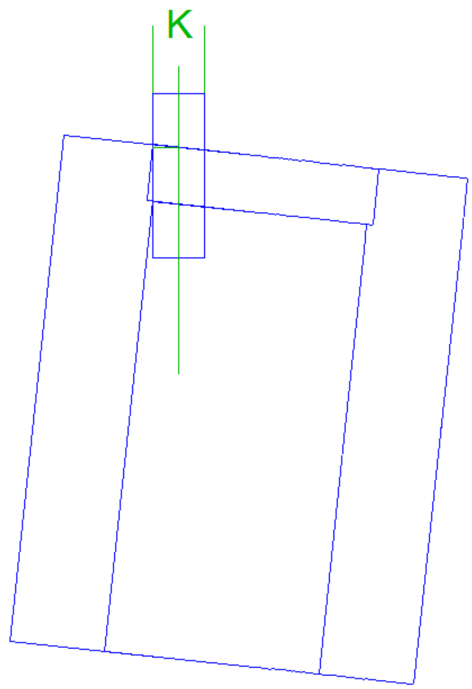
The tap hole diameter, D, is set by choosing the thread size. For example, a ¼-20 thread requires an F drill which has a diameter of .201".

The counterbore diameter, C, is also set by the thread size and equals the maximum internal thread diameter. For our ¼-20 thread, that would be .250".

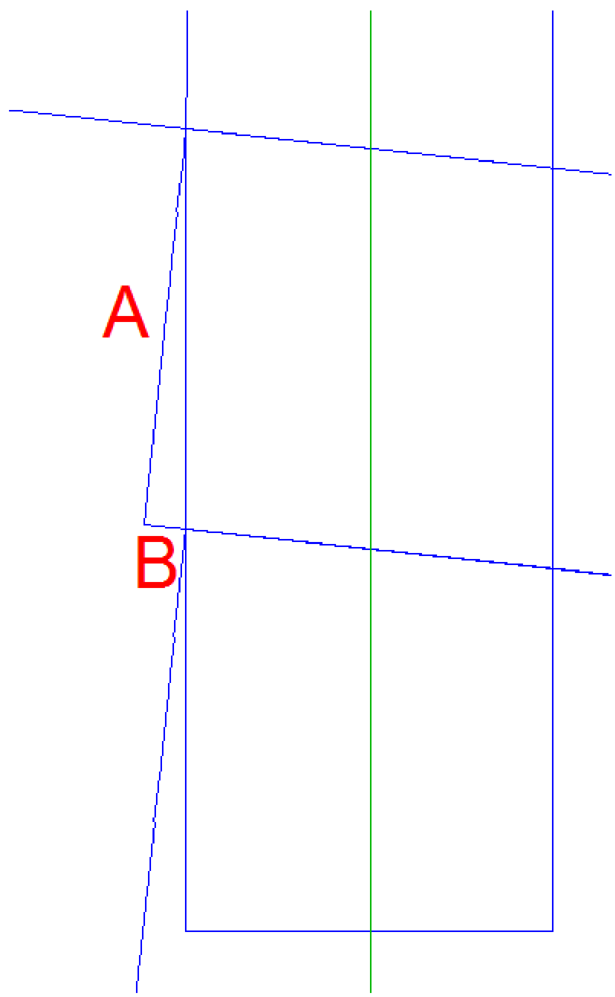
The depth of the counterbored hole, A, is set at 3 times the thread pitch by design. This was found to be a reasonable value given tradeoffs that will be apparent later.

$$A = \frac{3}{TPI} \qquad \text{(A1)}$$

Note that all lines are either perpendicular or parallel. When I rotate the workpiece, all lines will rotate by the same amount. This is the key to solving the math.



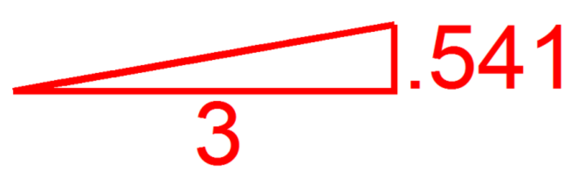
The guide rod is of diameter K. This value is not critical as long as the right flank of the rod does not hit the right side of the hole.



Take a close look at the right triangle defined by the left side of the counterbore and guide rod. The counterbore is "A" deep. We also know that the diameter of the counterbore and the diameter of the tap hole. Subtracting these two values and then dividing by 2 will give us the width of the step, B. However, the Standards also specify that this step equals the thread height "B":

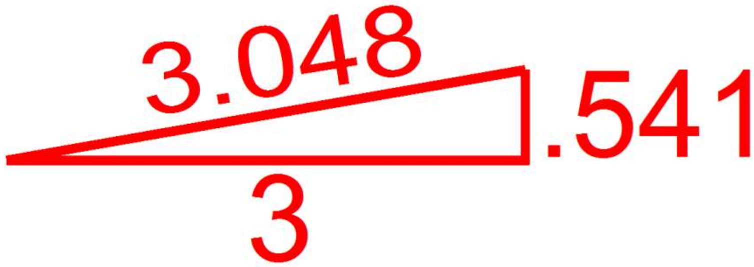
$$B = \frac{.541}{TPI} \qquad \text{(A2)}$$

This formula is handy because both "A" and "B" are functions of TPI. This means that this right triangle does not change any angles as TPI changes. The small angle is always 10.222°.



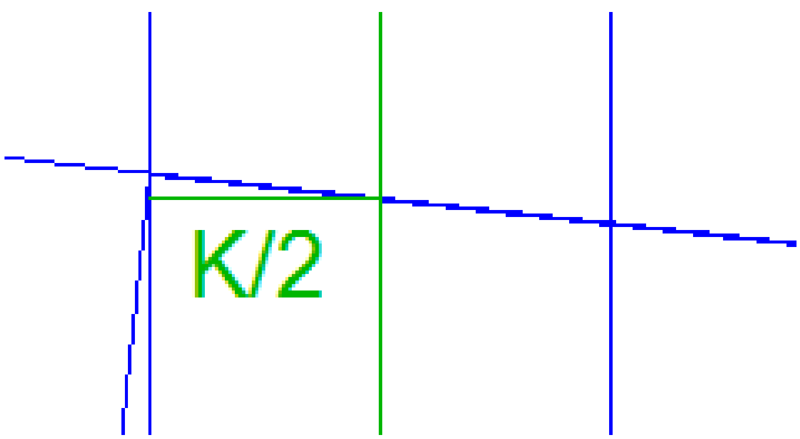
Since this is a right triangle and we know the base and rise, the hypotenuse can be calculated

$hypotenuse = \sqrt{3^2 + .541^2} = 3.048$

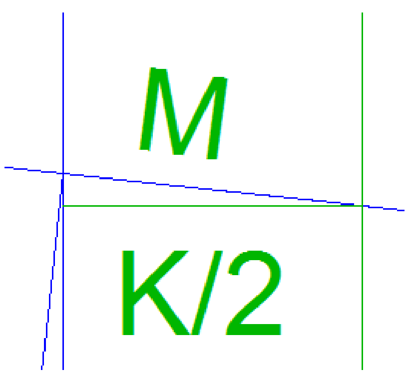


This reference triangle will useful as we find unknown distances.

Now we will return to the guide rod.



Note that the horizontal distance from the point of contact of the guide rod at the high end of the counterbore to the center of rotation of the spindle is a distance equal to the radius of the guide rod. This radius is also the base of a triangle. It can be proven that this triangle is "similar" to the triangle we generated above. This means we can use proportions to find the distance from the center of rotation to the lip along the surface of the workpiece:

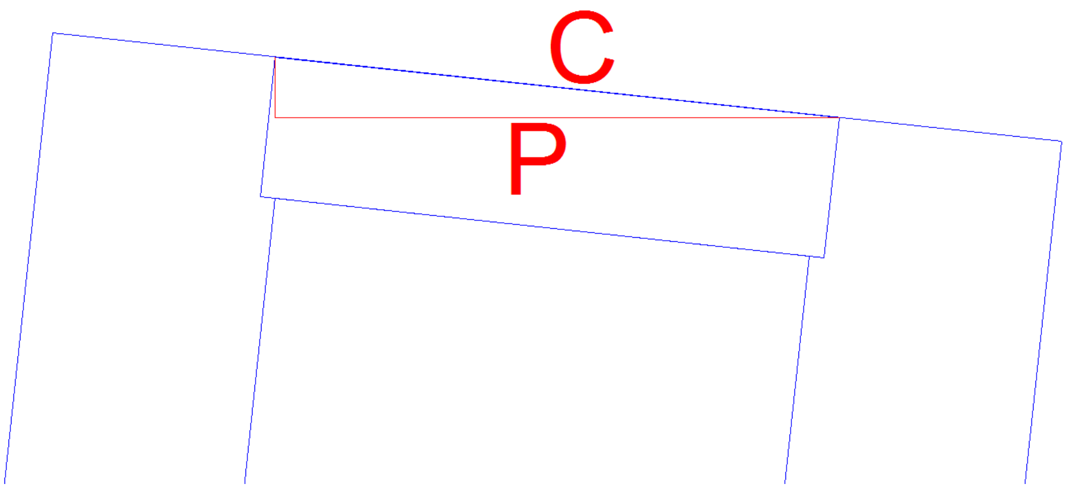


so

$$\frac{hypotenuse}{base} = \frac{3.048}{3} = \frac{M}{\left(\frac{K}{2}\right)}$$

$$M = 0.508K \qquad \text{(A3)}$$

Next, look at the counterbore.

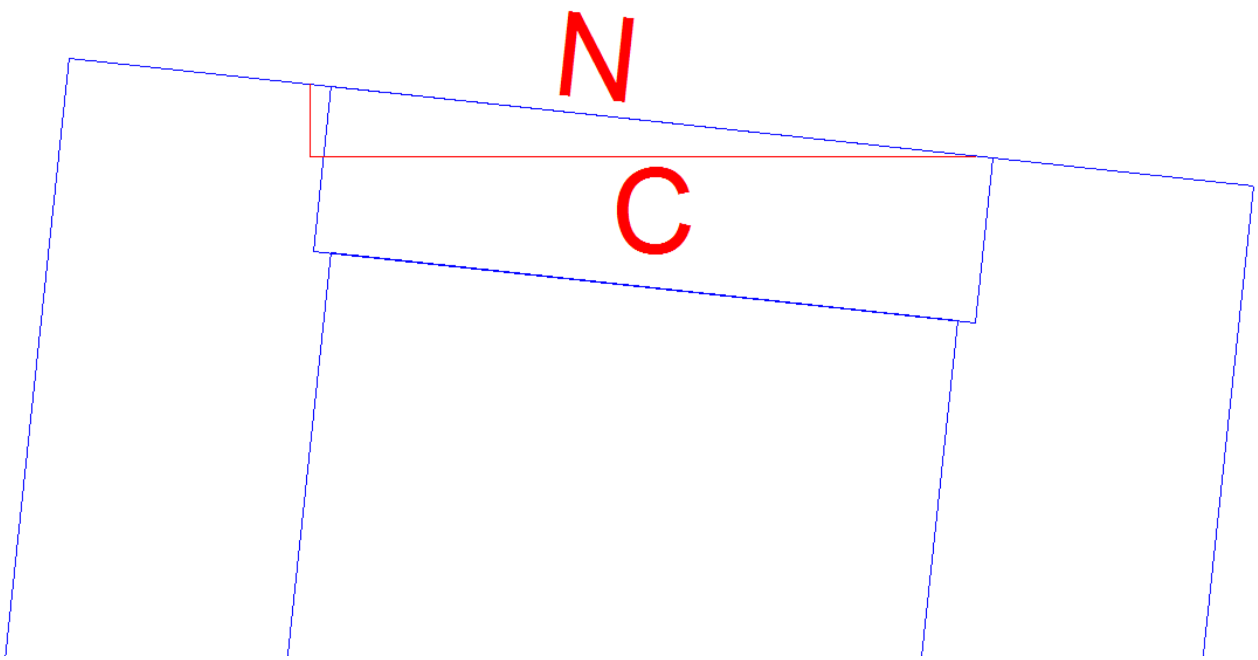


The diameter of the counterbore is "C" and this is also the hypotenuse of the triangle shown here. Call the base "P".

$$\frac{hypotenuse}{base} = \frac{3.048}{3} = \frac{C}{P}$$

so

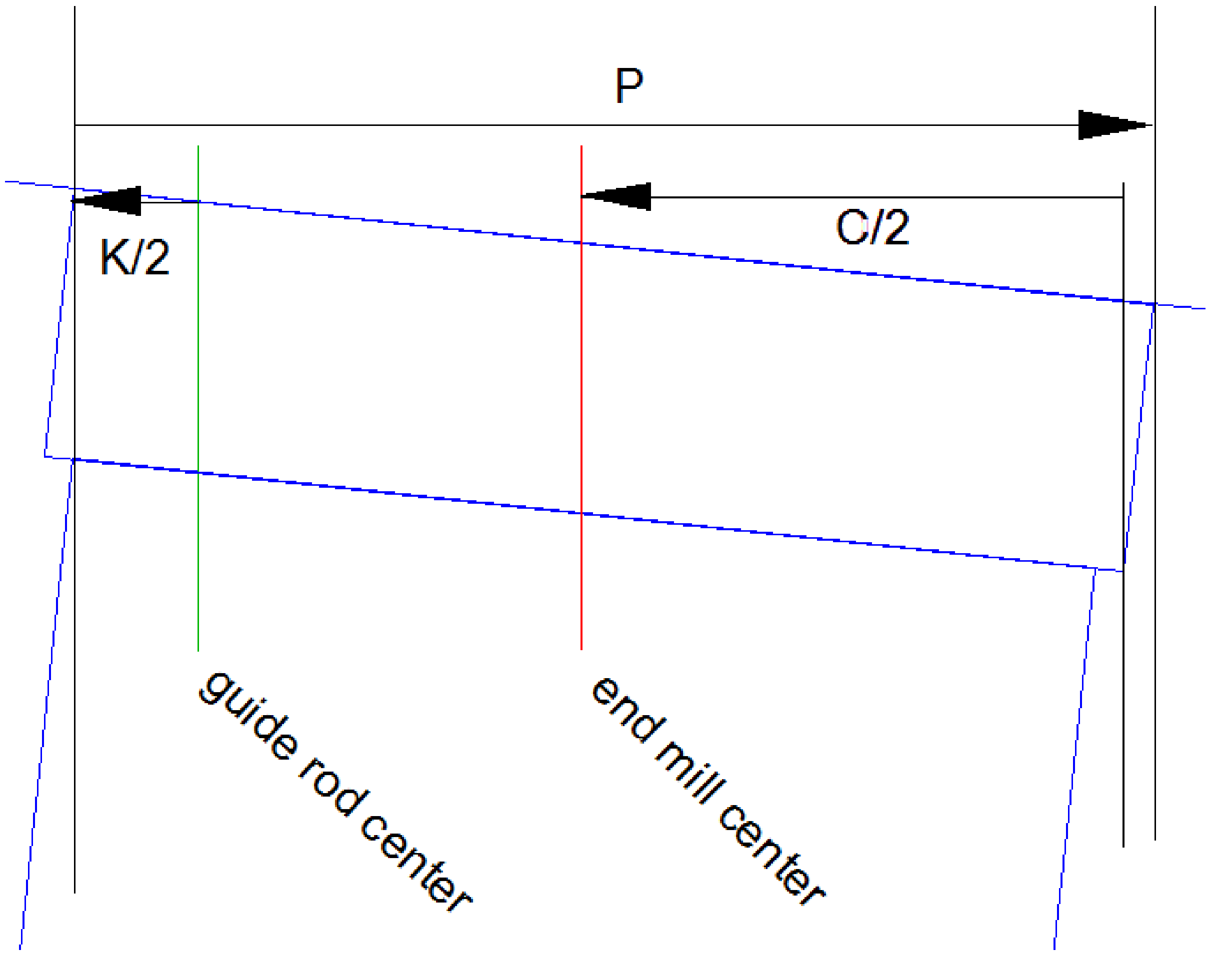
$$P = 0.984C \qquad \text{(A4)}$$



Now take a close look at the end mill's position.

By design, the right flank just touches the right-bottom of the counterbore. The end mill's diameter is "C". With the end mill mounted in the spindle, the center of rotation is $\frac{C}{2}$ from the right bottom corner of the counterbore.

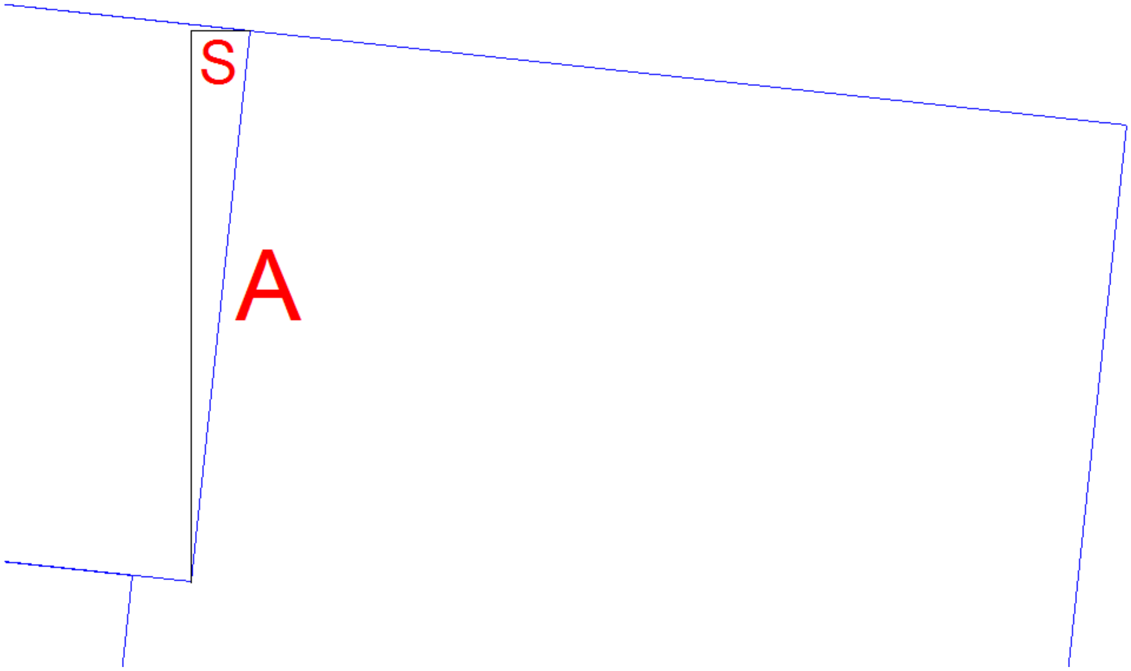
It may seem like I have collected random distances so let's put them together and see where we are.



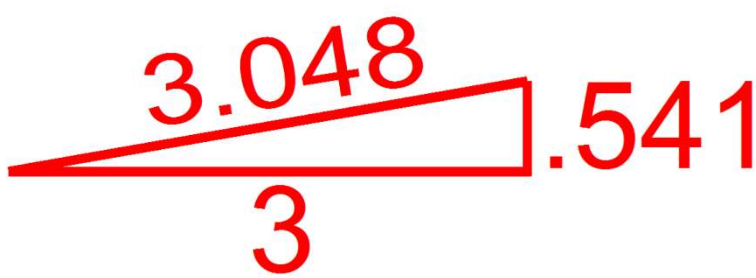
Ultimately, we need to know how much to move the mill table along the X axis after we swap out the guide rod for the end mill.

Starting with the guide rod in the spindle, the distance from the center of rotation to the top left lip of the counterbore is the radius, $\frac{K}{2}$. Then we calculated the distance "P" based on our reference triangle of page 19. And finally, we want the right face of the end mill to contact the bottom right corner of the counterbore. This puts the center of rotation at the end mill's radius from this corner: $\frac{C}{2}$.

Ah, but there is one piece missing here. The dimension "P" end at the top right lip of the counterbore but the dimension $\frac{C}{2}$ starts at the bottom right corner.



The base of our new triangle is "A" and the rise is "S". Referring back to our reference triangle, we see

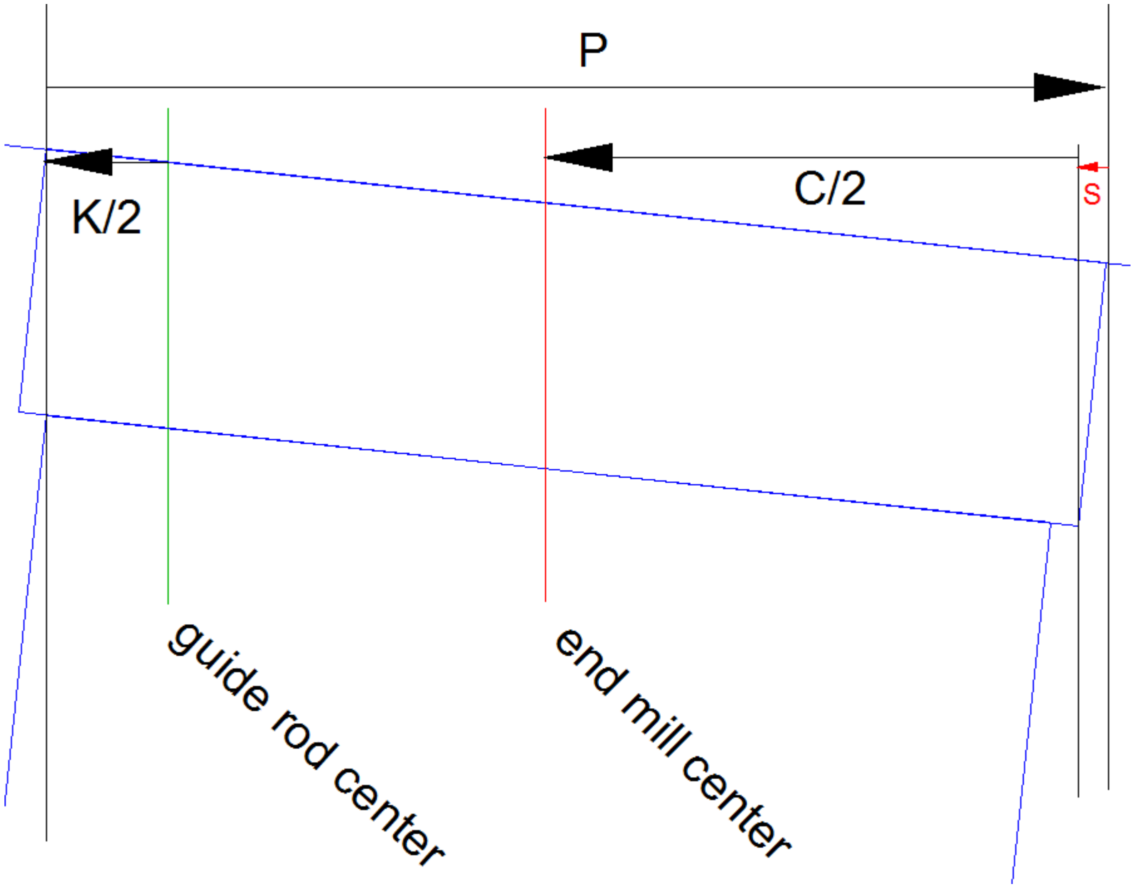


so can write

$$\frac{rise}{base} = \frac{0.541}{3} = \frac{S}{A}$$

which can be rearranged to

$$S = 0.180A \qquad \text{(A5)}$$



Now we have all the pieces needed to tell us how much to move the mill table. What is actually need is the distance between the end mill center and the guide rod center

$$guide\ rod\ center - \frac{K}{2} + P - S - \frac{C}{2} = end\ mill\ center$$

In English, this equation is say that I start at the guide rod center. Then I move away from the end mill center by $\frac{K}{2}$. Since I am moving away, I call it negative. Then I move towards the end mill center a distance P. Since I said "away" is negative, moving towards the end mill center must be positive. Next I turn around and move in the negative direction a distance of S followed by a distance of $\frac{C}{2}$. This gets me to the end mill center which is why I can use the equal sign.

With a little rearrangement, I have the distance between end mill center and guide rod center

$$end\ mill\ center - guide\ rod\ center = -\frac{K}{2} + P - S - \frac{C}{2}$$

$$end\ mill\ center - \ guide\ rod\ center = -\frac{K}{2} + P - S - \frac{C}{2}$$

Time to pull in a few equations

$$P = 0.984C \qquad (A4)$$

$$S = 0.180A \qquad (A5)$$

$$A = \frac{3}{TPI} \qquad (A1)$$

Plus recall that K is the diameter of the guide rod and C is the diameter of the counterbore and end mill.

$$end\ mill\ center - \ guide\ rod\ center = -\frac{K}{2} + P - S - \frac{C}{2}$$

Plug in A4, A5, and A1

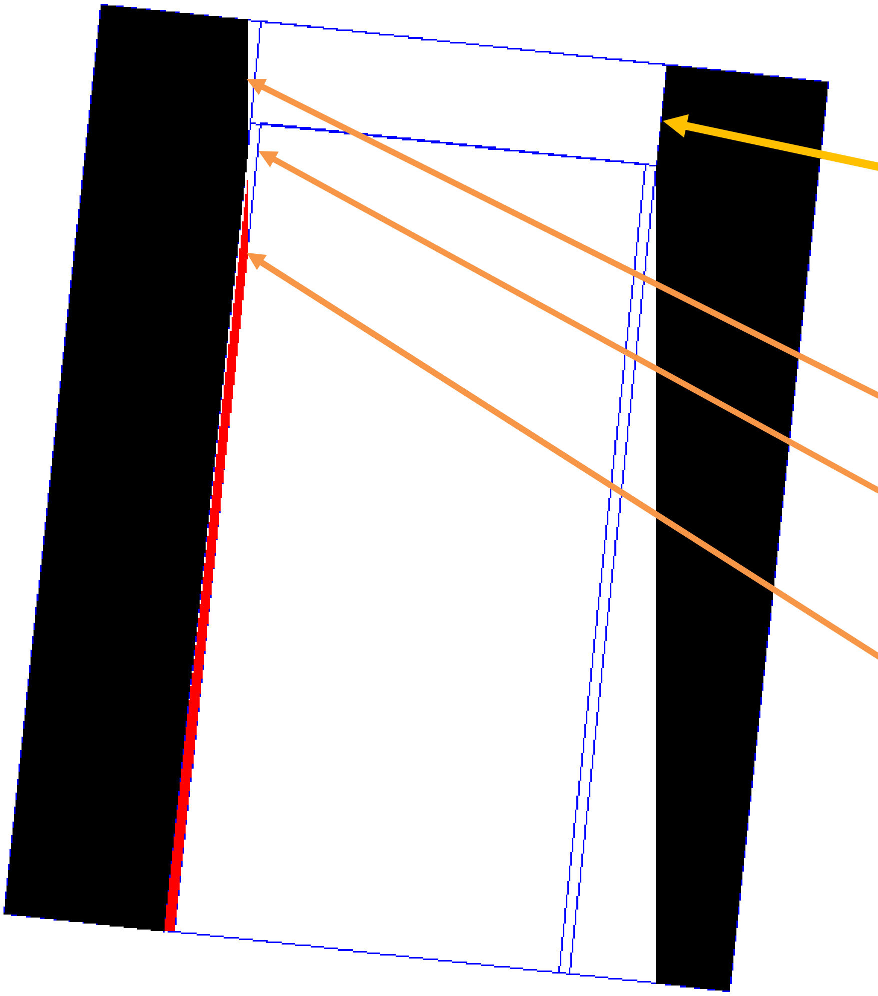
$$end\ mill\ center - \ guide\ rod\ center = -\frac{K}{2} + 0.984C - \frac{0.540}{TPI} - \frac{C}{2}$$

$$end\ mill\ center - \ guide\ rod\ center = -\frac{K}{2} + 0.484C - \frac{0.540}{TPI} \qquad \text{(A6) and (3)}$$

Where K is the diameter of the guide rod, C is the diameter of the counterbore, and TPI is the threads per inch of the nut.

There is one more loose end in this design - the thickness of the Angled Half Nut.

In order to appreciate setting the nut's thickness, let's look at its cross section.

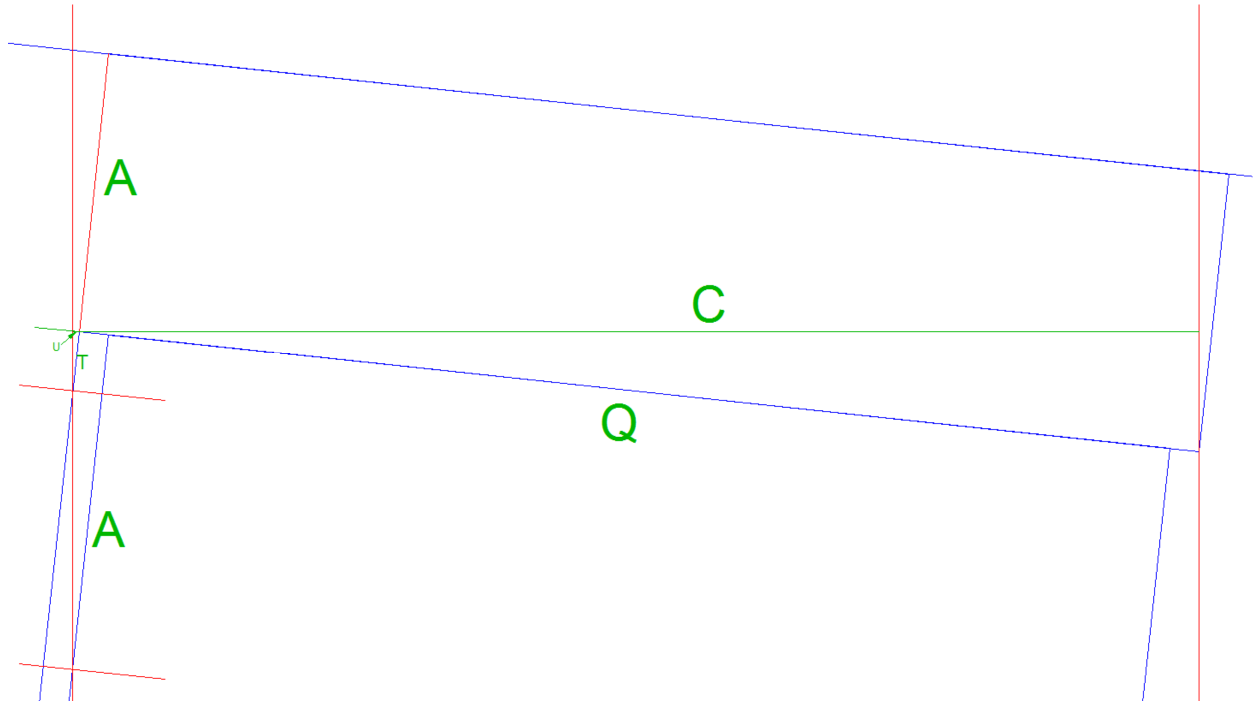


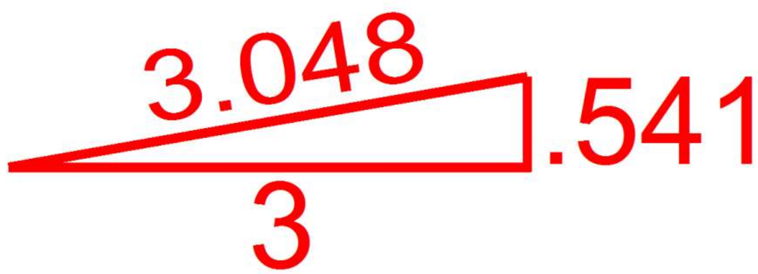
The right face of the counterbore is left untouched by the end mill. This face is what supports the threaded rod when the nut is tight. By design, it is $\frac{3}{TPI}$ tall.

The other face of the counterbore is machined off along with some of the thread.

Below this threadless area, the depth of thread ramps up until we are at full thread.

If the nut was too thin, we would end up with no thread on this face. A bit thicker and we would get only partial depth. But we want some full thread so must figure out the minimum thickness of the nut.



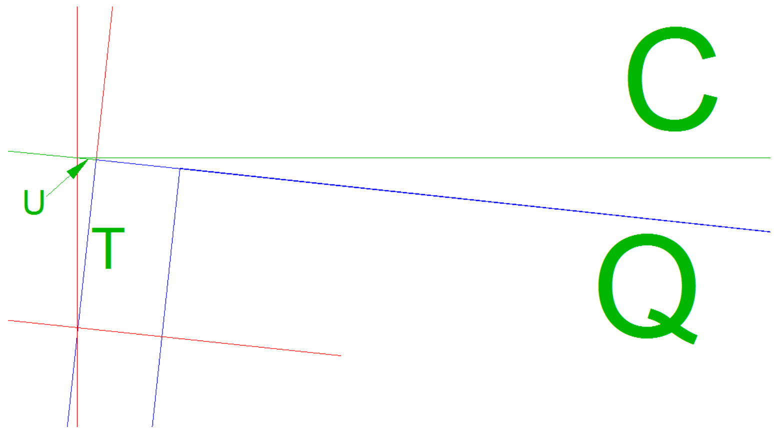


I have a right triangle with C as the base. The distance, "Q" also goes the width of the end mill but at the angle defined by our reference triangle. We can therefore find Q

$$\frac{hypotenuse}{base} = \frac{3.048}{3} = \frac{Q}{C}$$

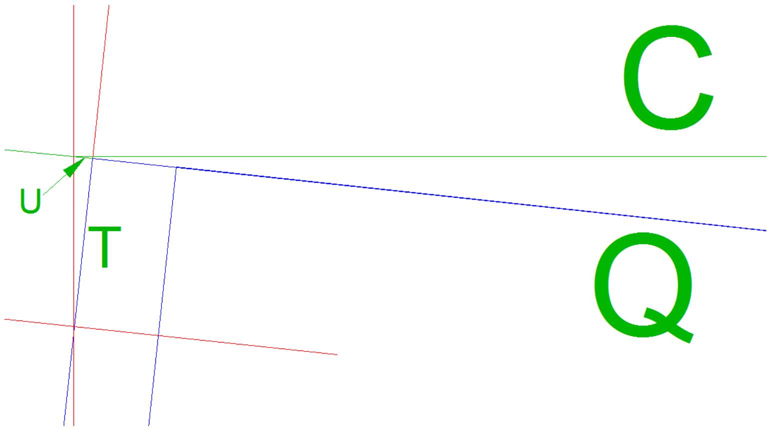
so

$$Q = 1.016C \qquad \text{(A7)}$$



The counterbore has a diameter of C. By subtracting C from Q, we determine the tiny sliver, "U".

$$U = 0.016C \qquad \text{(A8)}$$



$$U = 0.016C \qquad \text{(A8)}$$

We can again use our reference triangle. This time it will give us the distance T which is the distance from the bottom of the counterbore to where we begin to see thread

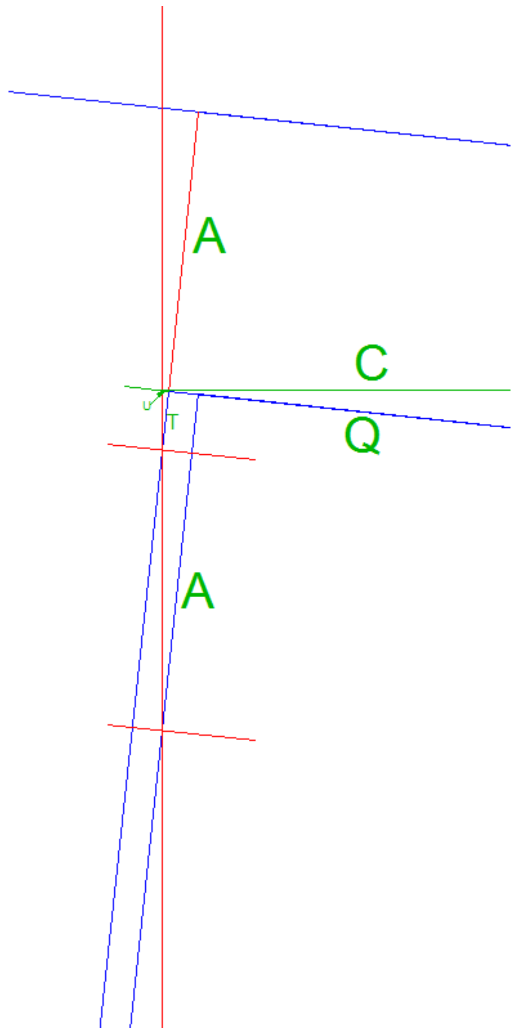
$$\frac{rise}{base} = \frac{0.541}{3} = \frac{U}{T}$$

Plug in A8 and we get

$$\frac{0.541}{3} = \frac{0.016C}{T}$$

So

$$T = .0887C \qquad \text{(A9)}$$



We are working our way down the Angled Half Nut and are almost done. Starting at the top face, we go down a distance "A" with the counterbore. Then there is the distance T where all thread has been removed. Below this we have the tapered thread section. It has a length of "A" because it forms the same right triangle as in the top "A" section.

What is left will be full thread. A common rule of thumb is that you need at least 3 full threads for strength. But our full threads are only on one side so we need 6 threads.

We would like to make the depth of the counterbore as deep as possible in order to support the threaded rod. But this depth also sets the section of thread that is tapered. The tapered thread is weaker than full thread so we want to minimize it. Shop experience has shown that having a counterbore depth of $\frac{3}{TPI}$ inches is sufficient. Having a tapered thread for $\frac{3}{TPI}$ inches is not too much compared to the full thread section $\frac{6}{TPI}$ inches long.

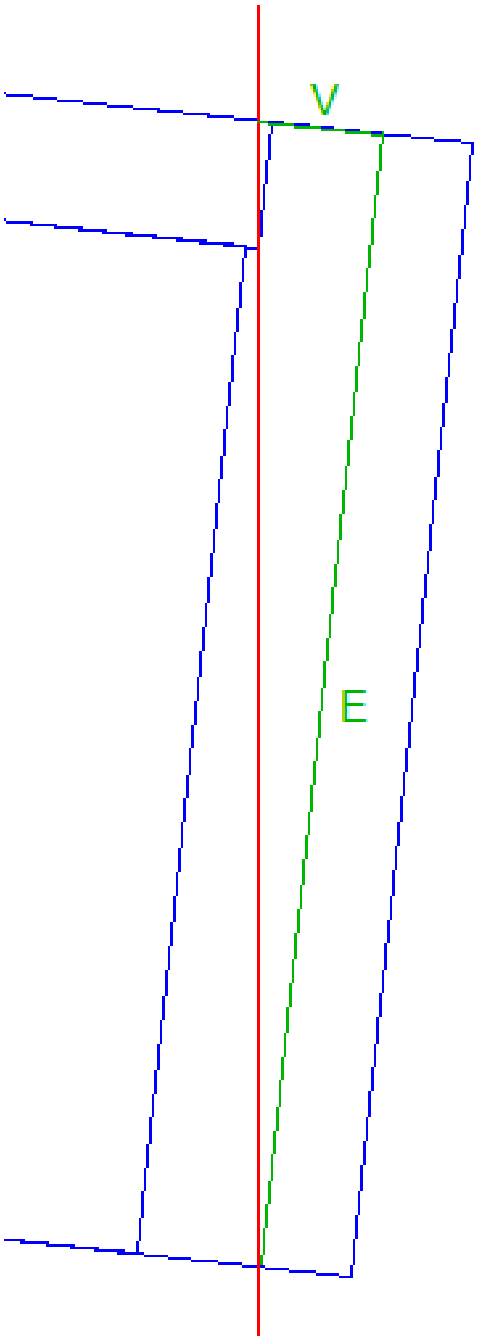
Knowing the TPI, we know that the full thread section will take up $\frac{6}{TPI}$ inches.

$$minimum\ nut\ thickness = A + T + A + \frac{6}{TPI} \text{ inches}$$

Plug in (A9) and (A1) we get

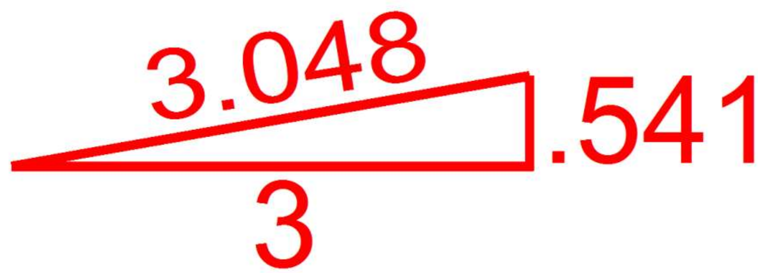
$$minimum\ nut\ thickness = \frac{12}{TPI} + .0887C \text{ inches} \qquad \text{(A10) and (1)}$$

where C is the end mill diameter.



We have one more parameter to determine - minimum nut diameter. If this diameter was too small, the angled hole would break out the side.

Once again the reference triangle solves supplies the answer.



$$\frac{rise}{base} = \frac{0.541}{3} = \frac{V}{E}$$

so

$$V = 0.180E \qquad \text{(A11)}$$

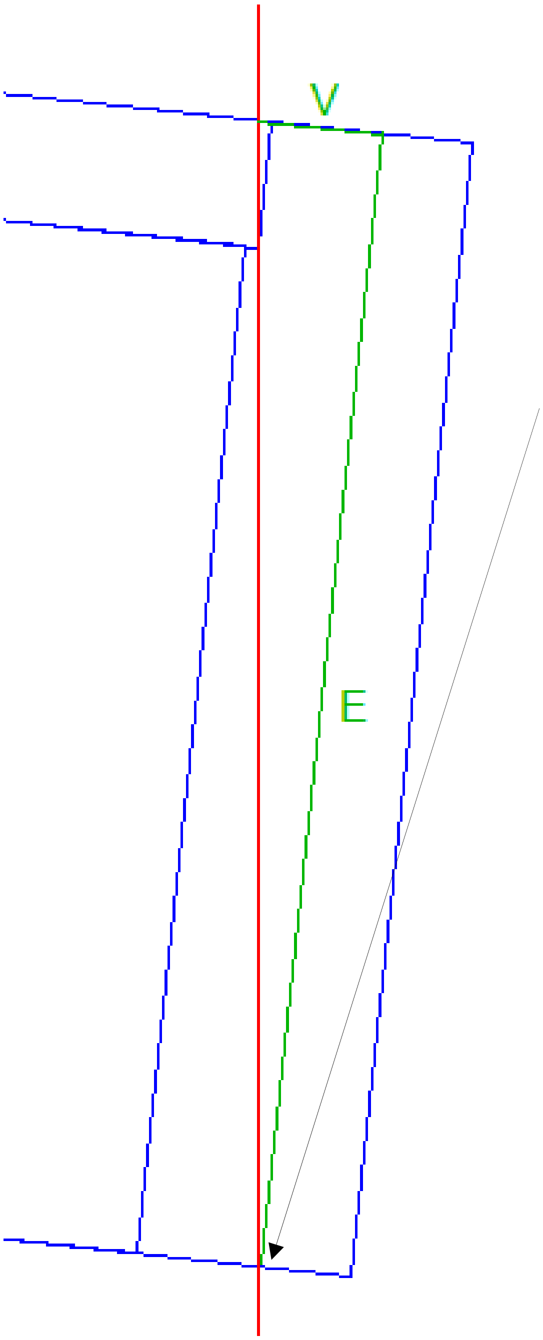
Note that "V" goes from the green "E" line to the red line. The distance from the red line to the side of the counterbore is B, the thread depth so equals $\frac{0.541}{TPI}$. Subtracting this off we get the minimum distance from the counterbore lip to the outside diameter. Starting at the center of the counterbore, we move a distance of $\frac{C}{2}$ to get to the counterbore wall. Then we go an additional V - $\frac{0.541}{TPI}$ and we are at the minimum outside radius. Putting this all together we get

$$\text{Minimum nut diameter } = \text{ C} + 2(0.180\text{E} - \frac{0.541}{TPI})$$

or

$$\text{Minimum nut diameter } = \text{ C} + .361\text{E} - \frac{1.08}{TPI} \qquad \text{(A12) and (2)}$$

where C is the counterbore diameter and E is the nut thickness.



With the minimum nut diameter, the angled hole will just break out of the side wall. You may want to add at least 0.1" so the wall thickness is .05" at the bottom.