Translating Total Feed Rate to A Axis RPMs and X/Y axis Feed Rates, Version 1.0

By R. G. Sparber

Conclusion

$$\boldsymbol{RPM\ of\ A\ axis = \frac{f}{3D}} \qquad \textbf{(1)}$$

$$\boldsymbol{X\ axis\ feed\ rate = RPM\ of\ A\ axis\ \times c} \qquad \textbf{(2)}$$

Where

$\boldsymbol{f}$ is the desired feed rate experienced by the cutter

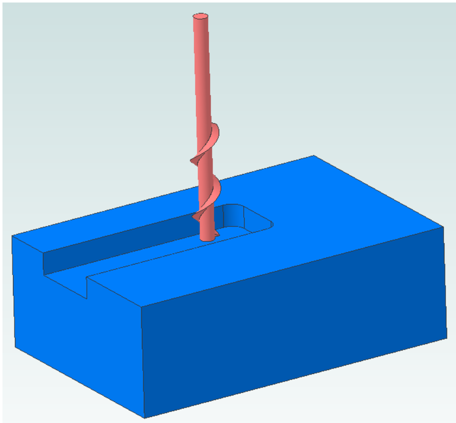
$\boldsymbol{D}$ is the diameter of the workpiece at the cut

$\boldsymbol{c}$ is the radial depth of cut

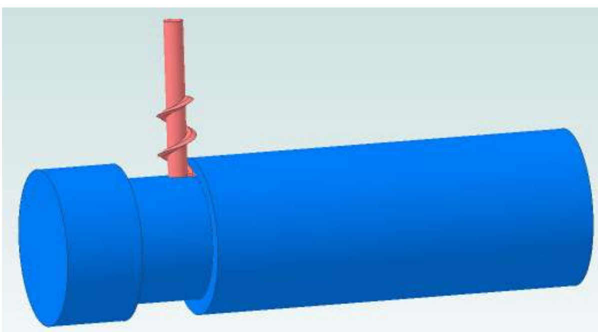
Example: If I want a feed rate of 3 IPM and am cutting a 2 inch diameter cylinder, I should set my A axis RPM to $\frac{3}{3 \times 2} = 0.5$ RPM. If I want a radial depth of cut of 0.1 inches, then the X axis feed rate should be $0.5\ \times 0.1 = 0.05$ IPM.

I know that the RPM and feed rate seem crazy slow, but that is what happens when you mill a rotating cylinder. Read on for details.

How I got There



I know from experience with my RF-30 mill/drill that a ¼ inch diameter 3 flute end mill[2] turning at 2500 RPM and cutting 0.2 inches deep in 6061 aluminum can smoothly run at 3 Inches Per Minute (IPM). Running much slower than this causes squealing as the flutes start to rub. Running much faster than this causes excessive vibration, poor finish, and in extreme cases the cutter pulls out of its holder.

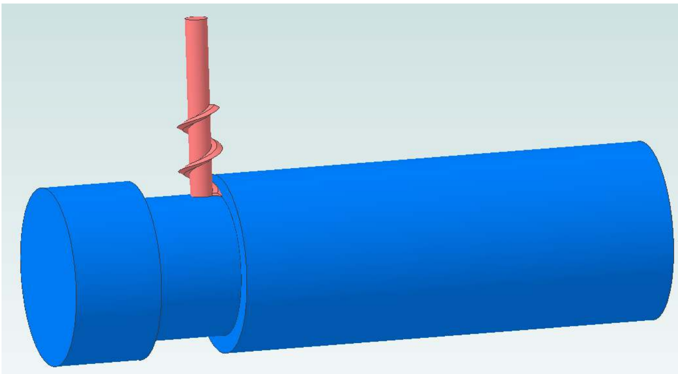


Recently I have been playing with milling while moving my X and Y axes and rotating my A axis. It didn't take me long to realize I had my feed rates wrong.

Sure I could search around and find the equations that govern this configuration. But it was more fun to derive the relationships.

[2] Yes, I know I have only drawn a single flute.

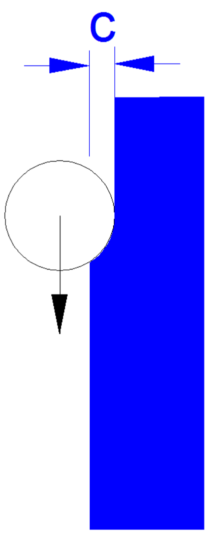
Three parameters must be known before we can proceed:



f is the desired feed rate experienced by the cutter

D is the diameter of the workpiece at the cut

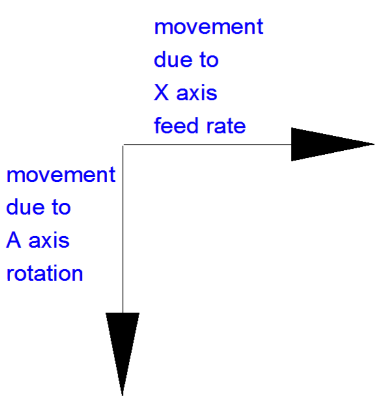
c is the radial depth of cut



The radial depth of cut is the amount of end mill buried into the wall of the cut.

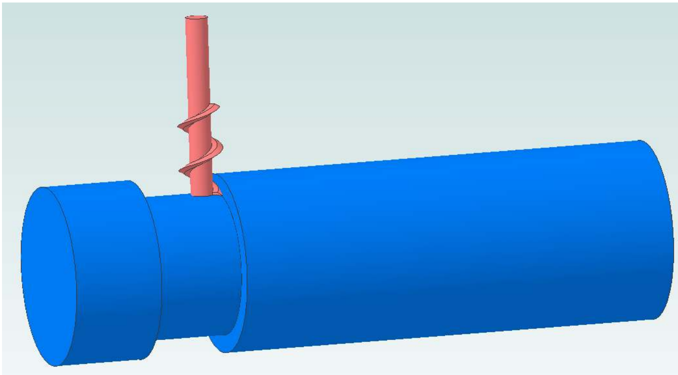
This is a top view of the side milling operation. As the end mill moves along the face of the work piece, it removes a thickness equal to the radial depth of cut.

It is also removing material due to the Z axis depth of cut but that parameter is tied into the desired feed rate experienced by the cutter.



The cutter is seeing movement in two directions at the same time. As the cylinder rotates, it sees material coming at it along the Y axis. As the table moves along the X axis, the cutter sees material coming at it from this direction. There are even times when there can be movement on the XY plane causing the cutter to see a total of three different movements at the same time.

Before you go screaming from the room, understand that we can ignore this complexity. I will show that as long as you are not milling a helix, only rotation of the A axis matters.



From the cutter's standpoint, it sees material coming at it as the A axis rotates. This feed rate is a function of both the revolutions per minute of the A axis and the diameter of the resulting cylinder.

For now, accept that the total feed rate seen by the cutter is very close to the desired feed rate: ***f*** inches per minute (IPM). I will prove this is true later.

The circumference of a circle is πD where D is the diameter of the circle. One lap around the circle is a distance of exactly πD inches.

I want to calculate the needed revolutions per minute (RPM) for the A axis:

$$\frac{f\ IPM}{\pi D\ inches\ per\ revolution} = \frac{f\,\frac{inches}{minute}}{\pi D\frac{inches}{revolution}} = \frac{f}{\pi D}\frac{revolutions}{minutes}$$

We don't need a lot of accuracy here so I will use 3 for π

$$\boldsymbol{RPM\ of\ A\ axis = \frac{f}{3D}} \qquad \textbf{(1)}$$

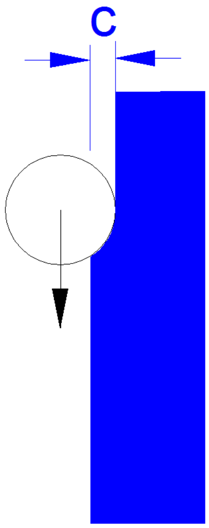
where f is the desired total feed rate in IPM and D is the diameter in inches.

Let's plug in some numbers to see how this works. From experience I know that I should run at a feed rate of 3 IPM. Say my cylinder is 2 inches in diameter:

$$RPM\ of\ A\ axis = \frac{f}{3D}$$

$$RPM\ of\ A\ axis = \frac{3\ IMP}{3 \times 2\ inches} = 0.5\ RPM$$

The surprise here is how slowly I must turn my A axis in order to get 3 IPM feed rate.



The second piece of the puzzle involves the X axis depth of cut and feed rate. Say I start with the cutter's flank just touching the wall to be milled. After one revolution I want to be in a depth of ***c*** inches.

I can say this in an equation:

$$X\ axis\ feed\ rate = A\ axis\ \frac{revolutions}{minute} \times c\,\frac{inches}{revolution}$$

$$\boldsymbol{X\ axis\ feed\ rate = RPM\ of\ A\ axis\ \times c\,\frac{inches}{minute}} \qquad \textbf{(2)}$$

Continuing the last example, we know the A axis should turn at 0.5 RPM. Say I want a radial depth of cut ($\boldsymbol{c}$) of 0.1 inches:

$$X\ axis\ feed\ rate = \ 0.5\ RPM\ \times 0.1\ inches = 0.05\ IPM$$

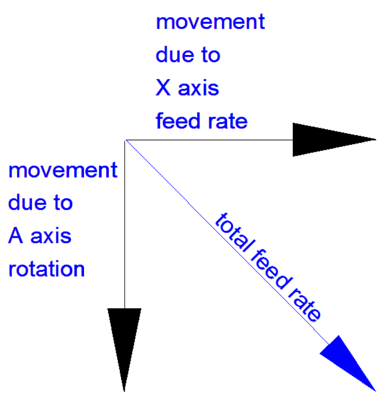
Are you kidding? Run at only 0.05 IPM! Yup. If you run any faster you will have a depth of cut greater than 0.1 inches. If you run at an X axis feed rate of more than 0.125 IPM you will cut a helix.

Let's go back and verify my initial assumption using this example. My feed rate due to the A axis turning can be found from (1)

$$RPM\ of\ A\ axis = \frac{f}{3D} \qquad (1)$$

Rearranging terms I get:

$$f = RPM\ of\ A\ axis \times 3D = 0.5 \times 3 \times 2 = 3 \text{ IPM.}$$



From (2) we calculated that the X axis feed rate must be 0.05 IPM.

Note that these two movements are perpendicular. In order to add them, I must do what is called a Vector Sum. This is a fancy term for solving a right triangle. My movement due to A axis rotation is the base of my triangle. The movement due to X axis feed rate is the rise. My hypotenuse is the Vector Sum:

$$\text{Total feed rate} = \sqrt{3^2 + 0.05^2} = 3.$$

In other words, the total feed rate is not significantly influenced by any practical X axis feed rate.

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Rick Sparber
Rgsparber.ha@gmail.com
Rick.Sparber.org