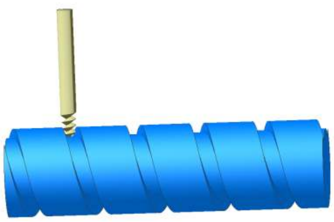
Hand Coding AX Plane G Code for a Centroid Equipped Mill In Order to Cut a Helix, Version 2.0

By R. G. Sparber

Summary



In order to cut a helix of length L, diameter d, with a pitch of P that starts at X = 0 and A = 0°:

$$number\ of\ degrees\ around\ the\ A\ axis\ = \frac{L}{P} \times 360^{\circ} \qquad (8)$$

The above equation shouldn't leave much room for controversy but when we get into feed rate, it can be confusing. This is because the specified feed rate's units can be linear or rotational but not both at the same time.

For Centroid, linear motion takes precedence over rotational motion with respect to feed rate. You specify the linear feed rate and the rotational feed rate is set by the software so it keeps up.

The speed along the X axis is s_x and is chosen by the user. Then the speed experienced by the cutter is $s_{effective}$

$$s_{effective} = s_x\sqrt{1 + \left(\frac{\pi d}{P}\right)^2} \qquad (12)$$

Parameters d and P must be in the same units.

If the diameter of the stock is at least as larger as the pitch of the helix we will be accurate to within 5% with

$$s_{effective} \cong s_x\left(\frac{3d}{P}\right) \qquad (13)$$

In case you are curious, the angular speed of the part rotating around the A axis is s_a

$$s_a = \frac{360°}{P} \times s_x \qquad (11)$$

s_x must use the same distance units as P; s_a is in degrees per the time unit of s_x.

Example

Say I want to cut a helix 4" long with a diameter of 1" and a pitch of 0.1" at an effective feed rate of 10 Inches Per Minute (IPM).

$$number\ of\ degrees\ around\ the\ A\ axis\ = \frac{L}{P} \times 360^o \qquad (8)$$

$$\frac{4"}{0.1"} \times 360^{\circ} = 14{,}000^{\circ}$$

The G-code should specify a move along the X axis of 4" and an A axis rotation of $14{,}000^{\circ}$

G01 X4 A14000

To achieve an effective feed rate of 10 IPM, use

$$s_{effective} = s_x\sqrt{1 + \left(\frac{\pi d}{P}\right)^2} \qquad (12)$$

and solve for s_x

$$s_x = \frac{s_{effective}}{\sqrt{1 + \left(\frac{\pi d}{P}\right)^2}}$$

Plug in the numbers for $s_{effective}$, d, and P

$$\frac{10\ IPM}{\left(\sqrt{1+\left(\frac{\pi \times 1"}{0.1"}\right)^2}\right)} = 0.32\ IPM.$$

Using the approximation,

$$s_{effective} \cong s_x\left(\frac{3d}{P}\right) \qquad (13)$$

so

$$s_x \cong s_{effective}\left(\frac{P}{3d}\right)$$

I calculate 0.33 IPM.

Going from 10 IPM down to 0.32 IPM is a huge reduction in feed rate but remember, you are rotating that cylinder so a lot of material is being removed. Our command line will read

G01 F0.32 X4 A14000

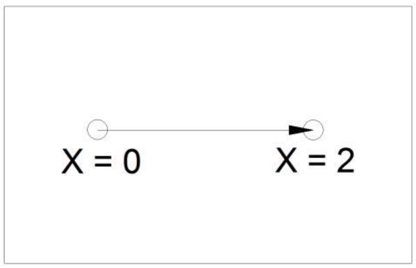
You can see a video of my machine cutting a helix based on these equations at:

https://www.youtube.com/watch?v=gAalEkMSsoY&feature=youtu.be

The Reasoning Behind the Equations

I will start by talking about machining on a plane and then show how it relates to having a rotational cylinder.

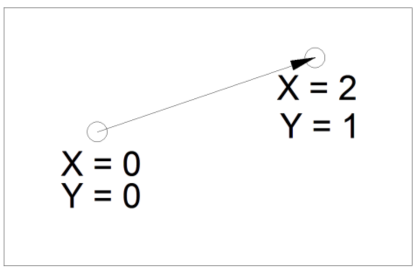
Hand G coding on the XY, XZ, or YZ planes means plugging in distances into various commands and setting the feed rate.



For example, say I start at X = 0 and execute

G01 F1 X2.

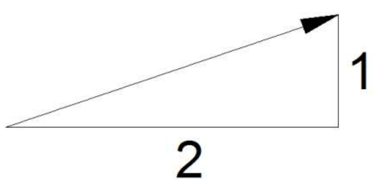
My cutter will move at a rate of 1 inch per minute (IPM) from X = 0 until it reaches X = 2 inch.



Moving in two dimensions, I can go from X = 0, Y = 0, to X = 2, Y = 1. This would require

G01 X2 Y1.

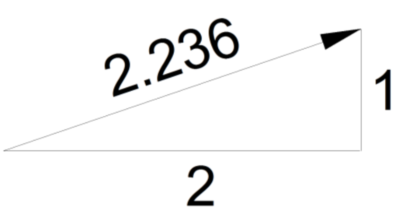
My cutter will move from (0,0) to (2,1) along a straight line path. By using the Pythagorean theorem, we can calculate the length of the tool path which is the hypotenuse of a right triangle



$$hypotenuse = \sqrt{(2\ inches)^2 + (1\ inch)^2}$$

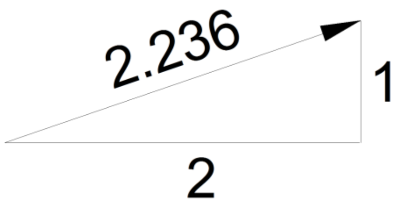
$$hypotenuse = \sqrt{5\ inches^2}$$

$$hypotenuse = 2.236\ inches.$$



Now let's add in a feed rate of 1 IPM

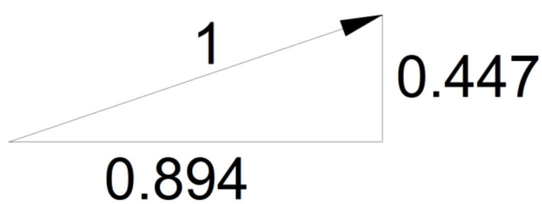
G01 F1 X2 Y1.



As this G code is being executed, the cutter will move 2 inches along the X axis ***while*** it moves 1 inch along the Y axis. Movement on both axes will start at (0,0) and will end on both axes at (2,1). The cutter will move 2.236 inches at a speed of 1 IPM. All numbers shown on this triangle are in inches but they could be in any units and still be valid. A triangle with a 2 meter base and 1 meter rise would have an hypotenuse of 2.236 meters. The key here is that all 3 numbers must have the same units.

It is therefore valid to divide the 3 numbers by time. The triangle is then showing us relative speeds. If we moved at 2 IPM along the X axis while moving 1 IPM along the Y axis, the cutter would move at 2.236 IPM along the hypotenuse.

Now, this is faster than specified by the G code. But if I divide all 3 numbers by 2.236 I get

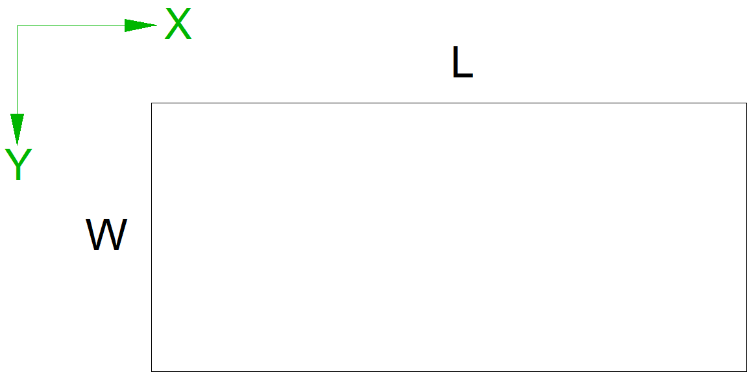


The diagram now matches my G code's "F1". You can see that as the cutter move at 1 IPM, we must move at 0.894 IPM along the X axis and 0.447 IPM along the Y axis.

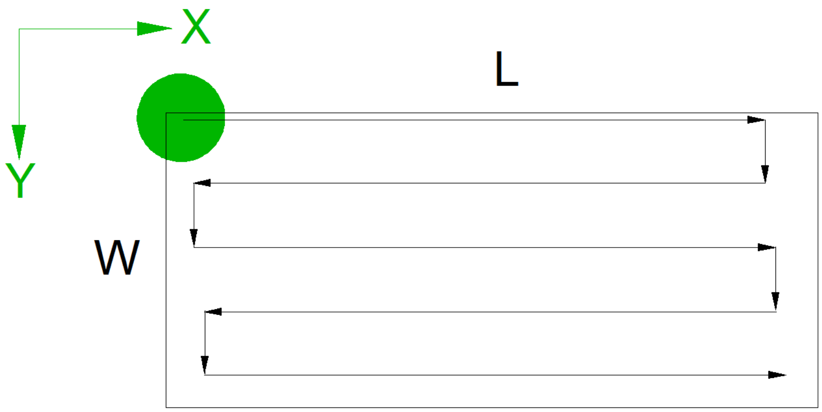
The key thing to remember here is that the F parameter specifies the speed experienced by the cutter. The software sets the X and Y speeds to insure that we arrive at the end point on the X axis at the same instant that we arrive at the Y end point. Only then will the tool path be straight.

We are now ready to talk about cutting a plate on the XY plane.

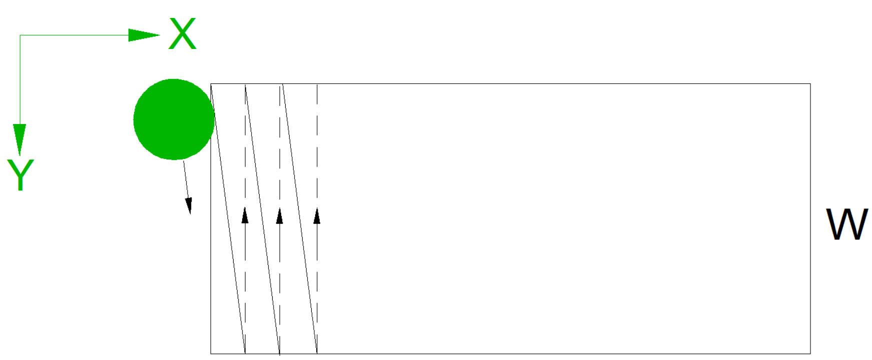
In the following discussion I have flipped the direction of the Y axis in order to avoid talking about negative distances.



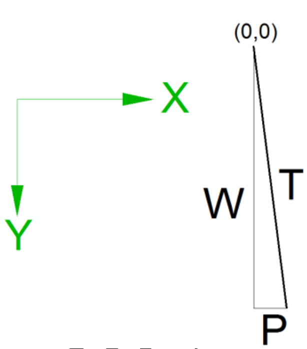
Consider a plate supported by the XY plane. My end mill could cut the surface flat.



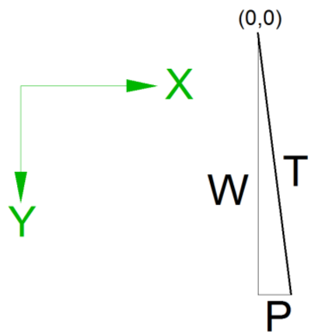
Any sane machinist would make run the end mill (the green circle) on a path parallel to the X and Y axes. Why make it hard?



With the power of G code, I don't have to be sane. I could cut this plate along an angled path. When I reached the maximum Y distance, the cutter can be quickly sent back to the top edge of the plate and the cycle repeated.



Focusing only on the tool path, T, there is a fixed relationship between X and Y motion as discussed on page 4. While I move a distance "W" along the Y axis, I must also move a distance "P" along the X axis in order to move the tool along the straight line T. Given the cutter started at (0,0), the G code would specify a movement to location (W,P) and we could cut the diagonal.



I can write an equation that describes the X and Y movement.

$$Y = \left(\frac{W}{P}\right)X \qquad (1)$$

For $0 \leq X \leq P$.

X and Y are in inches. $\frac{W\ inches}{P\ inches}$ have the inches cancel so becomes a unit-less value.

Let's see if it works. At X = 0

$$Y = \left(\frac{W}{P}\right)(0)$$

$$Y = 0$$

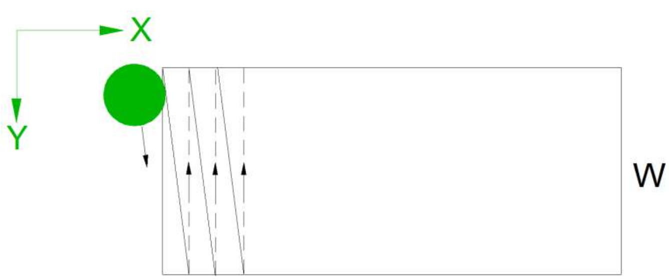
So our equation is correct at (0,0).

At X = P

$$Y = \left(\frac{W}{P}\right)(P)$$

$$Y = W$$

So our equation is also correct at (P,W). It works!



As I move a distance "P" along the X axis, I must make one pass along the Y axis. In order to move a distance "L" along the X axis, I must make a series of passes:

$$number\ of\ passes = \frac{L}{P} \qquad (2)$$

Does this makes sense? If L was equal to P, only one pass would be needed. If L = 10P, I would need to make 10 passes. OK. I will return to (2) later.

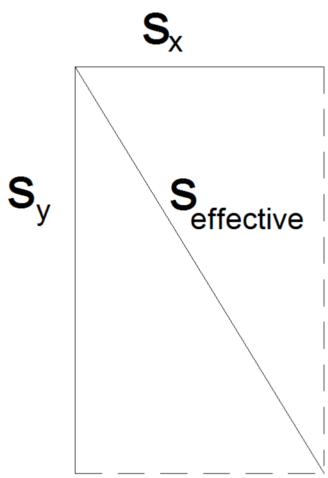
As explained on page 5, it is valid to divide both sides of an equation by the same units. If I take

$$Y = \left(\frac{W}{P}\right) X \qquad (1)$$

And divide both sides by time, I will get an equation that tells us about distance divided by time which is speed.

$$s_Y = \left(\frac{W}{P}\right) s_X \qquad (3)$$

Where s_y is the speed along the Y axis and s_x is the speed along the X axis. If I know the speed along the X axis, (3) tells me the required speed along the Y axis.



I can use the Pythagorean theorem to calculate the speed experienced by the cutter. I call this the effective speed.

$$s_{effective} = \sqrt{{v_x}^2 + {v_y}^2} \qquad (4)$$

Using (3) we get

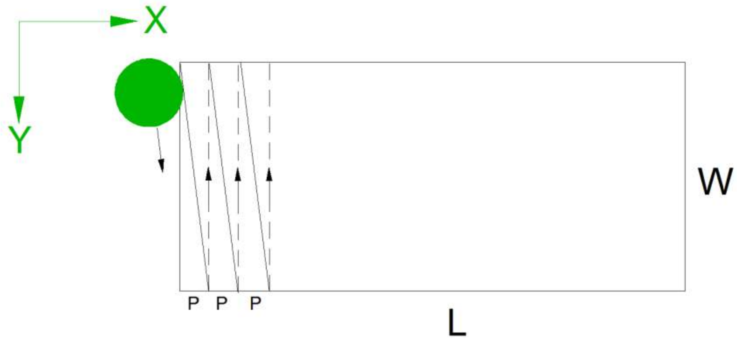
$$s_{effective} = \sqrt{{v_x}^2 + \left(\frac{W}{P}\, v_x\right)^2}$$

$$s_{effective} = v_x\sqrt{1 + \left(\frac{W}{P}\right)^2} \qquad (5)$$

Equations (3) and (5) fully describe movement of the cutter. Using (3), if you tell me the speed along the X axis, I can tell you what must happen on the Y axis. (5) will then tell you what the cutter experiences.

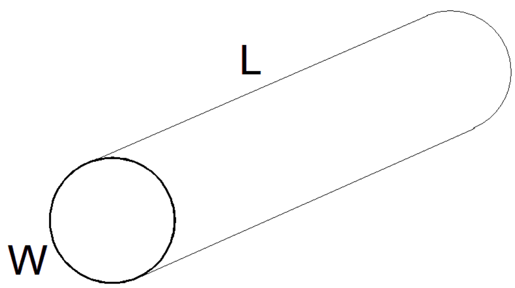
In other words, you get to set one of the three speeds and these equations will tell you what the other two speeds must be in order to cut a straight line.

So far we have only discussed moving around the XY plane. Time to think about moving along a cylinder aligned with the X axis while turning the A axis.

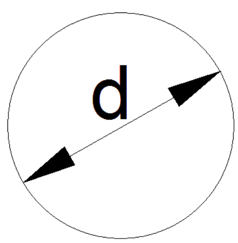


Back on page 6 we talked about moving a cutter on a diagonal in order to cut this plate flat. On page 7 we developed an equation that told us how many passes it would take to cut a plate that is L wide

$$number\ of\ passes = \frac{L}{P} \qquad (2)$$



What if I took this plate and curled it up into a cylinder? The length would still be L but W would now be the circumference.

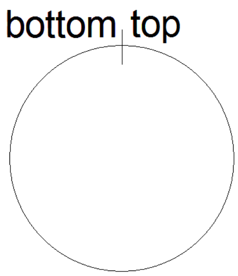


Looking at the end of the cylinder, I can measure the diameter. The circumference, C, is

$$C = \pi d$$

But the circumference is also our original plate width W. Therefore

$$W = \pi d \qquad (6)$$



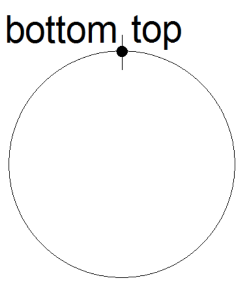
Here you see how the top edge of the plate has been bent around to touch the bottom edge. Back on page 7 we described the movement along the Y axis as a function of X axis movement with

$$Y = \left(\frac{W}{P}\right)X \qquad (1)$$

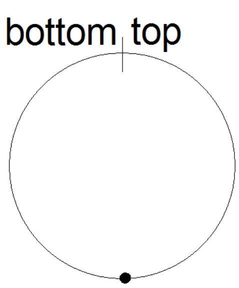
We can describe movement around this circumference from top to bottom by using degrees

$$angular\ position = \frac{A°}{360°} \times W \qquad (7)$$

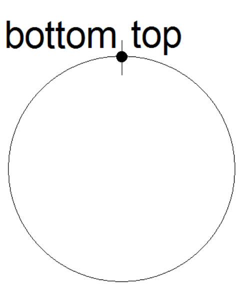
Does this makes sense? Best to try a few values to be sure.



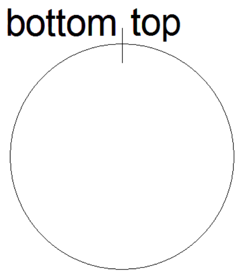
At an angle, A, of 0°, we are at the top of the plate.



At 180° we are half way around.



And at 360° we reach the bottom of the plate which is now also the top.



Recall

$$W = \pi d \qquad (6)$$

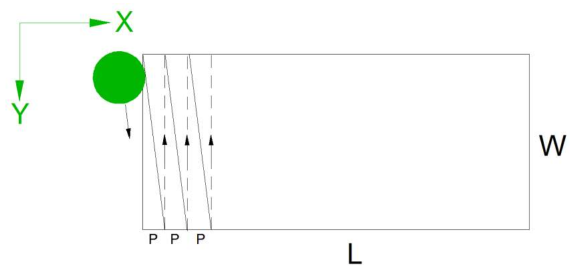
which relates diameter and plate width

and

$$angular\ position = \frac{A°}{360°} \times W \qquad (7)$$

we can relate angular position with diameter

$$angular\ position = \frac{A°}{360°} \times \pi d \qquad (8)$$



Uncurl our cylinder, and angular position is really our Y position. This means I can equate circumference, angular position, and the original Y movement down the plate.

Recall that

$$Y = \left(\frac{W}{P}\right)X \qquad (1)$$

Using

$$W = \pi d \qquad (6)$$

I can say

$$Y = \left(\frac{\pi d}{P}\right)X \qquad (9)$$

As far as the cutter is concerned, it doesn't know the difference between a cylinder of diameter "d" and a plate of width "W". I can therefore talk about the feed rate experienced by the cutter when milling a plate and it will be the same as if it was milling a cylinder.

We can also figure out angular speed. Since angular position is the same as my position on the plate along the Y axis, I can set

$$Y = \left(\frac{\pi d}{P}\right) X \qquad (9)$$

and

$$angular\ position = \frac{A°}{360°} \times \pi d \qquad (8)$$

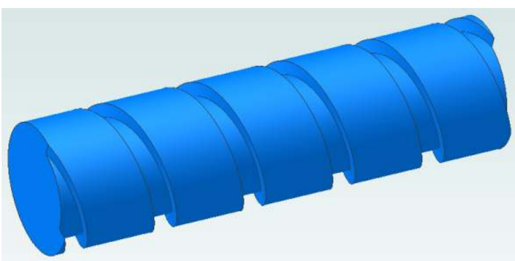
as equal. Note that angular position is in the same dimensions as d and does not contain degrees.

$$\left(\frac{\pi d}{P}\right) X = \frac{A°}{360°} \times \pi d$$

$$\left(\frac{\pi d}{P}\right) X = \frac{A°}{360°} \times \pi d$$

so

$$A° = \frac{360°}{P} \times X \quad (10)$$



We now have an equation that relates X axis movement to angular movement in order to cut a helix. Note that diameter is not a factor. All that matters is making those revolutions around the A axis as I move along the Y axis.

Divide both sides of (10) by time and I get

$$s_a = \frac{360°}{P} \times s_x \quad (11)$$

Where s_a is the angular speed around the A axis and s_x is the linear speed along the X axis.

Going back to page 8, we have for our plate

$$s_{effective} = s_x\sqrt{1 + \left(\frac{W}{P}\right)^2} \qquad (5)$$

Plug in

$$W = \pi d \qquad (6)$$

and we get

$$s_{effective} = s_x\sqrt{1 + \left(\frac{\pi d}{P}\right)^2} \qquad (12)$$

This says that the feed rate experienced by the cutter, $s_{effective}$, is related to the X feed rate, the stock's diameter, d, and the desired pitch of the helix, P.

Note that if the diameter of the stock at least as larger as the pitch of the helix we will be accurate to within 5% with

$$s_{effective} \cong s_x\left(\frac{3d}{P}\right) \qquad (13)$$

Conclusion

A Axis Rotation: The total number of degrees turned around the A axis is related to the length, L, of the helix and its Pitch, P.

$$number\ of\ degrees\ around\ the\ A\ axis\ = \frac{L}{P} \times 360^o \qquad (8)$$

Feed Rates: The speed along the X axis, s_x, is chosen by the user.

The speed experienced by the cutter is $s_{effective}$

$$s_{effective} \cong s_x \left(\frac{3d}{P}\right) \qquad (13)$$

assuming the diameter, d, is at least as large as the Pitch, P. Otherwise, see (12) on page 13.

The angular speed of the part rotating around the A axis is s_a

$$s_A = \frac{360°}{P} \times s_x \qquad (11)$$

Acknowledgements

Thanks to "diycncscott" and Keith McCulloch for explaining how Centroid deals with linear and angular feed rates.

I welcome your comments and questions.

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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