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There has been much confusion about how the Fanuc CNC's calculates feed times for 5-axis moves when using G94 (per minute) feed rates. Here is a brief description.

Calculating a 3-axis Feed Rate:

Calculate the Distance being traveled:

$$d = \sqrt{\Delta X^2 + \Delta Y^2 + \Delta Z^2}$$

Where:

ΔX = Change in the X-axis
ΔY = Change in the Y-axis
ΔZ = Change in the Z-axis

The programmed feed F for the move is then used to calculate a time:

$$t = \frac{d}{F}$$

This time is used to calculate the individual feed rate for each axis.

$$F_Z = \frac{\Delta Z}{t}$$

$$F_Y = \frac{\Delta Y}{t}$$

$$F_Z = \frac{\Delta Z}{t}$$

These are the feeds that are used at each axis. In this manner the axes will all complete their moves in a given time, t, and the motion of the tool will be linear.

Note: If any of the calculate axis feed rates are calculated to be higher than the maximum feed rate for that axis, then the time t is recalculated and all of the axes are slowed down to keep everything in sync.

Calculating 5-Axis Feed Rates

For a full simultaneous 5-axis move in G94 (ipm or mmpm), the controller first calculates a distance, just like in 3-axis machining. However, it must somehow account for the rotary moves as well as the linear portions. On the Fanuc controller, this is done by simply converting the rotary changes into linear units and including them in the distance calculation (in this example, we are assuming a AB table so C does not appear):

$$d = \sqrt{\Delta X^2 + \Delta Y^2 + \Delta Z^2 + \Delta A^2 + \Delta B^2}$$

Where:

ΔX = Change in the X-axis
ΔY = Change in the Y-axis
ΔZ = Change in the Z-axis
ΔA = Change in the A-axis (converted directly from degrees to the current linear units)
ΔB = Change in the B-axis (converted directly from degrees to the current linear units)

The programmed feed, F, for the move is then used to calculate a time:

$$t = \frac{d}{F}$$

This time is used to calculate the individual feed rate for each axis.

$$F_Z = \frac{\Delta Z}{t}$$

$$F_Y = \frac{\Delta Y}{t}$$

$$F_Z = \frac{\Delta Z}{t}$$

$$F_A = \frac{\Delta A}{t}$$

$$F_B = \frac{\Delta B}{t}$$

Just like for 3 axis moves, these are the feeds that are used at each axis. In this manner the axes will all complete their moves in a given time, t. However, the motion of the tool will not be linear. For larger rotary moves, this deviation can be quite large leading to gouging. CAMplete TruePath can deal with that problem using its Linearization optimization.

Note: If any of the calculate axis feed rates are calculated to be higher than the maximum feed rate for that axis, then the time t is recalculated and all of the axes are slowed down to keep everything in sync.

The Effect of Units

One of the more confusing aspects of 5-axis feed rates is what happens to the above equations when using mm or inches. Lets examine this by looking at an example. The following programs in inches and millimeters are identical in all values for axis moves and feed rates. However, as we shall see, they will both produce drastically different results.

The Inch Program:

```
N1 G20 G94
N2 G00 X0.0 Y0.0 Z0.0 A0.0 B0.0
N3 G01 X1.0 Y1.0 Z1.0 A10.0 B10.0 F100.0
```

And converted to mm:

```
N1 G21 G94
N2 G00 X0.0 Y0.0 Z0.0 A0.0 B0.0
N3 G01 X25.4 Y25.4 Z25.4 A10.0 B10.0 F2540.0
```

Lets calculate the time that it will take to execute line N3 for both programs. For the mm program:

$$\Delta X = 25.4$$
$$\Delta Y = 25.4$$
$$\Delta Z = 25.4$$
$$\Delta A = 10.0$$
$$\Delta B = 10.0$$

$$d = \sqrt{25.4^2 + 25.4^2 + 25.4^2 + 10^2 + 10^2} = 46.2mm$$

And time for the feed will be:

$$t = \frac{d}{F} = \frac{46.2}{2540.0} = 0.0182 \min = 1.092 \sec$$

So this move will be executed in 1.092 seconds. As you can see from the calculation, the 10 degree rotary moves (when converted directly to mm) to not effect the d calculation as much as the 25.4 mm linear move.

Now lets examine the inch program:

$$\Delta X = 1.0$$
$$\Delta Y = 1.0$$
$$\Delta Z = 1.0$$
$$\Delta A = 10.0$$
$$\Delta B = 10.0$$

$$d = \sqrt{1.0^2 + 1.0^2 + 1.0^2 + 10^2 + 10^2} = 14.2 inches$$

And time for the feed will be:

$$t = \frac{d}{F} = \frac{14.2}{100.0} = 0.142 \min = 8.52 \sec$$

This is over 10 times longer to complete the ***exact same move*** than the mm program! As you can see, the reason is because when converting the rotary moves from degrees directly to inches, they have a much bigger influence on the calculation of the d value then if we were working in mm.

For these reasons, it is recommended that you either work in G94 in millimeters only, G93 (inverse time) or use the Level Relative Velocity optimization option in CAMplete TruePath to properly adjust the feeds in inch G94 programs to account for this controller behaviour.