1. Multi-Axis Machine Types

A. Five-Axis Gantry

This machine has an A/C or B/C swiveling spindle assembly suspended from the Y-axis crossrail.
Key considerations are:

- The travel zone of the primary rotary axis, normally the C-Axis
- The method used for feedrate control during contouring motion
- The relationship of the rotary axes to the Cartesian coordinate system
- How the end user wants to define and control tool lengths
- Starting contouring motion with the correct head orientation to avoid hitting a travel limit during contouring motion.

Another consideration is whether the spindle motor assembly is offset from center of rotation, requiring a TRANS/ matrix to support it.

B. Five-Axis VMC With Stacked Tables

This machine consists of an A/B part rotation assembly mounted on the XY table.
Key considerations are:

- Where the user wants to set machine zero
- Pivot distances vs. CLfile zero
- Controlling RAPID positioning moves in the CAM system
- The rotary addressing scheme.

Since the spindle remains normal to the XY table and all Z-axis motion is truly Z, this machine type supports length comp, diameter comp, circular interpolation with the tables tilted, and all spindle oriented cycles.

C. Five-Axis VMC or HMC With Rotary Table, Tilting Head

This machine class consists of a part rotation stage having unlimited travel zone, and a tilting spindle that has a +/- 90-120 degree range.
Using a postprocessor to configure a horizontal spindle machine with a B-Axis part rotation stage is straightforward, whereas, when the spindle is vertical and the machine has an A-stage for part rotation, the post requires a TRANS/ matrix to work correctly.

A key factor here is setting the proper expectation since the machine can support circular interpolation, canned spindle cycles, length, and diameter comp when the part rotation stage is moving, but not when the head is tilting. Setting up a post can be tricky if the end user wants optimal use of these CNC-resident features.A key consideration is visualization of the true tool motion when the part rotation stage is at or near 180 degrees.
2. Multi-Axis Programming Considerations
In addition to normal two- or three-axis NC code production, a five-axis post is expected to provide:

- Coordinate Transformation
- Linearization
- Feedrate Conversion
- Spindle Cycle Emulation
- CNC Constraint Monitoring
- Correct Choice of Multiple Solutions

A. Coordinate Transformation
As discussed previously, five-axis machine types range from gantry/articulated head, to VMC/HMC with articulated table, to rotary table tilting head, to non-orthogonal rotary attachments. Each machine type has a different relationship to the coordinate system of the CAM programming system, which makes little or no attempt to flavor the toolpath for a specific machine.
In MULTAX mode, CAM systems produce tool motion in the following format:

GOTO/
Where: xyz ijk
xyz is the tip of the tool in model coordinates, and ijk is a unit vector representing the tool orientation
in model coordinates.

The ijk vector is used to transform the tool tip xyz point into machine coordinates. The transformation method varies with the type of equipment being programmed, as follows:

- For a machine with an articulated head arrangement, the GOTO/ xyz point must be projected along the ijk vector to derive the NC control point. This is frequently the case for solving the NC control point on gantry style machines
- For an articulated table machine, the ij, jk, or ik vector components are used to compute angles for pivoting the GOTO/xyz point in one or two steps to solve for the NC control point.

For rotary table/tilting head machines, a combination of the above methods is used, and so on

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B. Cartesian Axes Vs. Machine Axes

Most machine tool builders assign Y so that it is 90 degrees counterclockwise from X, and assign Z so a positive move retracts the spindle from the XY table surface. However, rotary table or head configurations and rotation directions frequently do not match industry standards, and there are several methods used by various machine builders for addressing a rotary table.

<u>Letter Assignments</u>

For example, the standard rotary arrangement is A = rotation about the X axis, B = rotation about the Y axis, and C = rotation about the Z axis. For NC Code compatibility, or sometimes simply due to an oversight, the A,B, or C axes are labeled incorrectly. The post writer must reassign them in the post or else the CNC executive must be changed.

<u>Addressing Methods</u>

The ANSI standard interprets +/-ABC as positive rotation from a fixed zero point (three o'clock when viewed in a negative direction along the pivoting axis). Some builders (Fadal is an example) interpret the +/- as the direction to go to get to a fixed clock-like representation. Still others (Boston Digital, for instance) use a linear addressing scheme for their part rotation stage based upon a fixed or programmable diameter, and standard degree notion for the tilting head.

<u>Rotation Direction</u>

The final determining factor in setting up a post to support rotary axes is pinning down which way the axis responds to a positive or negative command. Many times the power supply for the drive motors is wired backwards, causing the servo motor to turn in the opposite direction intended and in the opposite direction from what is shown in the programming manuals. If the user has legacy data and does not want to rewire the machine, the post must accommodate this anomaly.

<u>Switchable Table Assembly</u>

In many shops, the user will want the capability for a small rotary/tilting table to be setup in two ways because he can physically slide the table assembly into different positions for jobs that need it. This may need to be coded as a separate postprocessor by taking the final working post and making the axis changes required.

In summary, the post needs know what letter address should be substituted for the Cartesian standard letter address, and the switch settings to accommodate each rotary table type, zero point, and direction. Don't assume both rotary axes use the same method, and don't try to get overzealous in supporting multiple arrangements.

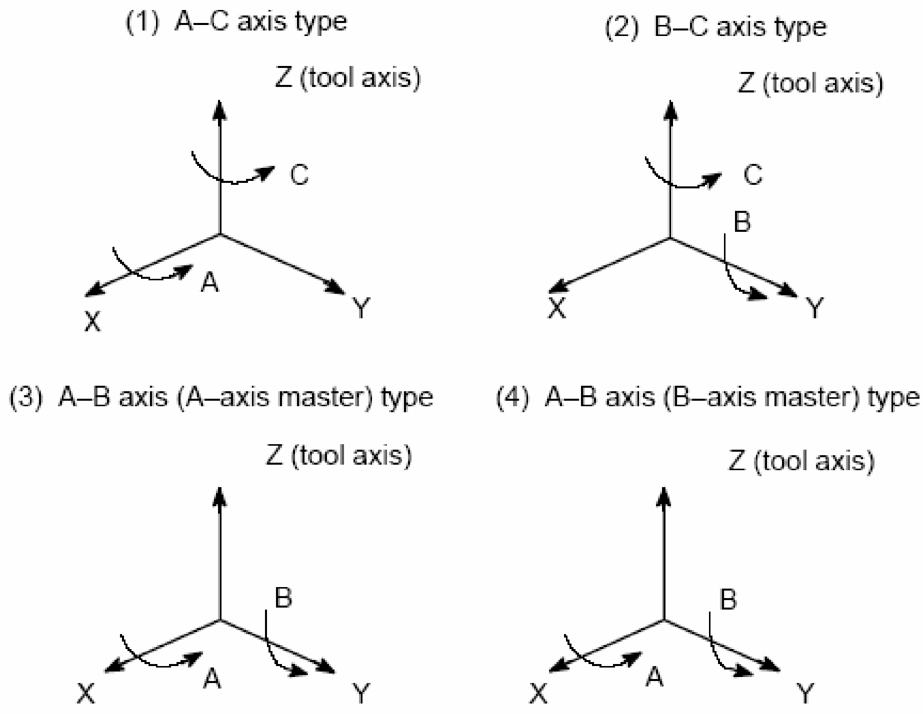
C. Inverse Time Feed Control

Most NC programmers think of the F-register in a CNC controller as the method for specifying linear velocity, i.e. uPM or uPR. This is true for two- and three-axis linear motion, but when rotary motion is to be controlled, the F-register takes on a different meaning. When combined linear/rotary motion exists, most good CNC controllers require the inverse of the amount of time necessary to make the move, and since each move has a different distance, the corresponding time varies for each block as well. The exact reasoning behind using the inverse value rather than the direct time in minutes or seconds is simply a historical matter.

<u>Calculating the F-Code</u>
The constant used to calculate the inverse time code is normally 1 minute, such that the equation is:

F(code) = 1(minute) / (time = 3D distance/velocity)

The 3D distance of the move is calculated in model coordinate space at the NC control point, not in machine coordinate space and not necessarily at the tool tip. For example, a 5-inch move at 50 IPM takes 5 50ths of a minute, yielding an inverse time calculation of 1/.1 and an F-code of F10. The same 5-inch move at 700 IPM would be 1(minute) / (time = 5 / 700) or (1/(5/700)) or (1/.0071428) or F1400.168

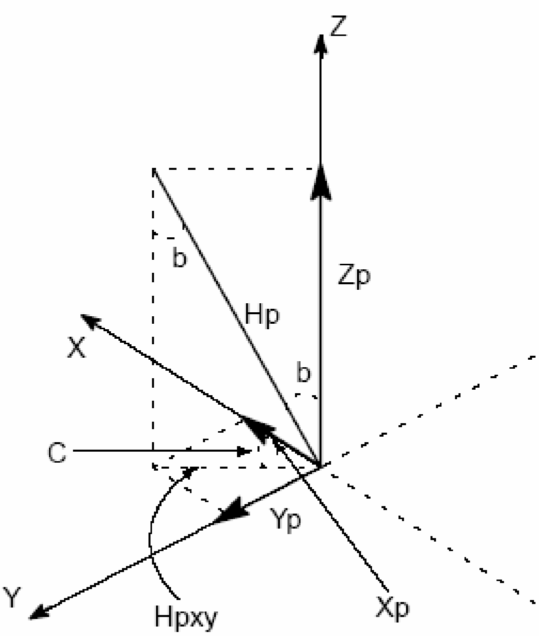


(2) B–C axis type

$Xp = Hp \times \sin(b) \times \cos(c)$

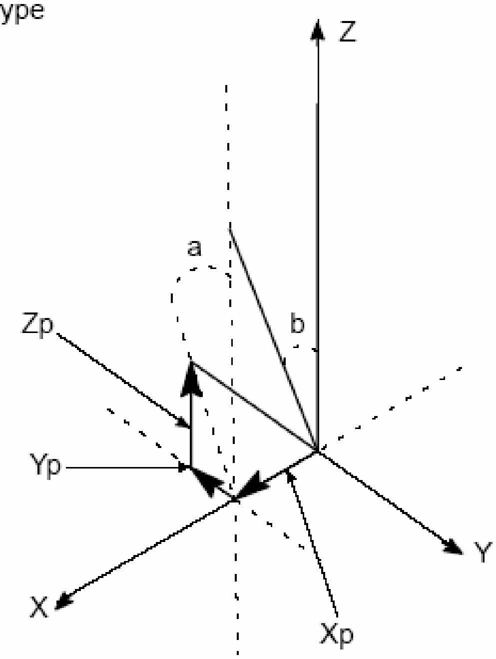
$Yp = Hp \times \sin(b) \times \sin(c)$

$Zp = Hp \times \cos(b)$



(3) A–B axis (A axis master) type

$$Xp = Hp \times \sin(b)$$
$$Yp = -Hp \times \cos(b) \times \sin(a)$$
$$Zp = Hp \times \cos(b) \times \cos(a)$$



(4)A–B axis (B axis master) type

$$Xp = Hp \times \cos(a) \times \sin(b)$$
$$Yp = -Hp \times \sin(a)$$
$$Zp = Hp \times \cos(a) \times \cos(b)$$