Development Report:

Advanced Control Technologies for 5-Axis Machining

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Demand for 5-axis machine tools has grown rapidly with the appearance of high-performance machines and growing requirements for high-efficiency to enhance competitiveness. To meet market needs, FANUC provides innovative CNCs, including the FS30i-A and FS31i-A5, that control up to 24 axes simultaneously with maximum paths of 10 enabling high-speed and high-precision multiple-axis and path control.
FANUC's wide-ranging functions developed for powerful 5-axis machining include tool center point control and tilted working plane command, which enable high-precision complex shape machining minimizing changeover. Nano smoothing, interpolation for generating smooth curves on a nanometer scale, enables high-quality workpiece machining. 3D interference checking enhances the safety of machines whose motion has become increasingly complex. Operability has also been improved to facilitate programming and simulation for 5-axis machining.
This report presents the latest control technologies maximizing 5-axis machine tool performance.

Keywords: 5-axis machining function, tool center point control, tilted working plane command, nano control, high-quality machining

1. Introduction

The major feature of 5-axis machine tools is their integration of machining, conventionally divided into multiple processes, into processes with a single setup thanks to their capacity for complex operation.

Reducing setup enables the following:

- Reduced interprocess wait and machining time.
- Improved machining precision due to eliminating mounting error due to setup changeover.

Because the tool axis can be controlled at any angle to the machining surface:

- The cutting tool angle to the machining surface can be controlled to be constant, it can improve surface roughness.
- Tool rigidity is improved by machining with short tool projection, thereby increasing the machining feed rate.

Using 5-axis machine tools increases the possibility of simultaneously reducing machining time and improving machining precision.

The high performance of machine tools and controllers have enabled 5-axis machine tools to evolve dramatically as the reduction in the number of machining processes has reduced manufacturing cost.

In keeping with the increasing scope of 5-axis machine tools, functions taking advantage of 5-axis control features have greatly advanced.

2. 5-Axis Machining Functions

Two major trends have emerged in the market – 5-axis machining centers based on machining centers and compound machines based on lathes capable of simultaneous 5-axis machining. In principle, the machine type is used based on the shape and type of the workpiece to be machined.

Five-axis machine tools based on machining centers are mainly divided into rotary heads (head rotation type), rotary tables (table rotation type), and combined rotary heads and tables (mixed type) (**Fig. 1**). Compound machines with both workpiece axis and tool axis are rotation axes can be handled as mixed type. Different 5-axis machining functions are applicable to different mechanical configurations.

Particularly important functions are tool center point control and tilted working plane command. Tool center point control is used in simultaneous 5-axis machining and tilted working plane command in tilted plane machining ($3+2$-axis machining), enabling different figures on different 5-axis machines to be machined while changing tools. Using tool center point control and tilted working plane command, programs can be easily changed even if cutting conditions are slightly changed. Using such 5-axis control functions, the number of times of reprogramming using CAM is dramatically reduced, which is expected to increase production efficiency.

3. Tool Center Point Control

Tool center point control makes it possible to program figures that conventionally must be specified with minute

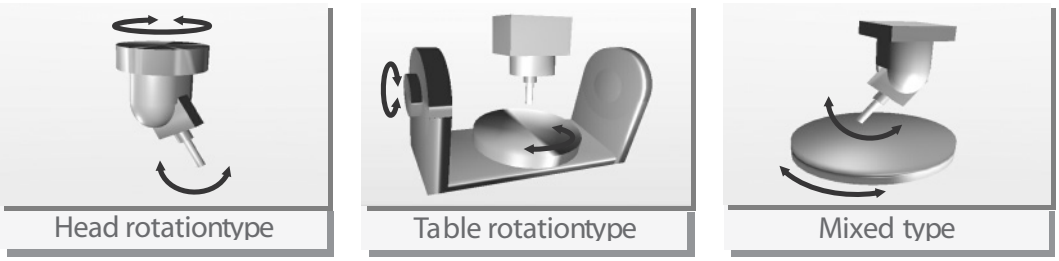

Fig. 1. Three mechanical configurations.

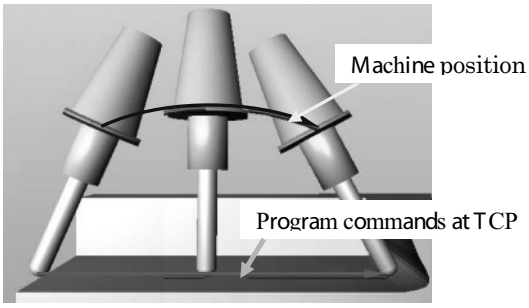

Fig. 2. Tool center point control.

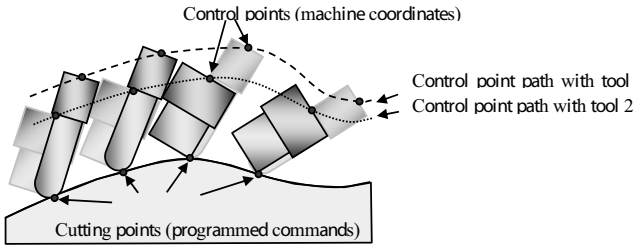

Fig. 3. Tool movement paths with cutting point commands.

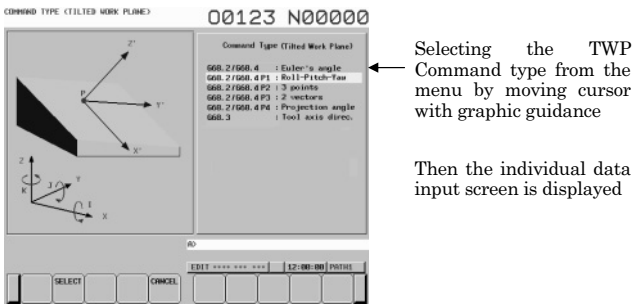

Fig. 4. Tilted working plane guidance screen.

line segments, using the same concept as an axis orthogonal to three axes as in linear interpolation, circular interpolation, etc. (**Fig. 2**). This has the following advantages:

- The number of program steps decreases, reducing cycle time.
- The CNC interpolates directly, increasing figure precision.
- The program is easy to understand intuitively, making it easy to make minute modifications in the field.
- The tool center point speed is specified, so the machining feed rate at the tool center point is made constant, improving surface precision.

The two types of tool center point control are type I, in which angular displacement of the rotary axis is specified directly to the rotary axis, and type II, in which it is specified with a vector. Using tool center point control type II enables the same program to be used regardless of the mechanical configuration (head rotation, table rotation, or compound). For ball-end mills, machining should be at a constant point on the tool tip with good precision/efficiency machining. With type II, it is easy to create data vertical to the machining surface because tool directions are specified with vectors as I, J, and K.

(1) Cutting point command

The cutting point on the machining path can be directly specified in the program. The control point used with the actual machine move command is automatically calculated from the cutting point, corner rounding compensation, cutter compensation, and tool length compensation to control the tool movement path. Even when the tool figure, tool radius, or tool length changes, the program need not be basically modified. Even when the tool is changed, the same program can be used, increasing programming efficiency (**Fig. 3**).

(2) Tool positioning control

By interpolating the attitude of the tool from the tool direction at the start point to the tool direction at the end point, a plane can be machined with the side face of the tool during Tool center point control.

When the tool passes near a singular point, however, the rotary axis becomes unstable, it may cause a large rotation. The tool must therefore be made to pass through a singular point while avoiding passing near the singular point and to keep the rotary axis from unstable operation by inverting the rotary axis sign. The travel distance and direction of movement of the entire block must be checked for whether the block is supposed to pass through a singular point and, if so, to modify the block command so that the block does so.

4. Tilted Working Plane

The tilted working plane command is used for free machining on a tilted plane. Simply by creating a machining