Study on Construction Method of Geometry Simulation Environment of Eight-axis with Five-axis Linkage Machining Center

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ABSTRACT

In order to solve the machining geometry simulation of an eight-axis with five-axis linkage boring and milling machining center produced by JOBS company in Italy, in this paper, the structure of geometry simulation environment was designed based on the analysis of functional requirements, the geometric constraint relations and motion relations of machine tool was analysed, the machine model, control model and measurement analysis model was built, and the machining geometry simulation environment was established that had the same all functions, characteristics and behaviours with real machine tool. The practical application shows that the simulation environment can factually reflect the static and dynamic characteristics of machine tool; the measurement analysis function can effectively ensure the quality of processing products and the safety of machine tool. The construction method of geometry simulation environment can provide a technology and method reference for constructing numerical control machining geometry simulation environment of other types multi-axis machine tool.

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INTRODUCTION

With product variability in global market and an emerge of sophisticated complex products, manufacturing industry have introduced into multi-axis numerical control machine tools to meet high-efficient, high flexibility, high productivity and high quality machining requirements of complex product, so as to realize the high-end product rapidly developed. Multi-axis numerical control machine tool is usually formed by increasing several rotating axes or moving axes on the basis of three-axis machine tool. Its motion relations are complex [1, 2]. NC program correctness of multi-axis numerical control machine tool is the key to ensure the safety of machine tool and the quality of parts during machining process. In order to verify the correctness of NC program, the traditional method is to repeat a cutting test until NC program is confirmed to be able to complete scheduled processing tasks. This method is not only inefficient and takes up machine resources, but also may cause economic losses in the course of a cutting test by collision or interference [3-5]. So the research on numerical control simulation technology has become an important research field. It is one of the key technologies to set up a numerical control machining simulation environment.

In this paper, taking an eight-axis with five-axis linkage boring and milling machining center produced by JOBS company in Italy as a prototype, and based on VERICUT software, the construction method and technology of geometry simulation environment is studied in order to provide technical support for the realization of numerical control simulation, improving efficiency, reducing costs and ensuring the safety of machine tool.

FUNCTION AND STRUCTURE OF SIMULATION ENVIRONMENT

Function of Simulation Environment

The final goal of constructing simulation environment is to establish a real machining environment, which is used to simulate and evaluate the influence of processing process to the products quality. Therefore, simulation environment compared with real processing environment should have the following functions and characteristics:

• Having the same structure as real machining environment. The machining simulation environment constructed is one-one corresponding relationship to the real machining system. It does not result in distortion or loss of information due to the use of a digital model.
• Having the capability of simulating dynamic operation process of real machining environment. Including workpiece clamping, tool call, operation panel control, and so on related to operation.
• Having the detection function of interference and collision. In machining process, it alarms and alerts for errors including over stroke of machine tool, collision between cutting tool and workpiece, and so on.
• Having data measurement and summary function. It can carry out intelligent measurement and data aggregation of workpiece in simulation environment, and provide analysis data for machining quality.

Structure of Simulation Environment

Simulation environment, which functions and characteristics are synthetically analyzed, is divided into four compositions, namely geometry model, motion model, control model and measurement analysis model. The structure of simulation environment and the contents of each model are shown in Fig.1.

![Diagram of Simulation Environment](image)

**FIGURE 1.** Structure of NC machining simulation environment.

In geometry model, the machine tool, fixture, cutting tool and workpiece is a static model, can be built only by geometry modeling.

In motion model, tool changing and workpiece clamping establishes the relationship between fixture, tool, workpiece and machine tool. And their static geometry models are loaded in machine tool model. The most important is the model construction of axis definition and multi-axis linkage. Building a dynamic machine tool model by assembly constraining the relationship between several motion freedom degrees of machine tool is also the focus of construction simulation environment.

Control model is to complete the format identification of NC code, and drive machine tool to achieve the simulation of NC program.

Measurement analysis model realizes the interference analysis between machine tool, fixtures, cutting tools and workpiece, and the data analysis of material removal.
ANALYSIS OF GEOMETRY RELATIONS AND MOTION RELATIONS OF MACHINE TOOL

The emphasis of simulation environment is to establish machine tool model with geometry model and motion model. Machine tool itself is a hierarchical assembly. The assembly relation is a description of relative position of machine tool components, which reflects the relationship between components, which mainly includes geometry relations and motion relations. The process of building machine tool model is to decompose the entities of real numerical control machine tool according to logical motion relations, and to build simple mathematical models for each component, then to assembly according to logical structure relations. Therefore, analysis of geometry and motion relations of machine tool, is the basis of setting up a dynamic machine tool model.

Analysis of Geometric Constraint Relations of Machine Tool

The eight-axis boring and milling machining center which is produced by JOBS Company in Italy is analysed. The geometric relations of each motion axis are as follows:

Three linear motion axes: X axis, Y axis and Z axis;

The three rotary motion axes: A axis which is formed by cutting tool rotating around X axis, B axis by worktable rotating around Y axis and C axis by cutting tool rotating around Z axis. Among them, A axis and C axis cannot be used at the same time, A axis and B axis or C axis and B axis can be combined use.

Two additional linear motion axes: U axis which is formed by worktable moving along Z axis and W axis by ram moving along spindle. W axis and Z axis cannot be used at the same time.

The geometric constraint relations of each motion axis are shown in Fig.2.

Analysis of Motion Relations of Machine Tool

The geometric relation of machine tool is a reflection of static characteristics. The validation of processing process also needs to be able to show the dynamic characteristics of processing object in a processing
environment. This is necessarily related to the problem of machine tool motion relations. Motion relations describe the motion of each axis in machining process. The most important to five-axis linkage machine tool is that the five motion freedom degrees are strictly defined, and that the corresponding relations are established between machine tool coordinate system $\text{XIZO}$, workpiece coordinate system $X_wY_wZ_wO_w$, tool motion coordinate system $X_sY_sZ_sO_s$, and rotational motion coordinate system $X_rY_rZ_rO_r$, so as to establish a machine tool motion.

The machine tool JOBS is analysed, among its eight axes, A axis and C axis are not used at the same time, Z and W Axis are not used at the same time. Then the combinatorial motion of eight-axis JOBS machine tool can be constituted by three methods:

The first method is that the synthesis motion is composed of X axis, Y axis, Z axis, A axis, B axis and U axis. Among them three linear axes of X, Y and Z and two rotation axes of A and B realize five-axis linkage function. Motion relations are shown in a) of Fig.3.

The second method is that the synthesis motion is composed of X axis, Y axis, Z axis, C axis, B axis and U axis. And three linear axes of X, Y and Z and two rotation axes of B and C realize five-axis linkage function. Motion relations are shown in b) of Fig.3. In order to better demonstrate the motion of C axis, a right angle tool is added to the sketch map.

The third method is that the synthesis motion is composed of X axis, Y axis, Z axis, B axis and U axis. And they realize the five-axis linkage function. Motion relations are shown in c) of Fig.3. In this type motion, Z axis is locked and does not participate in cutting motion, and by W ram movement achieve deep-hole boring processing.

![Diagram](image-url)

a) The first method of motion relations.

![Diagram](image-url)

b) The second method of motion relations.
c) The third method of motion relations.

**FIGURE 3.** Motion relations diagram of eight-axis with five-linkage machine tool.

**CONSTRUCTING SIMULATION ENVIRONMENT**

**Building Geometry Model and Motion Model**

Geometry model is the three-dimensional model of machine tool, cutting tool, fixture and workpiece. The three-dimensional model of tools, fixtures and workpiece is different with different parts, which must be set up in a machine tool model. Because the machine tool model is an invariant environment, it is the key link to build a machine tool geometry model. Due to numerical control machine tool itself contains a lot of components. In order to simplify the model, some components which is independent of simulation, such as: hydraulic system, electrical system, control panel, and etc., can be ignored, not be considered during building geometry simulation model. Each geometry component of machine tool model is built in the UG software environment through three-dimensional modeling. And they are assembled into machine tool by geometric constraint relations.

**FIGURE 4.** Model drawing of machine tool JOBS.

Motion model is to form an abstract machine model according to a certain logical structure relation and motion dependent relation. The model can truly reflect the logical relation and motion relation of each coordinate axis of machine tool, and can be used to reproduce the motion track of machine tool. In the VERICUT software environment, the motion model establishes the motion relations and the coordinate relations between various motion axis, and achieves the machine motion and the linkage relation of various axis.
Fig.4 is the construction machine tool model of JOBS.

**Control Model**

The simulation environment needs to have all functions, characteristics and behaviors of real processing system. Therefore, besides geometry model describing machine tool structure and motion model describing position relations between motion axes, the simulation environment also needs to include a control model of numerical control system [6,7].

First, the control model is to realize code identification, that is, to parse numerical control code, including G instruction, M instruction, variable and subroutine and so on. Another function is the execution of NC programs, namely, under the drive of NC codes, by using velocity planning, acceleration and deceleration control and linkage interpolation algorithm, control model realizes a translation and rotation of motion parts, so as to drive machine tool motion. In the VERICUT software environment, general CNC system files can be called directly, the special control system can also be customized.

**Measurement Analysis Model**

Measurement analysis model include collision interference analysis model and material removal analysis model. Collision detection algorithm of collision interference analysis model is to use a technology of whole process solid scanning to effectively avoid a collision and interference of machining process. Material removal analysis model is that the simulation model after processing is added together the design model to make a precise comparison, so as to check a phenomenon of over cutting and under cutting in the machining process.

In VERICUT environment, collision interference analysis module and material removal analysis module, which software itself has, can be used to measured and analyzed. X-Cliper analysis parts feature size and Auto-DIFF analysis parts overcut and residual [8,9].

**PRACTICAL APPLICATION OF SIMULATION ENVIRONMENT**

The constructed simulation environment has been applied in simulation and analysis of a number of product processing. The blank section before milling and the design model section of a shell parts is shown in Fig.5. Simulation and analysis are carried out to the inner cavity milling in the constructed simulation environment. The simulation results section and material removal and residual analysis are shown in Fig.6.
FIGURE 5. Section drawing of blank model and design model of inner cavity shell.

FIGURE 6. Section diagram of simulation results and material removal analysis.

CONCLUSIONS

According to the function requirement analysis of simulation environment, the structure of geometry simulation environment is designed, the geometry simulation environment of JOBS boring and milling machining center is built, and that is applied in practice, the conclusion is as follows:

• Established geometric constraint relations and motion relations of eight-axis with five-linkage machine tool reflect truly the static characteristics and dynamic characteristics of machine tool. That is the foundation of machining simulation environment.

• Constructed simulation environment of JOBS boring and milling machining center has all functions, characteristics and behaviour of real processing system. The simulation environment provides a technical means to ensure the quality of products and the safety of machine tool.

• The construction method of geometry simulation environment in this paper provides a technical reference and method reference for constructing geometry simulation environment of other types multi-axis machining.

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