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# Digital Twin Modeling of a Five-Axis Linkage Crossbeam Mobile Gantry Milling Machine

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**Abstract.** In the innovative design stage of machine tool (MT), in order to understand the motion status of the MT under different conditions, shorten the development cycle, and improve machining accuracy, this paper proposes a digital twin modeling method for large crossbeam mobile gantry milling machines. By combining digital twin technology, the selection of MT motion components and the design of various motion mechanisms were completed, as well as the machining scheme design of the MT bed. Modeling and simulation were conducted to complete the workpiece machining function, By using digital twin technology to virtually simulate CNC MT and verify their properties in physical prototypes, new ideas are provided for the application of digital twin technology in the design process of CNC MT.

**Keywords.** beam movable gantry MT; Digital twin; Virtual simulation; 3D modeling

## 1. Introduction

The five-axis linkage crossbeam mobile gantry milling machine is a five-axis double swing head (rotary axis and eswing axis) MT suitable for high-speed milling of large and heavy workpieces[1]. As a large-scale CNC gantry milling machine, it has a long machining process and a large gantry span, enabling complex CNC machining without moving the workpiece. However, some factors such as long stroke, large span, and high-speed milling can cause changes in the position of various components of the MT, seriously affecting machining accuracy. Therefore, how to improve the machining accuracy, service life, and production efficiency of gantry milling machines has become the main problem of research.

Digital twin CNC MT are driven by both 3D virtual models and data and achieve practical needs such as simulation, prediction, and optimization through a combination of the virtual and real worlds. The development of digital twin models is the prerequisite for achieving digital twins[2-3]. In the innovative design stage of MT, the

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use of digital twins for virtual simulation and verification of properties in physical prototypes helps to understand the motion status of products under different conditions, shorten development cycles, change the product quality, and accelerate iteration.

In recent years, many scholars at home and abroad have conducted research on the construction of digital twin models. At present, Tao et al.[4]have proposed the "four-formed, four-usable, and eight-usable" construction guidelines for digital twin models to provide theoretical reference for the construction and further implementation of digital twin applications. Wang et al.[5]established a multi-domain model of CNC MT to achieve the model's support capability and effectiveness for virtual commissioning. Xiao et al.[6]realized the virtual-real interaction capability and state monitoring efficiency of MT in three dimensions: geometry, logic, and data. Luo et al.[7]investigated key technologies such as predictive maintenance of CNC MT based on the concept and method of the digital twin.

In summary, the existing research on the system info of digital twin modeling has gradually improved, but the focus of current research is to establish models through digital twins and verify the properties of physical prototypes. By constructing a MT model through digital twins, establishing a control system, and combining virtual machine tools and control systems, the transformation from real MT to real debugging to digital twin machine tools to virtual debugging ensures the correctness and rationality of MT structure design, motion, and control.

This article uses NX 12.0 to design a mechanism model of a five-axis MT, establish a connection between the twin model and the CNC system, and complete a synchronous simulation of digital twin MT.

## 2. General frame of digital twin MT

Taking the five-axis linkage mobile gantry milling machine as an example, by constructing a digital twin MT, the mapping between the virtual environment and the physical world is achieved, and the properties of the physical prototype are verified. The overall framework designed in this article includes five parts: physical MT, digital twin MT, service systems, digital twin data, and connections. A digital twin system is built to simulate CNC MT in a virtual state, as shown in Fig.1.

Physical model (PE) is the foundation for building the digital twin, typically including mechanical systems, CNC systems, and electrical systems. Virtual model (VE) is a digital model that maintains consistency, authenticity and interactivity with physical entity. Virtual MT includes geometric modeling, logical model and data model. Service System (SS) is a service-oriented encapsulation of algorithms and models required for digital twin applications, mainly applied in dynamic process simulation. Digital twin data (DD) is the vital part of the virtual-real interaction between a physical entity and a virtual model, which realizes the dynamic control of analog physics in a virtual state. Connection (CN) is a bridge between virtual systems and physical models, mainly achieving information exchange between various parts of a digital twin system.

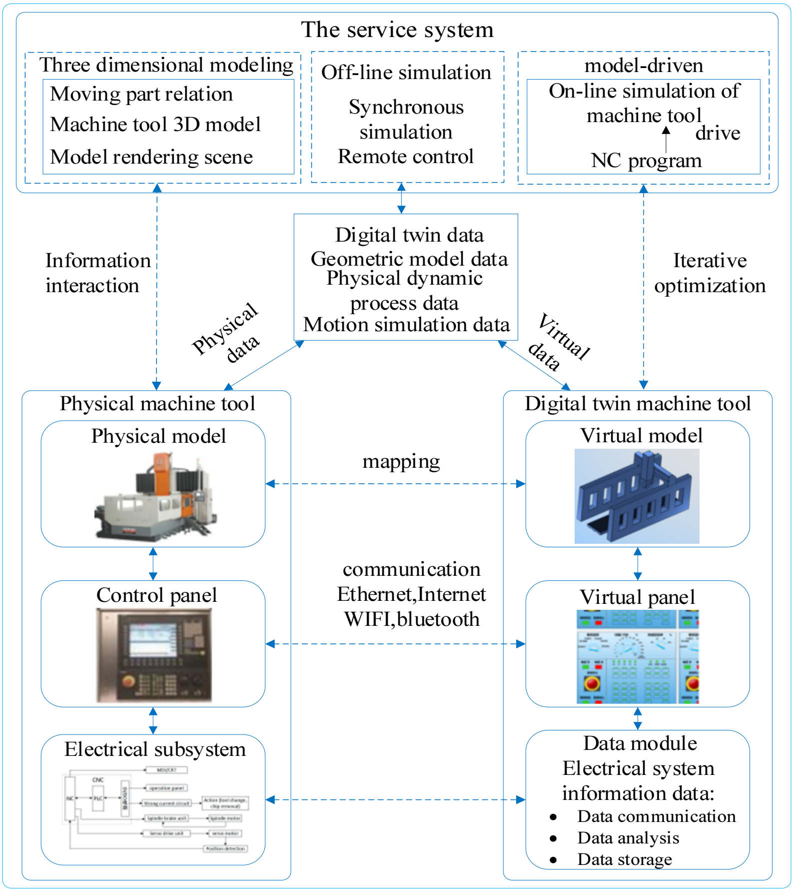


**Figure 1.** Digital twin MT general framework

## 3. Digital twin machine modeling

This article uses NX 12.0 to establish a three-dimensional solid model of each component of a five-axis linkage crossbeam mobile gantry milling machine, and then establishes the topological relationship of each component through a component tree to complete the modeling of a virtual MT. Digital modeling is carried out through the NX MCD platform.

### *3.1 Build a three-dimensional model of the MT*

Determine the key components of the MT and model the components for the X, Y, and Z three translational axes and the A and C two rotational axes of the five-axis linkage crossbeam mobile gantry milling machine. Using the CAD module in NX12.0, establish a virtual model based on the actual dimensions of each component, and assemble according to the actual motion structure of the MT, as shown in Fig.2.

### *3.2 Determine the motion relationship of the MT*

1) Determine the motion relationship of the MT through the motion relationship, direction, and stroke between various part of the MT. Under the NX12.0 MT constructor module, establish a topology structure based on the order of the moving axes of the MT components, as shown in Fig.3.

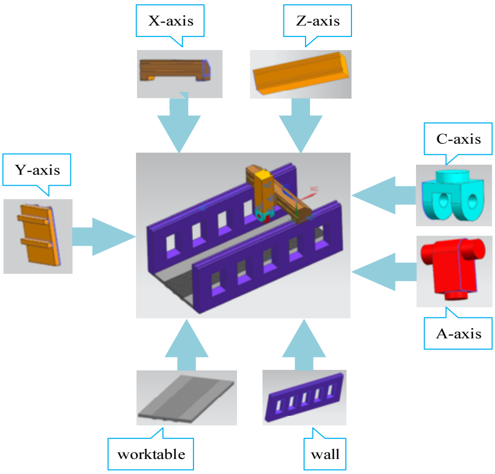


**Figure 2.** Third-dimensional MT

2) Set the limit position parameters for the X, Y, Z, C, and A axes according to the actual travel distance of the MT.

3) Establish a MT project tree. As shown in Fig.4, based on the X-axis movement, the Y-axis adheres to the X-axis, followed by the Z-axis moving on the Y-axis, the C-axis rotating on the Z-axis, and the A-axis swinging on the C-axis.

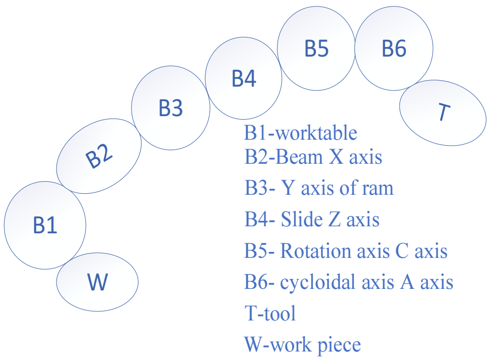


**Figure 3.** MT topology structure diagram

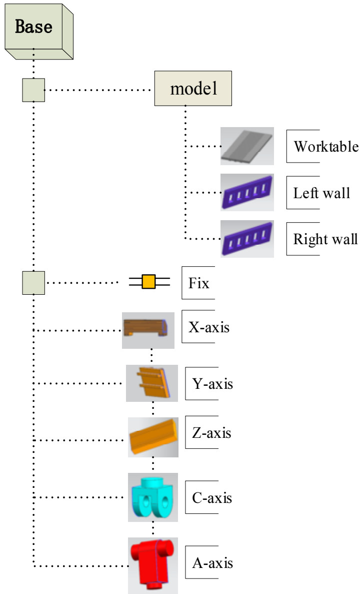


**Figure 4.** MT project tree

### *3.3 Digital twin MT virtual real interaction*

The virtual-real interaction system of CNC MT based on digital twins can achieve digital twin modeling, intelligent monitoring, remote control functions of physical MT, and involve engineering such as mechanical design, electrical design, and automation design, as shown in Fig.5.

### *3.4 Communication connections*

How to combine the two is crucial in the process of realizing the fictional fusion between physical entities and digital twins. Commonly used methods are PROFINET, MATLAB, OPC, PLC, etc, these methods can, to a certain extent, transfer processed data to the digital biosphere to realize synchronized movement and remote control. The control model established by the digital twins in this article in NX12.0 uses the 840D SL controller by connecting to the Profinet communication protocol for the combined deployment of the mechanical movement of the digital twin tool and the MT control system, as shown in Fig.6.

The project uses Step7 for 840D sl logical programming, virtual debugging of IO signal points collection and control, NX12.0 MCD for digital binoculars display, and MT movement simulation authentication. It connects MCD and 840D sl via the Profinet communication protocol.

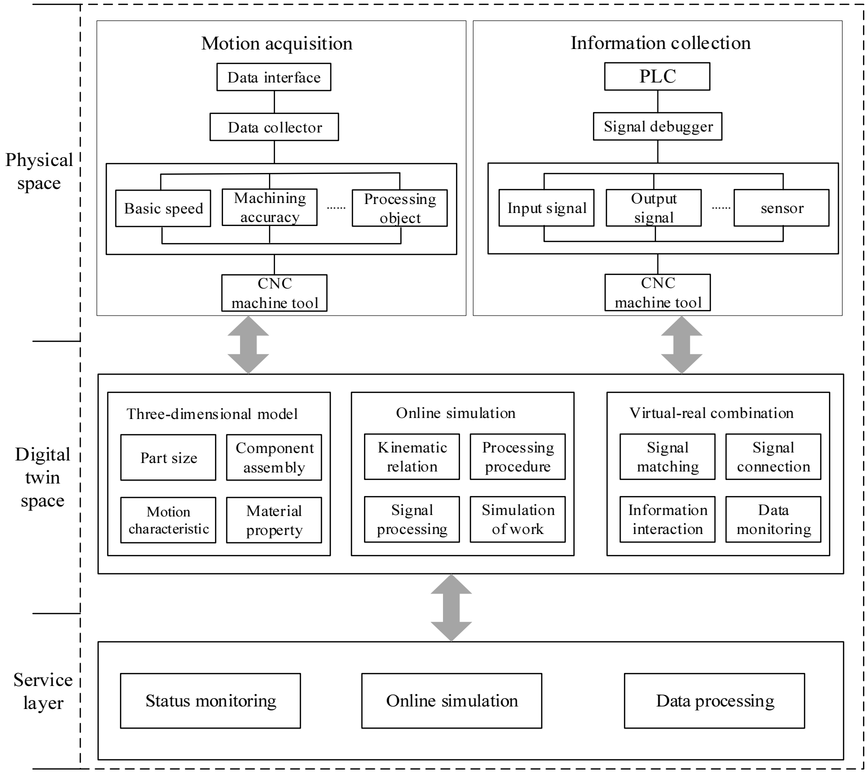


**Figure 5.** Framework for virtual-real interaction systems for CNC MT

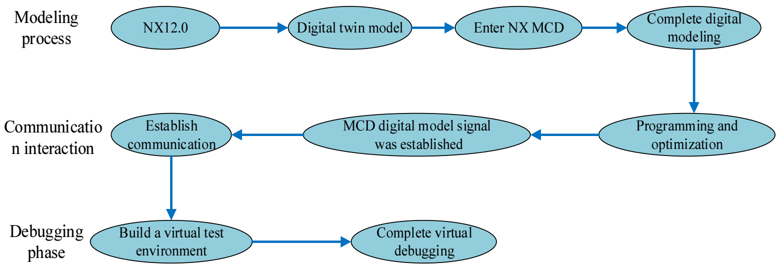


**Figure 6.** False interactive flow map

## 4. Similar operations

To create a blank model, it is necessary to overlap the blank processing zero point with the MT workbench zero point during operation. After completing the MT processing, set the appropriate tool specification, select the appropriate tool size and material, and edit the tool. After completing the tool settings, add a numerical control program to import the compiled G code program for workpiece simulation.

As shown in Fig.7, In a virtual testing environment, dynamic simulation of virtual MT machining processes can be achieved, and the correctness of CNC programs and MT paths can be verified. At the same time, the development cycle can be shortened, product quality can be changed, and technical support can be provided for the virtual simulation of other multi-axis machine tools of the same type.

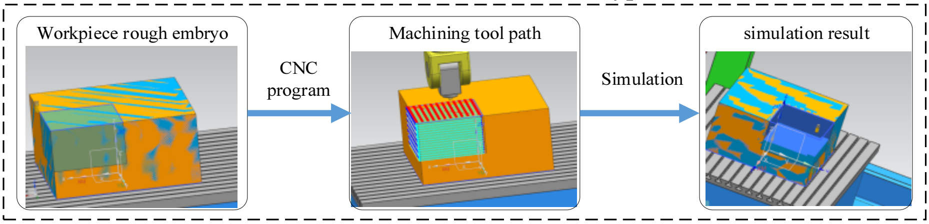


**Figure 7.** Simulation process

## 5. Conclusion

This article is mainly aimed at the virtual modeling and simulation experiments of crossbeam mobile gantry milling machines, providing new ideas and technical support for the MT design process combined with digital twin technology. By completing the selection of the moving parts of the MT, the design of each moving mechanism, and the design of the machining scheme of the MT bed, and conducting simulation, the machining function is realized. However, there are shortcomings in the electrical and control aspects, so we will carry out related work on this basis in the future, and further research on deep integration technology between physical MT and virtual systems to achieve optimization of MT design accuracy, fault prediction, and other functions. It provides a new idea and technical support for the integration of digital twin technology in the design phase of MT.

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