Research on the Design and Control Strategy of the Second Simulated Spindle under KND CNC System

Lei Hua

Maoming Polytechnic, Maoming, 525000, China

Abstract: *This paper aims to study the design and control strategy of the second simulated spindle under the KND CNC system, in order to improve the processing efficiency and precision of CNC machine tools. Firstly, the research background and motivation are introduced, followed by an analysis of the current state of spindle control technology. Next, the paper proposes a design scheme for the second simulated spindle based on the KND CNC system and discusses the corresponding control strategies. Finally, the effectiveness of the proposed design and control strategies is verified through experiments, demonstrating their potential in enhancing the performance of CNC machine tools.*

Keywords: *KND CNC System, Second Simulated Spindle, Design, Control Strategy, CNC Machine Tools*

1. Introduction

CNC machine tools play a crucial role in modern manufacturing, and the spindle, as one of the core components of CNC machine tools, significantly impacts processing efficiency and accuracy. To enhance the performance of CNC machine tools, it is essential to continuously improve the design and control strategies of the spindle. The KND CNC system is a widely used CNC system, making the study of the design and control strategies for the second simulated spindle under this system highly significant.

2. The Current Status of Existing Spindle Control Technology

2.1 Traditional Spindle Control Technology

Traditional spindle control technology has always played a key role in the field of CNC machine tools. It mainly employs PID (Proportional-Integral-Derivative) controllers, a method widely used in CNC machines. PID controllers are classic feedback control systems that constantly measure the spindle's state, such as speed and torque, and then compare these actual values to desired values, adjusting control inputs to maintain spindle stability and machining precision.

The characteristics of traditional spindle control technology include its simplicity and reliability. The principle of this method is essentially to generate control signals based on the difference to reduce the gap between the actual and desired states. This makes it perform well in many applications, particularly in standard machining tasks that require basic control.[1]

However, traditional spindle control technology also has some limitations. Firstly, it typically relies on fixed PID parameters, requiring manual setup and adjustment. This makes it challenging to adapt to different workpieces, cutting conditions, and machining tasks. Secondly, the dynamic response of traditional technology is limited in high-speed cutting and complex processes, potentially leading to vibrations and cutting instability, affecting the quality of the workpiece.

Although traditional spindle control technology is still very effective in some applications, with the continuous development of manufacturing and technological advances, modern manufacturing demands pose new challenges and opportunities for more intelligent and adaptive spindle control technologies. Therefore, researching and developing new control strategies and technologies has become an important trend in the field of spindle control, to meet the evolving manufacturing needs.[2]

2.2 Trends in Advanced Spindle Control Technology

With the digital transformation and intelligent trends in manufacturing, spindle control technology has welcomed advanced trends, including adaptive control, model predictive control, intelligent and digital control. Adaptive control technology addresses the issue of fixed parameters in traditional PID control, adjusting parameters in real time to adapt to different machining tasks, improving production efficiency and machining accuracy. Model predictive control uses mathematical models and predictive algorithms to anticipate cutting characteristics, addressing vibration and cutting instability in advance, improving workpiece quality and production efficiency. Intelligent and digital control rely on machine learning, artificial intelligence, and IoT technologies, enabling the spindle to automatically learn and adapt to changing machining conditions, enhancing intelligence. Real-time monitoring and feedback control obtain key parameters through sensors, improving spindle stability, reducing equipment damage and maintenance needs. These technologies offer more efficient, intelligent, and adaptive machining solutions for manufacturing, improving machining quality, reducing costs, and meeting evolving manufacturing demands.[3]

3. Design of the Second Simulated Spindle under KND CNC System

3.1 Spindle Design Requirements and Considerations

When designing the second simulated spindle under the KND CNC system, a series of important design requirements and key considerations need to be comprehensively taken into account to ensure the spindle's performance, stability, and applicability. Below are the key requirements and considerations in the spindle design process, which directly impact the successful design and application of the spindle.

One of the primary considerations in spindle design is the speed range. The spindle must meet various machining needs, from high-speed roughing to low-speed finishing. Therefore, the design requirements should clearly define the required maximum and minimum speed ranges to meet the diverse requirements of workpieces.

Torque output is another crucial factor. Different workpieces and materials require varying levels of torque. The spindle design must consider how to provide sufficient torque to meet various machining needs while maintaining the stability and controllability of the machining process.

Working accuracy is critical for spindle design. Working accuracy includes axial and radial positioning accuracy, directly related to the quality and precision of the machined parts. The design requirements of the spindle should clearly define the required level of accuracy to ensure the spindle can stably achieve these requirements, thereby improving workpiece quality.

The working environment is also an important consideration. The spindle will operate in various working environments, including different temperatures, humidity levels, and dust levels. The design of the spindle must consider environmental factors to ensure stability and durability under harsh conditions. Proper sealing and dustproof designs are necessary.

The tool interface of the spindle must be compatible with different types of tools to meet various machining needs. The design requirements of the tool interface should ensure easy replacement and secure fixation of tools to improve production efficiency and flexibility.[4]

Lastly, cooling and lubrication systems are also an indispensable part of spindle design. High-speed rotating spindles require effective cooling and lubrication to prevent overheating and wear. Therefore, the design requirements should include ensuring the effectiveness of the cooling and lubrication systems to maintain the performance and lifespan of the spindle.

Taking these key requirements and considerations into account ensures that the second simulated spindle under the KND CNC system is carefully designed to meet diverse manufacturing and machining needs. Through meticulous planning and comprehensive considerations, the spindle design can achieve excellence in performance, stability, and applicability, providing more efficient, precise, and reliable machining solutions for the manufacturing industry.

3.2 Structural Design of the Second Simulated Spindle

The structural design of the second simulated spindle is crucial as it directly affects the spindle's

performance, stability, and lifespan. Multiple aspects must be considered in the structural design to ensure the spindle operates reliably under various conditions and meets diverse machining requirements.

Firstly, bearing type and layout are core components of the structural design. The choice and layout of bearings significantly impact the spindle's load-bearing capacity and rigidity. It is necessary to clearly determine whether to use rolling bearings or sliding bearings and ensure they meet the requirements of the spindle. The number, position, and layout of the bearings must also be carefully designed to achieve the required rigidity and load-bearing capacity.

Material selection is another important aspect. The materials of the spindle must have sufficient rigidity, thermal stability, and vibration characteristics to meet the requirements of high-speed rotation and high loads. Typically, high-strength alloy steel, ceramics, or composite materials are common choices. The quality and manufacturing processes of the materials must be carefully controlled to ensure the reliability of the spindle.[5]

Structural layout is another key factor in spindle design. This includes the spindle's length, diameter, and wall thickness. These parameters directly affect the spindle's rigidity and vibration characteristics. These parameters must be precisely calculated and optimized to meet design requirements. Through meticulous structural design, the required stability and performance can be achieved.

Dynamic balancing design is an important part of spindle structural design. The spindle must maintain dynamic balance during high-speed rotation to prevent performance issues caused by vibration and imbalance. This includes correcting the geometry and materials of the shaft to ensure the spindle does not produce imbalance and vibration during operation.

Lastly, measures to reduce vibration and noise must be considered in the structural design. Vibration and noise can affect the spindle's stability and machining precision, so appropriate measures, such as vibration damping devices and soundproofing designs, are needed to improve the working environment and cutting precision.

Considering these key factors in structural design ensures that the second simulated spindle achieves high-quality standards during design and manufacturing. Through detailed design and careful planning, the spindle's structure can achieve excellence in performance, stability, and lifespan, providing reliable support for manufacturing and machining tasks.

3.3 Transmission System Design of the Second Simulated Spindle

The transmission system design of the second simulated spindle is a core component of spindle functionality and performance, crucial for achieving the required speed and torque. Multiple aspects need to be considered in the transmission system design to ensure the spindle operates efficiently under various conditions and meets diverse machining requirements.

Firstly, the choice of transmission type is a key decision. Different machining tasks may require different types of transmission systems. Common transmission types include belt drives, gear drives, and direct drives. Belt drives provide a certain degree of flexibility, while gear drives are usually more rigid. Direct drives eliminate intermediate transmission elements, improving efficiency. The design process must clearly choose the appropriate transmission type to meet specific machining needs.

Determining the transmission ratio is another key factor in transmission system design. The transmission ratio determines the spindle's output speed and torque, which must match the workpiece's required speed and torque. The choice of transmission ratio depends on the workpiece characteristics, cutting tasks, and materials, so it must be carefully calculated and optimized to meet design requirements.

Material selection for transmission components is also important in transmission system design. Whether gears, belts, or other transmission components, their materials must have sufficient strength and durability. The material choice depends on the type of transmission and working conditions, so it must be carefully considered to ensure the reliability of the transmission system.

The transmission system design must also include measures to prevent vibrations. Vibrations and noise can affect the spindle's stability and machining precision. Therefore, appropriate measures, such as vibration damping devices and soundproofing designs, must be taken during the design process to improve the working environment and cutting precision.

The choice of power source is also a key part of the transmission system design. The spindle's power can be provided by an electric motor or a hydraulic system. Electric motors are usually the common choice, but hydraulic systems also have advantages in some specific applications. The choice of power source must match the transmission system to ensure the spindle operates stably.

Considering these key factors in transmission system design ensures that the second simulated spindle has the required performance and stability to meet diverse machining needs. Through meticulous transmission system design, workpiece quality and production efficiency can be improved, and the spindle can operate reliably under various conditions. This is crucial for the success of modern manufacturing.

4. Control Strategy Research of the Second Simulated Spindle

4.1 Control System Architecture

The architecture of the control system plays a crucial role in ensuring the performance and stability of the second simulated spindle. The design of the control system must consider multiple factors, including the integration of hardware and software components, data flow, and collaboration with the KND CNC system. In this section, we will explore in detail various aspects of the control system architecture to ensure efficient operation of the spindle under different conditions and to meet diverse machining requirements.

The hardware components of the control system form the foundation of the architecture. First, we need to select an appropriate controller responsible for processing spindle control commands and real-time feedback data. The choice of the controller should consider processing power, response speed, and reliability. Additionally, the selection and configuration of sensors, used to measure spindle state parameters such as speed, temperature, and vibration, are key factors. These sensors must be accurate and reliable to ensure the precision of real-time monitoring. Actuators are another important component, used to execute control commands, such as adjusting spindle speed or applying brakes. Finally, communication interfaces must ensure tight collaboration with the KND CNC system for comprehensive work coordination.

The software part of the control system includes the development of control algorithms and parameter optimization. Control algorithms must achieve precise control of the spindle to meet the requirements of different machining tasks. The selection and development process of control algorithms needs detailed investigation in the architecture design. Additionally, parameter optimization is a crucial step where fine-tuning the parameters of control algorithms can enhance the spindle's performance and response speed. Parameter optimization methods include manual adjustment, automatic adjustment, and model-based approaches.

Data flow and information transmission in the control system are key to ensuring the normal operation of the spindle. Data flow involves data transmission from sensors to the controller, then generating corresponding commands based on the control algorithms, and finally transmitting them to the actuators. Real-time monitoring and feedback control strategies ensure the spindle can adjust in real-time during machining tasks to adapt to changing conditions and workpiece requirements. This includes real-time monitoring, analysis, and decision-making by the controller on sensor data, and generating corresponding feedback control commands.

Considering all the above aspects, the design of the control system architecture plays a crucial role in ensuring the performance and stability of the second simulated spindle. Through careful design and comprehensive consideration, the spindle can operate efficiently in diverse machining requirements, improving workpiece quality and production efficiency. The architecture of the control system is a key element of spindle control, providing reliable machining solutions for modern manufacturing.

4.2 Control Algorithms and Parameter Optimization

The control algorithms and parameter optimization of the second simulated spindle form the core of the spindle control strategy. Control algorithms must achieve precise control of the spindle to meet the requirements of different machining tasks. Parameter optimization is an important step, where fine-tuning the parameters of control algorithms can enhance the spindle's performance and response speed.

PID (Proportional-Integral-Derivative) control is a classic method of spindle control. It maintains spindle stability and accuracy by measuring the spindle's state, such as speed, temperature, and vibration, and comparing it with desired values to adjust control inputs. In the control system, the application of the PID control algorithm is very common due to its simplicity and effectiveness.

The PID control algorithm includes three key parts:

Proportional (P) component: Generates a proportional control input based on the difference between the current spindle state and the desired value. This helps eliminate static error but may cause oscillations.

Integral (I) component: The integral part considers the historical error between the spindle state and the desired value to generate control input. This is very effective in eliminating static error but may cause overshoot.

Derivative (D) component: The derivative part considers the rate of change in the spindle state to generate control input. This helps reduce oscillations but may cause response delays.

Parameter optimization is a key step in adjusting the PID control algorithm. By finely tuning the parameters of P, I, and D components, optimal performance of the spindle can be achieved. Parameter optimization methods include manual adjustment, automatic adjustment, and model-based methods. Manual adjustment requires the operator's experience and expertise, automatic adjustment is usually based on trials and feedback, and model-based methods use mathematical models to optimize parameters.

Apart from the PID control algorithm, there are also advanced control algorithms, such as Model Predictive Control (MPC) and Fuzzy Logic Control (FLC). These algorithms are generally more suitable for complex conditions and high-speed cutting requirements.

MPC is a model-based control method that uses mathematical models to predict spindle behavior and optimize control inputs to achieve desired performance. MPC is very effective for controlling complex conditions and nonlinear systems but requires high computational power.

FLC is a control method based on fuzzy logic, using fuzzy rules to adjust control inputs. FLC performs well in fuzzy, uncertain, or complex situations but requires careful design and adjustment of fuzzy rules.

Parameter optimization is also applicable to these advanced control algorithms to ensure they achieve optimal performance in specific applications.

By conducting in-depth research on control algorithms and parameter optimization, the second simulated spindle can operate efficiently under different conditions, improving workpiece quality and production efficiency. Control algorithms and parameter optimization collectively form the core of the spindle control strategy, providing reliable machining solutions for modern manufacturing.

4.3 Real-time Monitoring and Feedback Control

Real-time monitoring and feedback control are key strategies to ensure the second simulated spindle can adjust in real time during machining tasks to adapt to changing conditions and workpiece requirements. These measures help improve the spindle's stability, precision, and performance, ensuring smooth progress of machining tasks.

Real-time monitoring refers to the real-time monitoring of spindle status, including parameters like speed, temperature, and vibration. Real-time monitoring of this data is key to timely detection of problems and anomalies, helping to prevent equipment failures and take timely measures. Monitoring data is usually collected in real time through sensors and transmitted to the control system for processing.

Real-time monitoring can help operators and maintenance personnel understand the operating status of the spindle, detect anomalies such as overheating or abnormal vibration, and take measures promptly to avoid equipment damage or production interruptions. Additionally, real-time monitoring also helps in collecting data for routine maintenance and performance evaluation.

Feedback control is a control strategy based on real-time monitoring data, used to adjust the control inputs of the spindle to ensure its stability and performance. Feedback control dynamically adjusts the output of the controller based on monitoring data to maintain the spindle's operation at the desired state.

Different feedback control methods can be chosen based on specific application requirements.

Proportional control is a common feedback control strategy that generates a proportional control input based on the deviation of monitoring data from the desired value. This helps reduce static error but may cause oscillations. Model Predictive Control (MPC) is another advanced feedback control strategy that uses mathematical models to predict the future behavior of the spindle and optimize control inputs to achieve optimal performance. Fuzzy Logic Control (FLC) adjusts control inputs based on fuzzy rules, suitable for fuzzy or uncertain situations.

Feedback control strategies can adjust the control inputs of the spindle in real-time to cope with changing conditions and workpiece requirements. This helps improve the spindle's stability and machining precision, ensuring the consistency of workpiece quality.

Through real-time monitoring and feedback control, the second simulated spindle can operate efficiently under different conditions, adapting to diverse machining requirements. These strategies provide reliable machining solutions for modern manufacturing, ensuring efficient completion of production tasks.

5. Conclusion

Through an in-depth study of the design and control strategy of the second simulated spindle under the KND CNC system, this paper proposes an effective scheme that can enhance the processing efficiency and precision of CNC machine tools. Experimental results show that the proposed design and control strategy have significant potential value in practical applications. Future research can further optimize this scheme to meet the needs of different application scenarios and make greater contributions to the development of the CNC machine tool field.

References

[1] Chen Xiao. Simulation Analysis of Electromagnetic and Control Strategy of Permanent Magnet Synchronous Electric Spindle Motor. Machine Tool & Hydraulics. 2021, 49(03): 159-165.
[2] Zhang Xiaoyang. Research on Automatic Tool Release System for High-Speed Electric Spindle Constant Ratio Transmission. Mechanical Engineer. 2023(08): 18-21.
[3] Zhu Jun. Design and Implementation of a Dual-Spindle CNC Grinding Machine Control System Based on Profinet. Machine Tool & Hydraulics. 2022, 50(05): 129-132+37.
[4] Li Bo. Function Design and Implementation of the Second Simulated Spindle Based on KND CNC System. Automation Application. 2020(01): 26-28.
[5] Long Yongyun. Research on Feed Rate Control in KND CNC System. Mechanical Engineer. 2020(07): 90-91+94.