# Electric control system of numerical control machine tool based on PLC

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**Abstract.** In order to explore the advantages and disadvantages of electric control system of numerical control machine, the electric control system of numerical control machine is first of all designed. Firstly, the overall design scheme of electric control system is set up in accordance with the requirements of electric control system. In addition, through the calculation of electric load, the electric parameters of electric components are determined, which is convenient for the choice of types and wire of electric equipment. At the same time, the electric control system of main equipment is designed, focusing on the design of spindle, feed shaft, and PLC module. At last, the automatic tool setting control system is discussed, doing some preliminary work for realizing automatic tool setting in the future. The results showed that the electric control system has high accuracy and reliability. And it can be concluded that the electric control system can be widely applied in microelectronics, computer and so on fields.

**Key words.** Arduino, wireless sensing, network node.

## 1. Introduction

The performance of the control system is decided by the advantages and disadvantages of electrical control mode of CNC machine tools. A machine tool is essentially an electromechanical energy conversion device whose function is to convert electrical energy into mechanical energy required for processing. Therefore, the distribution and management of electrical energy is the energy guarantee of machine tools, and it plays a role similar with the heart in machine tools. The electrical control system of machine tools includes machine tool power supply and distribution system, spindle control system, feed shaft control system, cooling oil pump control system and other auxiliary equipment control systems. The introduction of electrical control, especially the electrical switching control, is a major improvement. In this paper, it mainly used to control cooling motors, oil pumps motors, and other auxiliary electrical control systems. It is applied to replace relay - contactor control system, which improves the reliability and flexibility of the system, resulting in a qualitative leap in control performance [1].

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Digital control technology refers to the technology making use of digital information to control. The machine tool which uses digital information to control the movement and machining process of machine tools is called NC (numerical control) machine tool. It is the product of the combination of digital control technology and machine tools. CNC machine is a typical mechatronic product, and it is a set of modern machinery manufacturing device with high efficiency, high precision, high flexibility and high automation, which integrates modern machinery manufacturing technology, automatic control technology, detection technology, and computer information technology [2]. It is the same as other mechatronic products, which is also composed of mechanical body, power source, electronic control unit, detection sensor part and executive machine (servo system)

# 2. Method

## 2.1. Overall design scheme of electrical control system for NC machine tools

In the CNC machine tools, the overall program of electrical control is shown in Fig. 1. ARM9 is used as the main control system, and DSP+FPGA acts as the motion controller and the core of servo drive, and PLC is used as the control core of the electric auxiliary system [3].
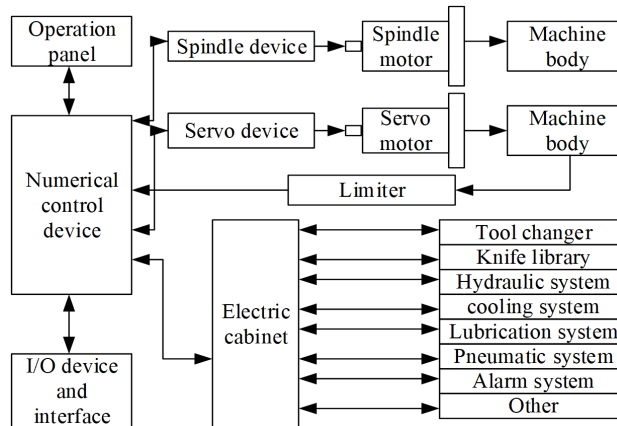
Fig. 1. Scheme of auxiliary electric control system

## 2.2. Control requirements of electrical control system for NC machine tools

This CNC electrical control system requires to realize the following movements and controls:

Overview of spindle control requirements: to realize the spindle motor start, stop, speed change, and speed control; require the smooth spindle speed, fast acceleration and deceleration response, low speed torque, overload ability and so on.

Overview of feeding shaft control requirements: $X, Y, Z$ axes have each servo motor drive, requiring the shaft to achieve speed and corner control. Precision requirements: repeat positioning accuracy is $\pm 0.005$ mm, and the positioning accuracy is $\pm 0.001$ mm; fast speed requirements: good acceleration and deceleration, relatively smooth three axis, good following performance; requirements for satisfying the requirement of stability with the fastest speed: small vibration, strong anti-interference ability and so on.

Auxiliary control: to realize the control of hydraulic pump, lubricating motor, automatic tool setting, cooling pump motor, and fan motor; system emergency stop and station limit protection; signal control of machine running state.

The main electrical rated load of this CNC machine tool is: voltage: three-phase 380 V, current: 40 A, power: 10 kW, and frequency: 50 Hz. The limit of the electrical parameter is 1.5 times of the rated load. The rated torque of the spindle is 25 Nm, the rated torque of the $X, Y$ and $Z$ axes is 11.5 Nm, and the rated torque of the shaft is 18 Nm.

## 2.3. Main functions of the motion controller module

The block diagram of the motion controller system is shown in Fig. 2. Its function is: receiving the interpolation and control signal after main controller decoding and compiler information processing, for speed processing and linear and circular interpolation operation. And by comparing the position and speed feedback signal with all kinds of servo systems, it thereby generates the interpolation direction and pulse to the servo system [4].
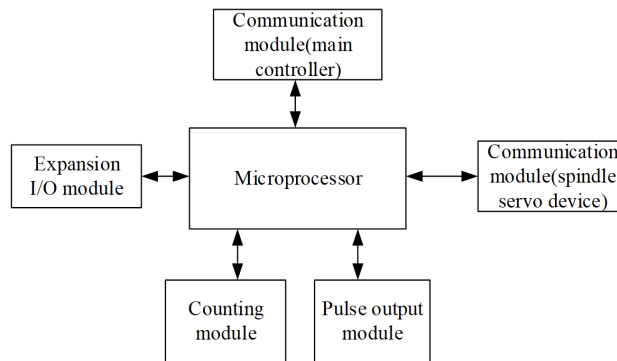


Fig. 2. Block diagram of motion controller system

Microprocessor module: according to the function number and so on information obtained by the main controller decoding, the acceleration and deceleration control and the precise interpolation calculation of the line and arc are performed. Encoder decoding module: decoding is carried out on the received encoder signal and the decoded structure is passed to the counter for counting processing to obtain the position information of the motor. Pulse output module: the interpolation pulse and direction are generated to the servo system according to the result of micro processing interpolation to control the rotation of the motor. Communication module: through

the MAX3490 bus and the main controller for full duplex communication, function number and other control information after the host computer decoding are received, and relative coordinates and absolute coordinates information are sent to the main controller. Extended I/O module: I/O port is reserved to facilitate connection with auxiliary equipment, such as lubrication mechanism, hydraulic system, limit switch and other I/O equipment.

## 2.4. Functions of PLC in the electric control system

PLC (programmable logic controller) is commonly used for automatic control of equipment, which uses replacing the relay control circuit to realize the control function of CNC machine tools. The significant performance lies in its control function with a high degree of flexibility. In the permission scope, NC axis configuration control signal changes the control signal of auxiliary feed shaft, which can control machine operation panel signal and interface switch control. And only by changing the programming can it make the appropriate configuration efficient immediately, and the same numerical control system can be flexibly applied to CNC machine tools with different configurations [5].

PLC is used in numerical control machine tools, mainly for the auxiliary electrical control of the periphery of machine tools. It is also called programmable machine tool controller, referred to as PMC.

The realization of the control of machine tool auxiliary equipment (including cooling system, lubrication system, lighting system, tool change system, automatic tool setting, control panel and so on) is accomplished. The peripheral circuit (strong circuit) cannot be directly connected with each other, so the peripheral circuit must be converted through the relay loop in the middle [6]. The entry must be converted into a weak signal, and for controlling the peripheral circuit, the output weak signal must be converted into a strong signal.

## 3. Design of electrical control system for main equipment

### 3.1. Design of electric control system for spindle motor

Spindle control requirements are: the spindle speed is stable, acceleration and deceleration response is fast, low speed torque is large, and the overload ability is strong and so on [7]. Machine spindle is generally used to provide power for the processing of machine tools. The NC machine model is lokson650 vertical machine tools, so it is spindle drive cutting work-piece rotation. The spindle drive uses the closed loop vector control mode with Yaskawa inverter as the core, and the incremental photoelectric encoder as the feedback as spindle speed meter [8]. The frequency converter and system communication adopt RS485 bus.

## 3.2. Electric control design of feed shaft

This type of numerical control machine tool is a half line rail machine tool, that is to say, one shaft adopts the line rail, and the other shaft adopts the hard rail. Feed shaft using the line rail has small contact surface with mechanical body, the friction is small, the resistance is small, and the load capacity is relatively light, generally used for light load cutting, machining metal parts, auto parts and other products [9]. While the feed shaft using hard rail has rough surface, the friction is large, the resistance is large, and the load capacity is strong, can be used for processing heavy cutting, which is generally used for processing mold products. The machine adopts half line rail, and its use is a product between the two, mainly used for processing hardware, auto parts, small molds and other products. Therefore, the cutting requirements are divided into: feed shaft requirements and spindle requirements, and we focus on the feed requirements: accuracy requirements: the repeat positioning accuracy is $\pm 0.005$ mm, and the positioning accuracy is $\pm 0.001$ mm [10]. Fast speed requirements: good acceleration and deceleration, relatively smooth three axis linkage, and good following performance. The average processing progress per second is 20 cm/min, and the fastest can reach 1 m/min. Stability requirements: small vibration, anti-interference ability and so on.

## 3.3. Design of PLC module

Lubrication system of auxiliary electric control system of this system has two inputs and two alarm outputs; cooling system also has two inputs and two alarm outputs; automatic knife has 6 inputs and 6 alarm outputs; lighting and signal lamp system has 1 input and 4 outputs; ATC (Automatic tool cutting) system has 5 inputs and 5 outputs. As a result, in the choice of PLC, taking into account the leave of 1/3 allowance, we use Huichuan's PLC [11]. It has 24 inputs and 15 outputs. The scanning frequency is up to 1000 Hz, which fully meets the requirements.

# 4. Result and discussion

The automatic tool setting needs to set the cutter parameters, including the center of length tool detection head and the radius tool detection head, the radius length and height between the center of length tool detection head and that of the radius tool detection head. These parameters must be sure to be correct; otherwise, in the tool setting process, it will easily lead to crash tool presetting instrument [12]. After manually changing the cutter, the user shall remove the tool mark corresponding to the cutter number, and avoid the tool setting instrument because of the misoperation of the user (for the re-setting tool, see Fig. 3).

The length manual cutter and the radius manual tool cutting process have the locking axis direction, which is related to the mode of the installation position of the tool setting instrument. The radius too cutting needs to determine the close direction of the tool detection. The step system will be automatically set in processing the standard cutter, and the user does not need to participate in, to avoid misoperation.
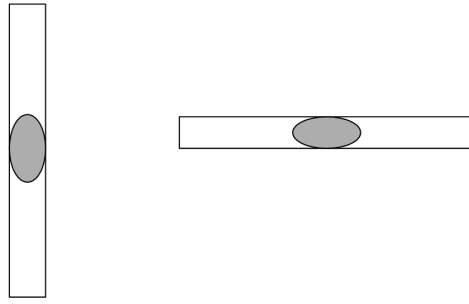
Fig. 3. Mode (1) and mode (2) of cutter installation

### 4.1. Manual tool setting principle of tool length

(1) Correctly set the parameters of the tool setting tool, the safe position of the cutter, the tool length and the function of the tool setting.

(2) Enter the electronic hand-wheel mode and choose the tool positioning function. The system will be positioned to the security tool in the current position, and then positioned to the center of the length cutter detection head. In the process, the electronic hand-wheel pulse will automatically disappear [13].

(3) Shake the electronic hand-wheel to move the tool head close to the length tool detection head (suggested here). This process can move the non locking shaft.

(4) Press the tool locking function, and then the system will make the electronic hand-wheel gear locked in the file, while telling the locking tool point.

(5) Shake electronic hand-wheel, to make the cutter head slowly contacting the length tool detection head, locking tool parameters (including $X, Y, Z$ and $A$, four parameters). ARM will store four parameters, and if the standard cutter parameters have been already set. ARM will automatically calculate the cutter tool length compensation value and store to the corresponding cutter number. Finally, $A$ means Auxiliary control, to realize the control of hydraulic pump, lubricating motor, automatic tool setting, cooling pump motor, and fan motor.

(6) Shake the electronic hand-wheel, to make the tool head lift, slowly get away from the length tool detection head, and push out the cutter tool locking function.

### 4.2. Automatic tool setting control principle of tool length

(1) Correctly set the parameters of the cutter tool setting, the safe position of the cutter, the tool length and the function of the tool setting.

(2) Ensure that the reference knife parameters have been correctly set, the cutter number is correct, and the length is manually or automatically adjusted.

(3) Enter the electronic hand-wheel mode or manual mode and select the length setting function. The system will be positioned to the security tool in the current position, then positioned to the center of the length cutter head, and to the locking value of the cutter tool. In this process, the electronic hand-wheel pulse will automatically disappear, and the manual button mobile function will be screened. If the

system opens knife angle positioning function, it also need to position the spindle.

(4) The system locates the tool head above the locking value $Z$ of the tool point of the cutter number [14].

(5) ARM tells DSP to lock the tool point. The system locates the tool head above the locking value Z of the tool point of the cutter number.

(6) The tool head slowly contacts the length tool detection head, and DSP locks the cutter tool point parameter. ARM will store these four parameters, and automatically calculate the tool length compensation value and store it to the corresponding cutter number.

(7) The cutter head lifts the locking point, and slowly gets away from the length tool head. The tool head is raised to the tool safety point $Z$, and the tool locking function is introduced.

## 5. Conclusion

Manufacturing is an important cornerstone of human economic activity, as well as the motive force of human historical development and civilization progress. The level of manufacturing is an important indicator of the degree of industrial development in a country. The manufacturing industry, represented by the traditional electromechanical industry, is undergoing profound changes. Modern science and technology, especially the rapid development of microelectronics, computer, information and other science and technology, and its wide application in all walks of life, have brought profound changes to the machine building industry. In this paper, the electrical control system of NC machine tools is deeply studied and analyzed. An electric control system is designed and installed to satisfy the requirements of high speed, high precision, high reliability and intelligence of NC machine tools. The electrical control system of CNC + PLC + external electric appliance is adopted, and the control system of the main equipment is designed, in which the control of spindle motor, $X, Y, Z$ axes control, and the design of PLC module are mainly described. In addition, at the end of the thesis, the tool setting control system is designed.

In the CNC machine tools, the overall program of electrical control is shown in Fig. 1. ARM9 is used as the main control system, and DSP+FPGA acts as the motion controller and the core of servo drive, and PLC is used as the control core of the electric auxiliary system [3].

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