Research on Position Control of Mechanical Numerical Control Machine Tool Based on Action Orientation

Liyuan Liu, Ping Wang

Yantai Vocational College, Yantai, Shandong 264670, China

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Abstract: In order to overcome the defects of the conventional full closed-loop position control system, it is necessary to break the shackles of the traditional theory of constructing a full closed-loop position control system based on the speed inner loop. The traditional single-machine mode has been difficult to meet the needs of the current economic development due to its high cost, backward technology and low production efficiency. For the numerical control turntable which uses worm gear and worm gear pair as the deceleration and indexing execution components, the pitch error values are quite different when moving in the same coordinate interval in the forward and reverse directions. Based on action orientation, this paper studies the position control of mechanical numerical control machine tools, systematically discusses the characteristics of the existing methods for improving the spatial positioning accuracy of mechanical numerical control machine tools and the problems to be solved.

1. Introduction

When the NC machine tool is required to have complex curve and curved surface processing capability, it must be equipped with a rotating shaft, and the NC rotary table is a direct component to complete the rotary feed function on the NC machine tool. Its function is to synchronize the machine tool with the control system and establish the starting point [1] for measuring the movement coordinates of the machine tool. Especially in the process of machining complex thin-walled structural parts, the phenomena such as dimension deviation and surface corrugation are easy to occur, which seriously affects the machining quality of the parts. Therefore, based on the domestic reality, accelerate the development of domestic high-precision CNC machine tools with strong competitiveness, and continuously expand the market share [2]. In view of this, document [3] proposes a tool head guiding control for machining based on the automatic measurement method of vision guiding theodolite. At present, due to factors such as high cost and difficult installation of feedback elements, full closed-loop control is less used and semi-closed-loop control is more used. Due to high cost, backward technology and low production efficiency, the traditional stand-alone mode has been difficult to meet the needs of economic development at this stage. Based on action orientation, this paper studies the position control of mechanical numerical control machine tools, systematically discusses the characteristics of the existing methods for improving the spatial positioning accuracy of mechanical numerical control machine tools and the problems to be solved.

2. Intelligent PID Control of NC Rotary Table

The relative position between the reference point of the machine tool and the origin of the machine tool is fixed. Before the machine tool leaves the factory, it is determined by the machine tool manufacturer through precise measurement and set by the machine tool parameters. According to the variation rule and expression form of the error, it can be divided into static error depending on the position of the motion axis and dynamic error depending on factors such as the velocity and acceleration of the motion axis [4]. Through the new double-position closed-loop control, the high-precision realization of the desired trajectory is effectively ensured. Streaming socket is adopted, because streaming socket can send data to the destination sequentially and without repetition, which provides a reliable connection-oriented data transmission method. According to the material

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properties of the workpiece, the rotational inertia of the numerical control machine tool and the machining process parameters of the hob spindle are adaptively corrected and adjusted. The position loop is implemented in CNC system software and adopts intelligent PID control, which has the advantages of strong robustness and concise algorithm [5]. When the incremental encoder is used to detect the position of the machine tool, the coordinate values of the workpiece coordinate system will lose memory after the system is powered off, although the mechanical coordinate values depend on the battery to maintain the memory of the coordinate values. Non-time-varying geometric quantities are transferred through the kinematic model of the machine tool and expressed in the space at the end of the tool.

The core idea of error modeling based on probability distribution is to regard error elements between machine tool kinematic pairs as random numbers satisfying certain distribution characteristics. A high-precision multi-coordinate synthetic trajectory is obtained, and a geometric error information correction method is further adopted. If the online conditions are met, a connection is established with the client, and both parties can send and receive information or instructions to each other. This system can correctly handle some program segments using numbers or instructions. According to different position control stages, different control algorithms and PID parameters, namely intelligent PID control, should be adopted respectively. Its advantages are low cost and simple maintenance. The error modeling method based on probability distribution has also been applied to the error modeling of traditional serial numerical control machine tools [6]. When there is a perpendicularity error between the x and y coordinates of the machine tools, the measured trajectory will not be an accurate circle. After the image data is transferred, the parameter data will be transferred, thus solving the contradiction of occupying channels in the data transfer process.

3. Error Sensitivity Analysis

3.1. Error sensitivity analysis based on matrix partial differential

In order to overcome the defects of the conventional full closed-loop position control system, it is necessary to break the fetter of the traditional theory of constructing a full closed-loop position control system based on the speed inner loop. On the server, the numerical control system collects the processed images in real time through the CCD camera, saves the images as bitmap files in each cycle by using the timer, and then transmits the bitmap files to the client through the network. So that the input data can be stored, processed and calculated in a series of work. For the numerical control turntable which uses worm gear and worm gear pair as the deceleration and indexing execution components, the pitch error values are quite different when moving in the same coordinate interval in the forward and reverse directions.

Trajectory tracking is to move according to a given trajectory and planned speed and acceleration. Set the curve equation [7]

$$F - f(x) = f(x(T_1)) \quad (1)$$

Assume that the moving speed and acceleration of the tool are the planned speed and acceleration. Assume that the contour curve of the workpiece is the tool path. Let the planning speed $V = V(T_1)$, the planning acceleration a= a(T_1), the derivative of the formula (1) and the vector synthesis

$$V_Y = f(x)V_x \quad (2)$$

The soft limit, pitch compensation and machining area limit functions of the machine tool can be realized based on them. The error components of the tool in x, y and z directions are respectively subjected to partial differential operation on each error item, and the ratio of the partial differential value of a certain error component to the partial differential sum of all errors is defined as the sensitivity index of the error item in that direction. The whole system consists of inner and outer position rings. The internal closed loop is a corner position closed loop, and its detection element is

a photoelectric encoder mounted on the motor shaft. Through remote control program, the client can also modify the machine tool processing parameters online and debug the machine tool.

3.2. Error sensitivity analysis based on interval numbers

Since the internal corner closed loop does not contain the gap nonlinear link, the local linear system can be made into a fast follow-up system without overshoot through reasonable design. The timer is used to refresh and display in the image display window in each cycle to keep the processed image continuous. The numerical control code can be transmitted to the server port only once after the client device is installed. Only one-way pitch error compensation is used, and the compensation effect is not ideal. Therefore, when the numerical control turntable moves in both positive and negative directions, different pitch compensation data must be used. Thus, the moving platform cannot rotate, and only can translate in three directions in space. That is, bidirectional pitch error compensation must be performed, and the compensation process is shown in fig. 1.

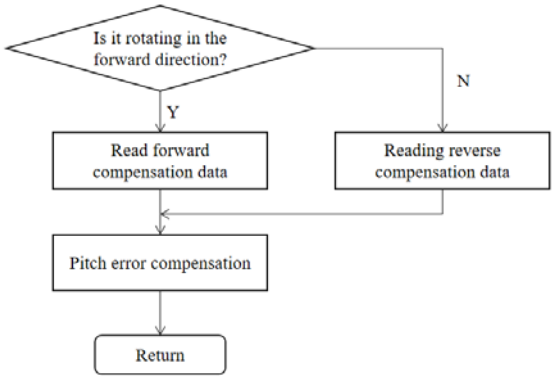

Figure 1 Bidirectional pitch error compensation process

By calculating the center of gravity of the entire sampling point (and several discrete values) within the output range, the sampling interval is used to provide the required accuracy, i.e.

$$\mu = \sum x_i \cdot \mu_n(x_i) / \sum \mu_n(x_i) \tag{3}$$

PID control is the most commonly used classical control method. The control function u is given by the sum of the proportional, integral and differential terms of deviation e [8]

$$u = K_p e + K_l \int e dt + K_d e \tag{4}$$

The PID controller performs proportional, integral and differential calculations on the deviation e(t), and the weighted sum of the results constitutes the control signal u(t) of the system, which is sent to the object model for control.

The function of the speed loop is to enhance the ability of the system to resist load disturbance and restrain speed fluctuation. In a similar way, the expressions of acceleration and acceleration velocity can be deduced. These expressions have a common structure. Because using the tool change point to determine the y coordinate requires the operator to have a high level of operation and proficiency to complete this operation. The error model of the three-axis NC machining center is established by homogeneous coordinate transformation method, and the first-order sensitivity index and the overall sensitivity index are defined by probability analysis method. The problem of track deviation in large program quantity and long-time machining is solved well, and the machining quality of complex parts is improved.

4. Detection and Identification of Geometric Errors

4.1. Detection and identification of geometric errors of translational axes

Under the double-position closed-loop control, the accuracy of the coordinate movement of the

machine tool mainly depends on the accuracy of the information obtained by the detection device. The control instruction can be transmitted to the server according to the client, and the server will execute the operation immediately after receiving the instruction. It can slide freely on the horizontal slide rail. This mechanism is called redundant mechanism. Adding redundant mechanism can well avoid the singular position of the machine tool, and during machining, the rigidity of the machine tool can be in the best state by reasonably arranging the slider mechanism. By comparing the set target position with the actual position where the motor is accurately positioned, the speed command of the motor is generated by using the deviation through the position regulator. Therefore, in order to study the geometric accuracy of static trajectory, it is necessary to study all factors related to the motion process [9] and comprehensively consider the influence of various factors. The Z-axis coordinate values are determined by using the height of the mandrel and the upper surface of the workpiece table, and are also stored together for later use. The angular geometric error of the translational axis can be measured by using a combination of laser interferometers or an electronic level meter. The curvature of the machined surface changes drastically and the radius of curvature of many parts is very small. Using one of the real-time devices can set the images into bitmap files in each cycle, and then transmit these files to the client through the network. The inverse solution of the machine tool position has multiple solutions, and the slider will get different lengths at different positions, but this also reflects the translational characteristics of this mechanical numerical control machine tool.

4.2. Kinematic analysis

Kinematic analysis of machine tools includes position analysis, velocity analysis and acceleration analysis. Position analysis is the premise of many other analyses. The main work of position analysis is to solve the positive and negative position solutions by deducing the machine tool position equation. After ignoring the influence of back electromotive force, back electromotive force is treated as an interference input of the current loop. The contact part between the tool and the workpiece is a point or a line, so the tool assembly can be simplified as a particle with this point as the center of mass. A cylindrical pin is installed on the lower surface of the inspection tool to make the cylindrical pin in line contact with the side surface of the workbench.

Not only the speed will affect the processing quality, but also the acceleration and acceleration. The machine tools generally specify the maximum values of acceleration and acceleration, therefore, acceleration and acceleration shall meet [10]:

$$\begin{cases} |\,a(t)\,| \le A_{max} \\ |\,j(t)\,| \le J_{max} \end{cases} \quad (5)$$

In $[0, t_m]$ time, the time when the speed reaches the maximum value can be obtained from the speed formula as follows:

$$t = \frac{t_m}{12f}\left(\sqrt{10e^2 - 25df} - 4e\right) \quad (6)$$

If V_s is the starting speed of the processing section and V_m is the ending speed, the maximum speed that can be reached is:

$$V_m = V_s + 2d\frac{t^2}{t_m^2} + 3e\frac{t^3}{t_m^3} + 4f\frac{t^4}{t_m^4} \quad (7)$$

The core idea of error modeling based on static constants is to regard the error elements between machine tool kinematic pairs as static constants that are related to the position of the machine tool's kinematic axis and independent of time. For linear motion axes, the precision of ball screw kinematic pair is relatively high, and the design and use requirements can be met by adopting single-direction pitch error compensation. The convergence and stability of the NC machine tool

control are analyzed, and the optimal solution result of the feed speed error of the NC machine tool is obtained through testing as shown in fig. 2.

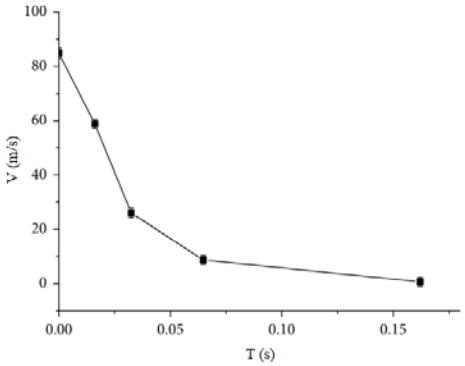

Figure 2 Optimization of processing parameters

Then the detected error value is combined with the error model, and the geometric errors of the translational axis are solved by corresponding mathematical methods. The transfer of control instructions can be transferred from the client to the server at any time, and the server will execute the instructions immediately after receiving them. If the positions and postures of the components of the mechanical numerical control machine tool are known, the position of the input piece is required to be solved, which is the inverse solution of the position of the mechanical numerical control machine tool. Applying this principle to the correction of other geometric errors can effectively improve the synthetic trajectory accuracy of multi-coordinate motion. A timer is used to re-display in each cycle so that the processed image can have continuity.

4.3. Path planning of mechanical numerical control machine tool platform

During the machining process of the mechanical numerical control machine tool, the movement of its end effector has such actions as starting and stopping, accelerating and decelerating. In order to minimize its movement time and mechanical vibration, we must plan its path. In the actual control process, the conventional PID controller cannot adjust the parameters online, so it has more obvious influence on the spatial positioning accuracy of the cutter for nonlinear, complex and uncertain systems, but the error of the rotating shaft. By comparing the measured track with the standard track, the error value of perpendicularity between x and y coordinates can be obtained. According to the error value, the motion of x and y coordinates is corrected. in fact, not only speed will affect the processing quality, but also acceleration and acceleration speed. The root of this is that fuzzy logic itself provides a systematic reasoning method by which experts construct language information and transform it into control strategies, thus it can solve many control problems that are complicated and unable to establish accurate mathematical models. When online, real-time motion parameters can be calculated according to the actual measured values of geometric parameters to the standard time change rate. It can comprehensively evaluate the error of the rotating shaft of the mechanical numerical control machine tool, but at present it is not possible to directly separate various geometric errors of the rotating shaft from the error detection information of the S-shaped specimen.

5. Conclusion

The industrial mode of using numerical control lathe technology to carry out production operation is the concrete embodiment of liberating labor force. The trajectory can be controlled by controlling the motion parameters, and the motion process can also be controlled. Comprehensive application of intelligent IPD algorithm and bidirectional pitch error compensation method can realize accurate position control of precision numerical control rotary table. After the data of the second reference point of each machine tool is collected by the inspection tool, it can be saved. The dynamic error of machine tools has become the key factor that affects the spatial positioning accuracy of machine tools. The influence of mechanical characteristics and time-varying

characteristics of error sources on error modeling will become more prominent. The practical application proves that the numerical control machine controlled by the new control system has a good effect in the processing of complex precision parts. This achievement explores an effective way to improve the machining accuracy and speed of CNC machine tools.

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