Retraction

Retracted: Analysis and Design of Cooperative Control Solutions for Electrical Systems of Laser CNC Machines

Shock and Vibration

This article has been retracted by Hindawi following an investigation undertaken by the publisher [1]. This investigation has uncovered evidence of one or more of the following indicators of systematic manipulation of the publication process:

(1) Discrepancies in scope

(2) Discrepancies in the description of the research reported

(3) Discrepancies between the availability of data and the research described

(4) Inappropriate citations

(5) Incoherent, meaningless and/or irrelevant content included in the article

(6) Manipulated or compromised peer review

The presence of these indicators undermines our confidence in the integrity of the article's content and we cannot, therefore, vouch for its reliability. Please note that this notice is intended solely to alert readers that the content of this article is unreliable. We have not investigated whether authors were aware of or involved in the systematic manipulation of the publication process.

Wiley and Hindawi regrets that the usual quality checks did not identify these issues before publication and have since put additional measures in place to safeguard research integrity.

We wish to credit our own Research Integrity and Research Publishing teams and anonymous and named external researchers and research integrity experts for contributing to this investigation.

The corresponding author, as the representative of all authors, has been given the opportunity to register their agreement or disagreement to this retraction. We have kept a record of any response received.

References

[1] S. Shao, "Analysis and Design of Cooperative Control Solutions for Electrical Systems of Laser CNC Machines," *Shock and Vibration*, vol. 2022, Article ID 1423767, 14 pages, 2022.

Research Article

Analysis and Design of Cooperative Control Solutions for Electrical Systems of Laser CNC Machines

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In order to further improve the collaborative control efficiency of the electrical system of the laser CNC machine tool, an electrical system based on the ultrafast laser CNC machine tool is proposed. The design of the collaborative control scheme is discussed from three aspects: the overall control scheme design, hardware structure design, and control software implementation of the electrical system of the laser numerical control machine tool. The experimental results show that the length of the metal sheet processed by the electrical system of the laser CNC machine tool is 5.3 cm and the width is about 3.6 cm, and the actual processing aperture size will also change according to the set number of variable radius turns, and more precise processing can be enabled in the online test. The research results show that this electrical collaborative control system scheme has strong practicability and feasibility. With the help of system upgrades and optimization, the efficient integration of laser processing technology and numerical control technology can be better achieved. It should be noted that the machining process of the machine tool is also required to make in-depth improvements, which can maximize the operating efficiency and machining accuracy of the electrical system of the CNC machine tool. The laser CNC machine tool researched and developed in this paper verifies the rationality and feasibility of the collaborative control scheme through practical experiments, which can meet the processing requirements and realize the integration of laser processing technology and numerical control technology. High machining efficiency and machining accuracy.

1. Introduction

Computer engineering has gradually replaced modern work tools, and office equipment has never been adapted to current work needs. While the development of computer technology and its application in the field of the machinery industry have changed the traditional processing methods, the work efficiency of the equipment has been further improved by integrating computer technology, automated control systems, and CNC machine tool technology. Compared with traditional CNC machine tool technology, with the improvement of computer technology, on the basis of the full integration of automation control technology, computer technology, and CNC machine tool technology, laser CNC machine tools integrate optical, mechanical, electrical, detection, and other technologies into one. Based

on the integration of laser processing and CNC machine tools, compared with traditional CNC machine tools, laser CNC machine tools have many advantages and characteristics of traditional CNC machine tools and laser manufacturing machine tools and can better replace the work of traditional props. The machining speed of the tool is faster, the surface deformation of the machined workpiece is smaller, and a wider variety of complex workpieces can be machined. On the basis of synthesizing a variety of technologies, laser CNC machine tool technology has higher processing efficiency, greatly improved processing accuracy, and a higher degree of automation. Based on these characteristics, a control system for CNC machine tools based on ultrafast laser is proposed, which can better realize the coordinated control of the electrical system of CNC machine tools.

2. Literature Review

Macmammah et al. said that the application range of CNC machine tools in the industry is constantly expanding, and it has many advantages compared with ordinary machine tools, but at present, CNC machine tools cannot completely replace ordinary machine tools, nor can they be the most economical way to solve all problems in the machining process [1]. Klausen et al. said that CNC machine tools are mainly suitable for processing complex shapes and high precision requirements while producing parts with small batches but many varieties [2]. Singh and Kedia said that a large number of CNC machine tools are needed to support their production in the automobile manufacturing industry, machinery industry, and military industry [3]. Singh et al. said that CNC machine tools, as the working machine of equipment manufacturing, are the mainstay of a country's industrial development [4]. Lee and others said that due to the continuous advancement of industrial modernization, the requirements of modern manufacturing for CNC machine tools have long been no longer focused on simple automated processing but have put forward more advanced processing accuracy, processing speed, and processing technology for high demands [5]. Lan et al. stated that from the perspective of these needs, high-end CNC machine tools would be a good choice, but the actual processing of high-end CNC machine tools is only used to complete the processing process and for the similarity processing of microholes. While precision cutting requires precision, it is difficult for high-end CNC machine tools to meet the requirements [6]. At this time, it is necessary to find a more suitable processing method and processing technology, and laser processing is the best choice for this kind of processing. Compared with traditional machine tool processing, laser processing has the following advantages: Lui et al. said that laser processing has high production efficiency, reliable workpiece processing quality, and processing accuracy that can reach the order of microns [7]. During the laser processing, there is no contact with the workpiece to be processed, which will not bring about "tool" wear, and at the same time, there is no direct impact on the workpiece, so there is no mechanical deformation; it is suitable for the processing of some metals and nonmetals, especially for high hardness and processing of materials with high brittleness and high melting point; Gupta and Paliwal said that the beam guidance and focusing of the laser are simple in the processing process, which can easily realize the transformation of all directions, which is very suitable for the processing of complex workpieces with the numerical control system [8]. As can be seen from the advantages of laser processing, laser processing is a very simple process. Zahedmanesh et al. said that the combination of laser processing and CNC machine tools and the use of lasers to convert the machine tools into laser CNC machine tools for operation is not only the function of CNC machine tools but also the quality of laser processing [9]. Therefore, laser CNC machine tools will have the advantages of CNC machine tools and laser processing at the same time. For precision processing such as microhole processing, it can not only

achieve a high degree of automation of processing but also achieve higher processing accuracy and processing efficiency. Sanjareh et al. said that although the current applications of laser CNC machine tools in China's processing industry are mostly special-purpose mid-to-low-end machine tools, mainly used for laser cutting, cladding, heat treatment, laser welding, etc. with the development of laser processing technology and the continuous improvement of CNC machine tools and the deepening of technical research, laser CNC machine tools will have a wide range of applications [10]. Laser CNC machine tools combine the advantages of CNC machine tools and laser processing, are necessary to improve the efficiency of the processing process, and are an important part of the development and adjustment of CNC machine tools. At present, the development of laser CNC machine tools is still in its infancy, but it has been widely used in production. It can be seen that laser CNC machine tools can be improved. The next step in the research of laser CNC machine tools will only focus on the integration of CNC machine tools and laser processing equipment in the processing process to improve the process and make tool making and setting easy so that the advantages of CNC machine tools and laser processing can be effectively utilized to implement manufacturing innovation. The electrical system of the CNC machine tool is shown in Figure 1.

3. Methods

In the CNC machining system, the processing of the corners of the motion segment is the key issue to improve the smoothness of the motion trajectory. The problem includes two aspects: first, the determination of the corner speed. The smoothness of the motion is significantly reduced; secondly, the smoothness of the trajectory at the corner is improved. Under the condition of ensuring the trajectory error, a motion segment with smooth characteristics is added to the corner to satisfy the better trajectory smoothness [11]. In order to solve the above problems, this chapter has carried out research on the transition technology at the corner of the motion segment. The basic idea is shown in Figure 2.

The technical introduction is shown in Figure 3.

Set points, $Pi-1$, Pi, $Pi+1$, are the endpoint positions of the two motion segments of sequential processing, as shown in

$$\overline{Q_0 Q_1 Q_2}. \tag{1}$$

It is the transition arc that is tangent to the two line segments at the same time, wherein $Q0$ and $Q2$ are the tangent points of the transition arc and the adjacent motion segments $Pi-1Pi$ and $PiPi+1$, respectively, and $Q1$ is the midpoint of the transition arc. The geometric relationship between the transition arc and the two adjacent motion segments is analytically represented, as shown in Figure 4.

In the figure, $\Delta Q_0 O Q_2$ is easily known as an isosceles triangle according to the knowledge of plane geometry. According to the basic properties of the tangent, it can be concluded that $\Delta Q_0 P_i Q_2$ is also an isosceles triangle. Therefore, the corner point P_i of the two motion segments
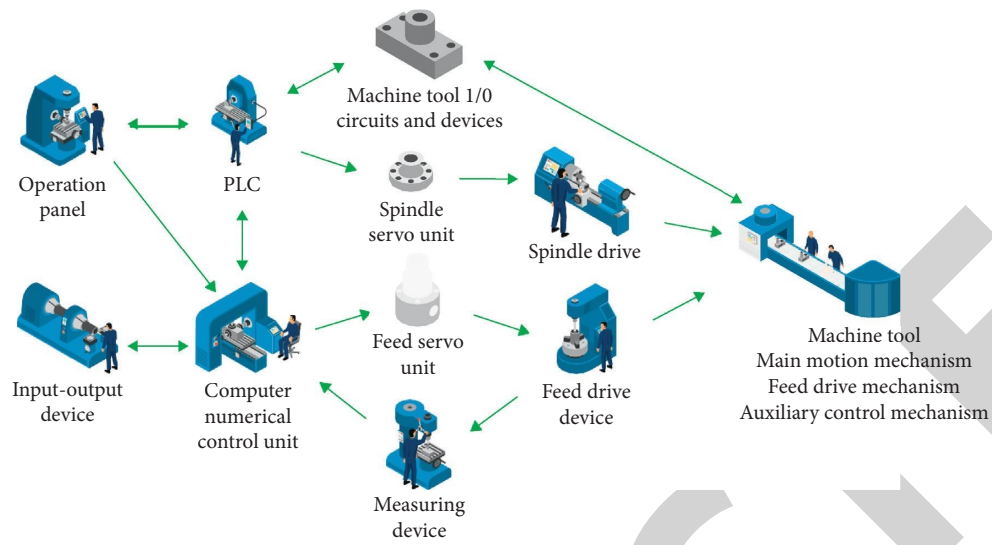
Figure 1: Cooperative control of the electrical system of the laser CNC machine tool.
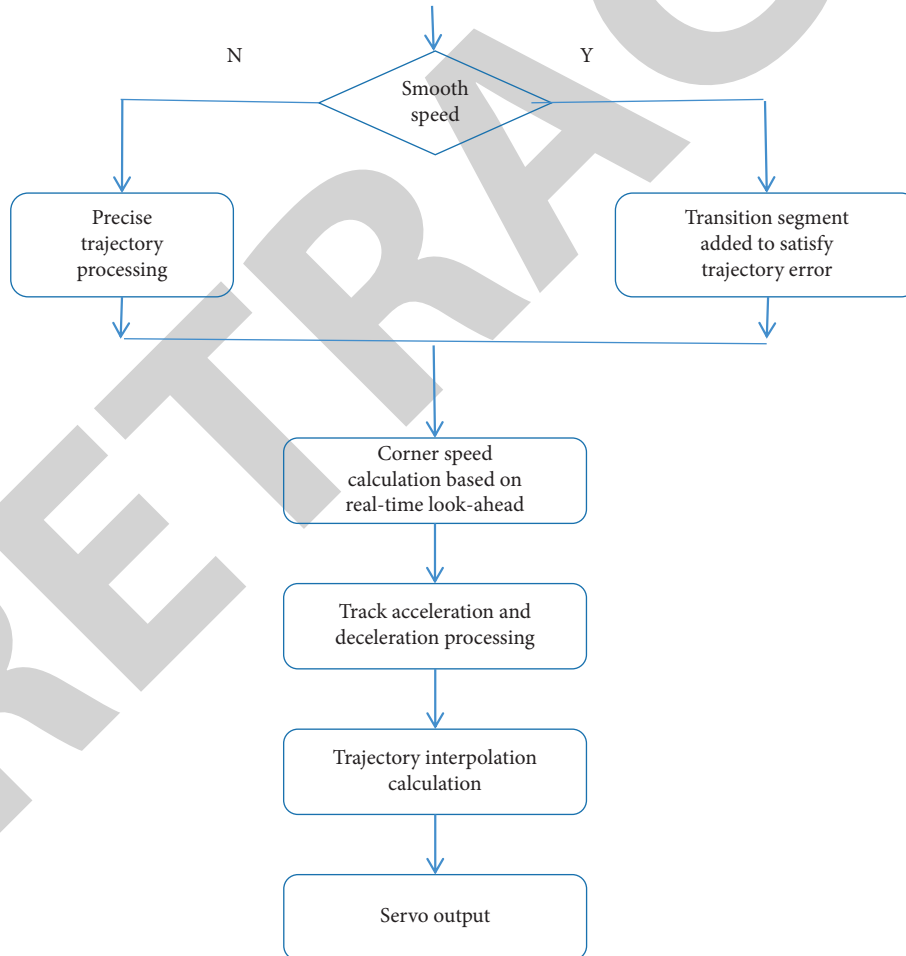

Figure 2: Transition processing flow at the corner of the motion segment.

and the starting point $Q0$ and the end of the transition arc of the points $Q2$ are equidistant, and the above distance is defined here as the transition distance, that is, the distance from P_i to the starting point $Q0$ and the ending point $Q2$. Assuming that the lengths of two adjacent motion segments $Pi-1Pi$ and $PiPi+1$ are represented as Si and $Si+1$,
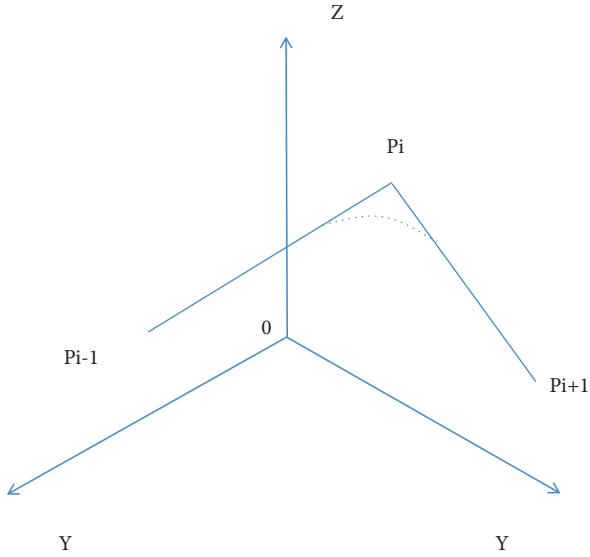
Figure 3: Schematic diagram of arc transition.

respectively, and the included angle between the two motion segments is α, according to the knowledge of plane geometry, the following relationship can be obtained as follows:

$$\begin{cases} \phi = \alpha, \\ \dfrac{r}{e+r} = \cos\dfrac{\phi}{2}, \\ \dfrac{l}{e+r}\sin\dfrac{\phi}{2}. \end{cases} \quad (2)$$

It can be further deduced through the above formula relationship. According to the angle α between adjacent motion segments and the contour error determined by the machining accuracy, the transition distance l between the two motion segments and the radius r of the transition arc are, respectively, related to α and α. The relationship of e is shown in formulas (3) and (4):

$$l = \frac{\sin(\alpha/2)}{1 - \cos(\alpha/2)}, \quad (3)$$

$$r = \frac{\cos(\alpha/2)}{1 - \cos(\alpha/2)} e. \quad (4)$$

When the transition arc is used to achieve a smooth transition between adjacent motion segments, there is a fitting error between the actual path and the original path. First, considering the requirements of contour error after fitting the motion segment, according to the geometric relationship between the contour error, the angle between the two motion segments, and the length of the motion segment, the radius of the transition arc and the start and end points of the transition arc are determined. Second, it is necessary to consider that the feed rate on the transition arc must meet the maximum acceleration performance of the machine tool, and the maximum feed rate of the transition arc is determined by the maximum acceleration.

3.1. Determine the Transition Arc Radius, Start Point, and End Point.

In order to meet the requirements of contour machining accuracy, the requirements of contour error must be met first when determining the radius, starting point, and end point of the transition arc. Therefore, the maximum contour error E_m needs to be used as a constraint to determine other parameters of the transition arc. Substituting E_m into equations (3) and (4), the transition distance l_c that satisfies the maximum contour error can be obtained

$$l_c = \frac{\sin(\alpha/2)}{1 - \cos(\alpha/2)} E_m. \quad (5)$$

Since the above formula is obtained according to the geometric relationship, for the motion segment under normal circumstances, E_m is much smaller than the length of the motion segment, so the transition distance l_c under the constraint of E_m must be smaller than the length of the adjacent motion segment. Taking any three adjacent motion segments to form 2 corner points, the situation in the figure may occur because the middle motion segment is the upper transition distance, as shown in Figure 5.

That is, the two transition arcs before and after do not intersect, which means that the radius of the transition is too large, and the transition distance does not satisfy the connection relationship, so not only the contour error but also the length of the motion segment itself determine the radius of the transition arc and the transition distance and other parameters [12, 13]. In order to ensure that two adjacent transition arcs can intersect, it must be ensured that the transition distance on each motion segment cannot exceed half the length of the motion segment

$$l_s = \min\left(\frac{S_i}{2}, \frac{S_{i+1}}{2}\right). \quad (6)$$

Consider the case of $l_c \leq l_s$, in which the transition distance can satisfy the constraint condition of the length of the motion segment, and the parameters of the transition arc are completely determined by the maximum contour error, as shown in formulas (7)–(9):

$$r = \frac{\cos(\alpha/2)}{1 - \cos(\alpha/2)} E_m, \quad (7)$$

$$Q_0 = \frac{l_c}{S_i} P_{i+1} + \frac{S_i - l_c}{S_i} P_i, \quad (8)$$

$$Q_2 = \frac{S_{i+1} - l_c}{S_{i+1}} P_i + \frac{l_c}{S_{i+1}} P_{i+1}. \quad (9)$$

When considering the case of $l_c > l_s$, in this case, the transition distance cannot meet the constraint condition of the length of the motion segment. According to the aforementioned method, the problem of overlapping transition distances will occur. Therefore, in this case, the parameters of the transition arc should first consider the motion segment and the constraints of its own length, as shown in formula (10)–(12):
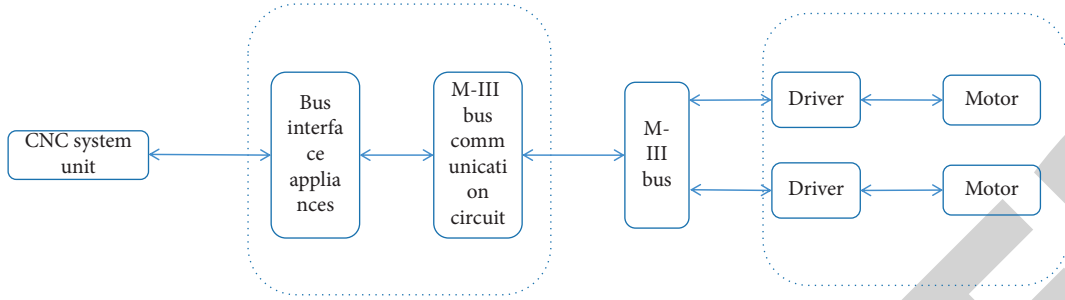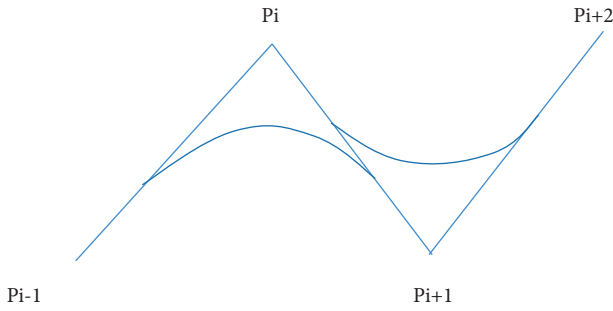
FIGURE 4: Arc transition coordinate system.

FIGURE 5: Schematic diagram of transition distance overlap.

$$r = \frac{\cos(\alpha/2)}{\sin(\alpha/2)}l_s, \tag{10}$$

$$Q_0 = \frac{l_c}{S_i}P_{i-1} + \frac{S_i - l_c}{S_i}P_i, \tag{11}$$

$$Q_2 = \frac{S_{i+1} - l_c}{S_{i+1}}P_i + \frac{l_c}{S_{i+1}}P_{i+1}. \tag{12}$$

3.2. Determination of the Maximum Feed Rate of the Transition Arc Segment. From the centripetal acceleration formula, the constraint relationship between the maximum feed rate v_m and the maximum acceleration of the machine tool is a_m, and the radius r of the transition arc is shown in

$$v_m = \sqrt{a_m r}. \tag{13}$$

Therefore, in order to ensure that the transition arc processing can meet both the requirements of the machining accuracy and the acceleration and deceleration performance of the machine tool, the maximum speed of the transition arc segment processing should be selected from the maximum processing speed set by the workpiece program and the speed constrained by the maximum acceleration of the machine tool. The smaller value in v_m is

$$v = \min(F, v_m). \tag{14}$$

In order to meet the feed rate when processing the transition arc segment, before the transition arc segment, the feed rate is planned based on the forward-looking algorithm, so that the feed rate of the starting point of the transition arc

is v, and the transition arc is guaranteed. The speed remains constant during the processing.

$Pi-1$, Pi, and $Pi+1$ are the endpoints of adjacent arc segments and straight-line segments, and the arc $\overline{Q_0Q_1Q_2}$ is the transition curve inserted between the program segments. It can be divided into two cases as shown in the figure, and the processing method is similar, as shown in Figure 6.

Similar to the transition processing between two straight-line segments, the length of Pi from the tangent point between the transition arc and the two adjacent program segments is called the transition distance. The distance e between Pi and the transition arc vertex is the shortest distance from Pi to the transition arc $\overline{Q_0Q_1Q_2}$, which is called the contour error, as shown in Figure 7.

Assume that the central angle of the transition arc is ϕ, the error between the transition arc and the original trajectory is e, the distance between Pi and $O1$ is h, and the length between Pi and the tangent point is d:

$$\begin{cases} \theta = \dfrac{\pi - \phi}{2}, \\[2mm] h = \dfrac{e}{1 - \sin\theta}, \\[2mm] d = h \cdot \cos\theta. \end{cases} \tag{15}$$

Considering the limitation of the length of the motion segment itself, the transition distance on each line segment does not exceed half of its own length, as shown in

$$l_s = \min\left(\frac{S_i}{2}, \frac{S_{i+1}}{2}, d\right). \tag{16}$$

And the radius is determined after trimming as shown in

$$R_1 = l_s \cdot \tan\theta. \tag{17}$$

And the processing of the transition arc needs to meet the normal acceleration requirements. Let the radius that meets the requirements be $R2$, the processing speed that meets the process requirements is v, and the normal acceleration is an
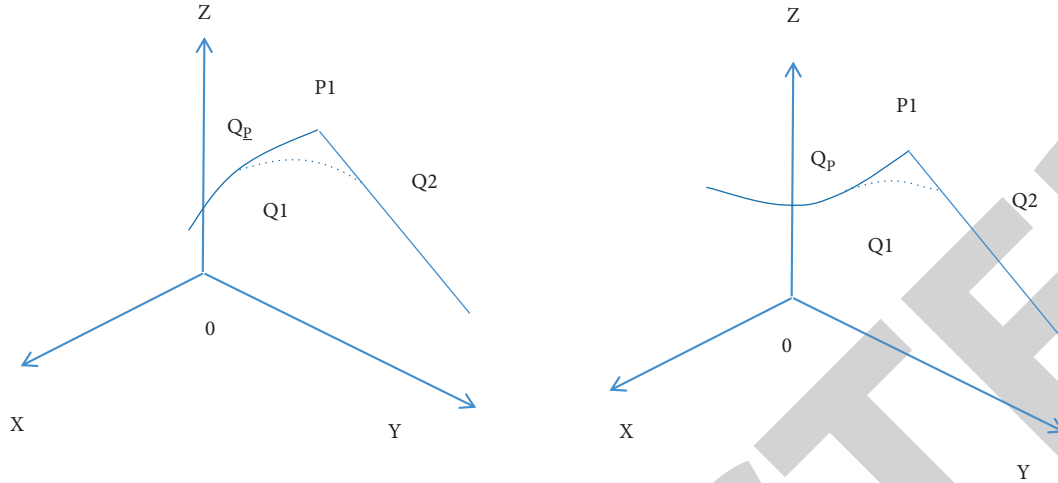
$$R_2 = \frac{v^2}{a_n}. \tag{18}$$

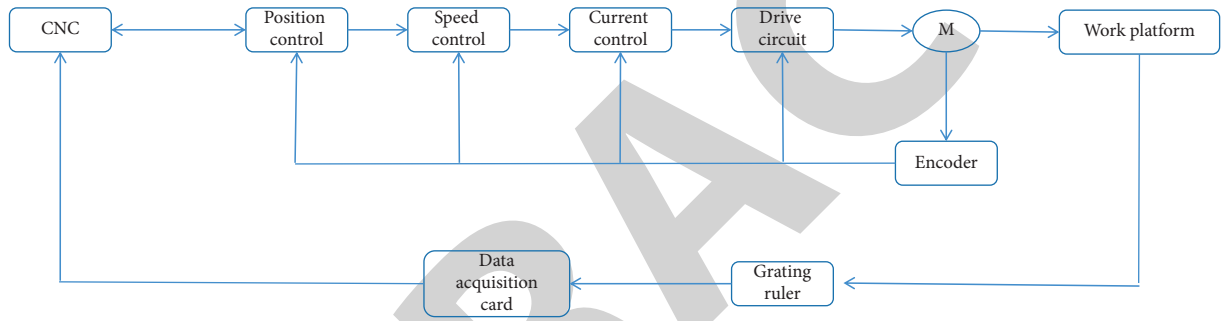FIGURE 6: Schematic diagram of the transition between the arc and straight line.

FIGURE 7: Arc and straight-line transition coordinate system.

The radius R satisfying the above constraints is

$$R = \min\{R_1, R_2\}. \tag{19}$$

The transition length $l1$ of the straight-line segment satisfying the constraints is shown in

$$l_1 = \frac{R}{\tan \theta}. \tag{20}$$

Let $\overline{O_2O_1}, \overline{O_1P}$ be a unitized vector, and the transition length of the arc segment that satisfies the constraints is shown in

$$l_2 = \arccos(\overline{O_2O_1} \cdot \overline{O_1P}). \tag{21}$$

Machining speed and precision are the key factors that affect the machining performance of CNC machine tools. The two restrict each other, and the optimal effect of the two cannot be obtained at the same time. Usually, the machining speed is maximized under the condition of ensuring the machining accuracy. From this point of view, the machining accuracy has a decisive effect on the machining speed, and the machining accuracy depends on the ability of the controller's trajectory to follow. Therefore, factors such as the accuracy of acceleration and deceleration of each axis of the machine tool, as well as the sudden change of feed rate and feed rate, have resulted in the reduction of the precision of CNC machine tools.

In the CNC system in the form of front acceleration and deceleration, since the theoretical trajectory error is zero, the machining accuracy is relatively high. The sudden change of feed is the main factor of machining error [14, 15]. Therefore, in this form of acceleration and deceleration, in order to minimize the machining error, the feed rate must be adjusted smoothly, and the axis speed must be limited within the allowable value range. In order to adjust the change of feed smoothly, it is necessary to ensure sufficient acceleration value of each axis, so as to maximize the acceleration and deceleration performance of CNC machine tools. When two shorter program segments are connected one after the other, since the length of the two programs is too short, the acceleration distance required by the commanded speed cannot be reached, and the obtained speed curve shows a special shape similar to the sawtooth. Therefore, it is necessary to comprehensively consider the commanded speed and the length of subsequent blocks to minimize the fluctuation of the feed speed.

4. Experiments and Analysis

Laser CNC machine tools not only include processing equipment but also monitoring and testing equipment. At the same time, because the laser processing equipment is different from the tools of general machine tools, its
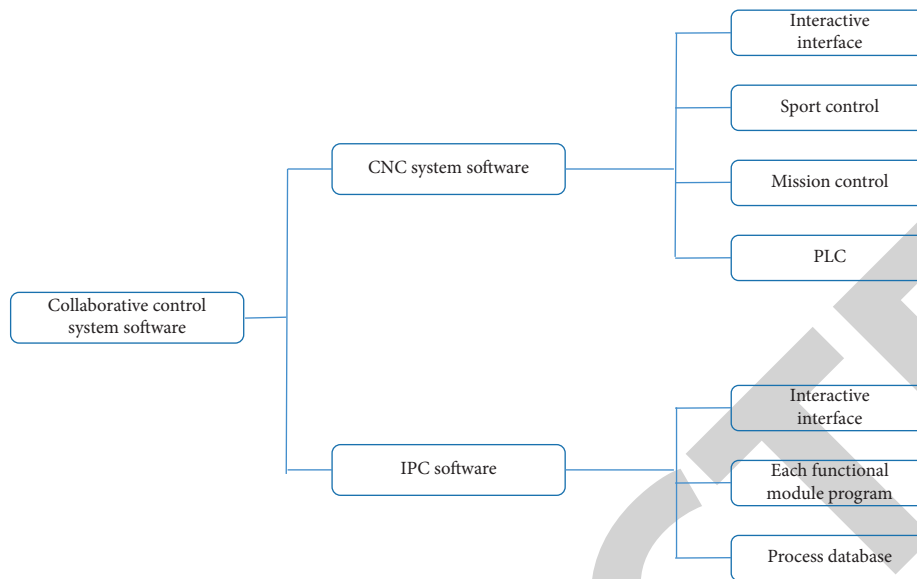
Figure 8: Overall design structure diagram of collaborative control system software.

composition includes laser, light guide system, and monitoring system. Therefore, compared with the general CNC machine tool processing technology, the operation mechanism of the laser CNC machine tool will include additional processing technology [16]. In response to this problem, according to the research on the control system of the laser numerical control machine tool in Figure 7, the actual operation process can be divided into different functions according to the different operations, which can be obtained from the processing process which is independent, as shown in Figure 8.

According to the above processing flow, it can be seen that the software modules included in the actual demand functions of the collaborative control system software design include three-dimensional measurement, focal length measurement, process database, laser and processing head adjustment, terminal monitoring, pointing monitoring, and power monitoring [17]. According to the processing flow, it can be seen that the collaborative control system software needs the coordination and cooperation of various functional modules in the specific processing process, so the design of the entire control system is also designed in accordance with the collaborative control scheme. According to the hardware structure of the machine control system, software integration can be divided into two parts by function: industrial computer control software and numerical control system software. All software design architecture of the integrated control system is shown in [18]. The CNC system part of the control system software adopts the open-source existing CNC system, which was approved as the Linux system platform at that time, realizes the functions of task control, motion control, and PLC through the software, and provides a human-computer interaction interface for display processing. information. In the actual processing process, the numerical control system is mainly responsible for realizing the axis motion control and focal length measurement module, the communication between

the industrial computer and the numerical control system is realized through the serial port, and the coordinated control system can directly send the control to the numerical control system through the industrial computer to control the movement of the machine tool axis. The command is then handed over to the CNC system to complete. Therefore, the development environment of other functional modules has nothing to do with the operating environment of the CNC system. The computer software industry is developed and used by *Qt*. *Qt* is a cross-platform C++ GUI application development framework that supports Linux, Mac OS X, Windows, Linux, Android, and other platforms. It can design GUI services as well as non-GUI services such as console tools and servers. *Qt* is not only easy to connect but also allows the latest component programming. With *Qt*, you can create an application that does not change the code and can be used on multiple platforms, which reduces the installation time of the application. This topic chooses *Qt*4 to realize the development of industrial computer software man-machine interface and processing auxiliary module software, and the development tool chooses *Qt* Creator. *Qt* Creator is a lightweight integrated development environment (IDE) that supports the cross-platform operation and supports multiple operating systems [19].

In order to achieve higher benefits and reduce research costs, the CNC system part of the collaborative control system of this project adopts the GJ430 system developed by High Precision CNC Intelligent Technology Co., Ltd., which avoids the redevelopment of CNC system software. Therefore, the main task of collaborative control system software development is to complete the development of other specific functional modules based on the industrial computer platform on the basis of the existing CNC system and to realize the entire CNC machine tool electrical system in the processing process through the operation of these functional modules. According to the analysis of the laser CNC machine tool processing process and the overall design
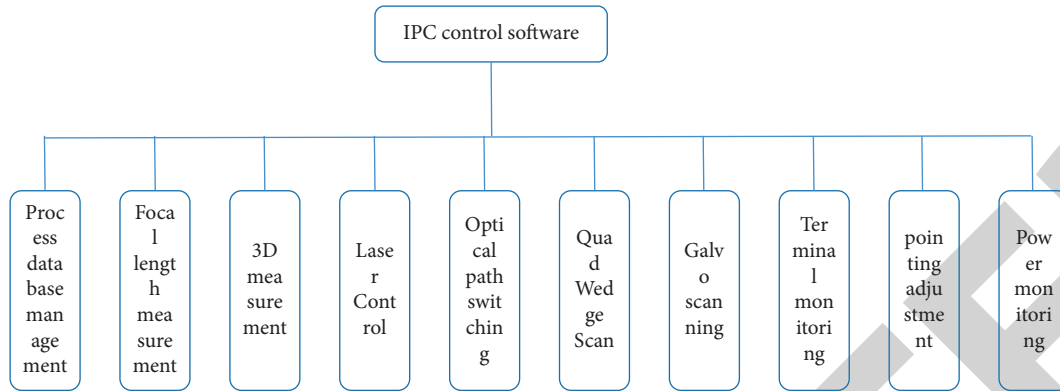
FIGURE 9: Structure diagram of IPC software module.

TABLE 1: Process database parameter table.

Serial number	Parameter	Type of data	Unit	Scope
1	Hole serial number	Unsigned int	—	1~1 0000
2	X coordinate	Float	mm	0~1 000.000
3	y coordinate	Float	mm	0~450.000
4	Z coordinate	Float	mm	0~500.000
5	A coordinate	Float	deg	−95.000~95.000
6	C coordinate	Float	deg	0~359.999
7	Feed rate	Unsigned int	mm/min	0~2000
8	Single layer feed	Float	mm	0~1.00

planning of the collaborative control system software, the functional module structure diagram of the industrial computer software is shown in Figure 9.

The following introduces the realization of the main functional modules in the process of IPC control software processing.

The process database is used to store the processing parameters. According to the processing requirements, the processing parameters, data types, units, and values in the process database are shown in Table 1.

Among them, the serial numbers 2 to 6 in the parameter table of the process database are the coordinate parameters of the hole-making machine tool; the serial numbers 7 to 10 are the Z-axis feed process parameters for the helical scanning; the serial number 11 is the laser output power value during hole making (when the actual setting is ready, the output power value is converted into a percentage for display); serial numbers 12 to 17 are the parameters of the four-beam beam scanning module when making holes; serial number 18 is the process identification, which is used to mark the scanning track of the four-beam wedge scanning head during laser hole making, including helix line scan (ID: 0), circle scan (ID: 1), and selection processing (ID: 2) methods, which can be defined or modified according to the configuration file. Each vertex of the special-shaped hole in the selected processing method is determined by separate software. The interface is defined in polar coordinates, and the center point of the polar coordinate system is concentric with the center of the circular hole nested in the special-shaped hole. Among them, the coordinates of the hole-making machine tool from 2 to 6 are the parameters

obtained automatically by the 3D detection auxiliary positioning module, and the other parameters are obtained by the operator manually editing the data table [20–22].

The function of the 3D measurement module is to realize the auxiliary positioning of the workpiece processed by the machine tool, determine the accurate representation of the workpiece in the machine tool coordinate system, and save the final measured processing position information to the database. It can be seen from Chapter 2 that there are two main methods for the 3D measurement module, one is line laser scanning assisted positioning, and the other is point laser six-point assisted positioning [23, 24]. The software realization of the three-dimensional measurement module of this subject adopts the method of point laser six-point auxiliary positioning. The working flow chart of the 3D measurement module using the point laser six-point assisted positioning measurement method is shown in Figure 10.

According to the workflow of the 3D measurement module, it can be known that the function realization of the 3D measurement module needs to be completed through the cooperation of the numerical control system and the 3D measurement software. The 3D measurement software is provided with a supporting executable program by the 3D measurement equipment provider. The executable program runs on the industrial computer. The industrial computer communicates with the 3D measurement equipment through the RS232 serial port. Therefore, the 3D measurement software realizes the control of the 3D measurement equipment through this connection and acquisition of measurement data. During the execution of the 3D measurement module, the CNC system mainly obtains the axis
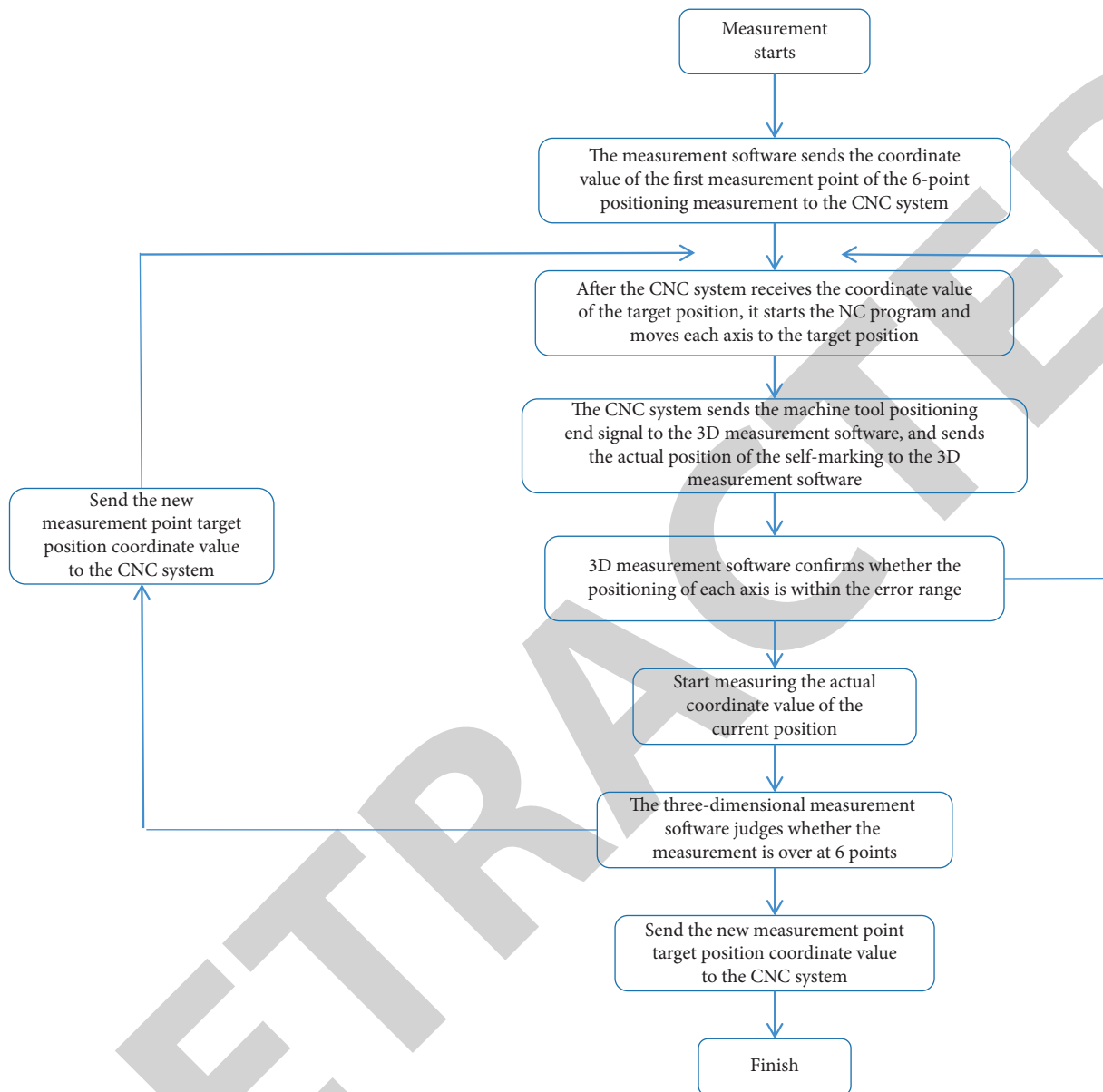
Figure 10: Workflow of the 3D measurement module.

position information and sends the axis position information to the 3D measurement software of the industrial computer and at the same time moves the machine tool coordinate axis to the target position according to the command of the industrial computer [25, 26].

The main purpose of focal length measurement is to ensure that the focus of the laser beam falls on the center of the workpiece during processing. The realization is based only on the input data of the measuring sensors and the axis movements of the CNC system. The computer focal length measurement module includes a comprehensive axis display, measurement axis measurement, and measurement results. The function of the data table is similar to the function of the data table in the database module process, and the data in the database can be selected for analysis

[27–29]. The workflow of focal length measurement is shown in Figure 11.

The focal length measurement function of the industrial computer software makes it possible to measure the focal length of all the machined holes directly from the human-machine interface during specific operations, save the measurement results in the process database, and directly load the process database during processing to obtain the processing parameters and speed up processing [30].

The Modbus protocol adopts a master-slave communication method and is a question-and-answer communication protocol. A communication station can connect one or more slave communication stations through an interconnection line. Among them, the master station of the station gives the address of the slave station, starts to ask the
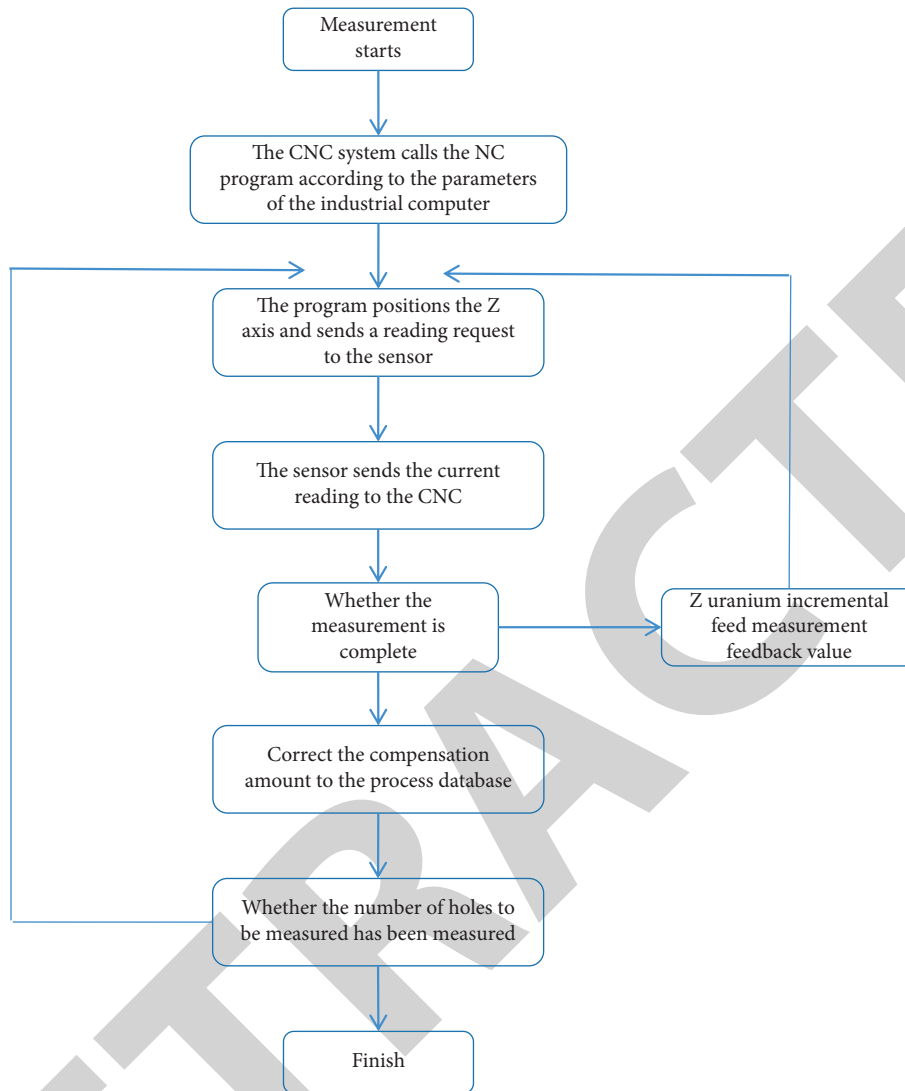
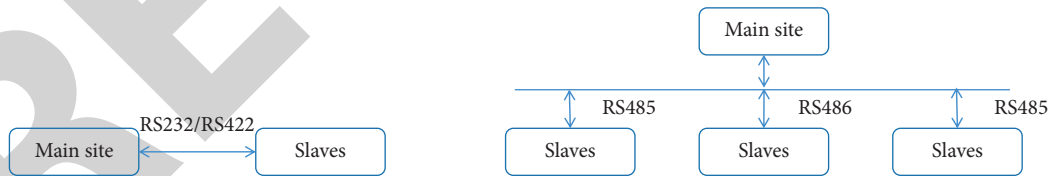FIGURE 11: Flow chart of focal length measurement.

FIGURE 12: Comparison of Modbus protocol point-to-point communication and multipoint communication.
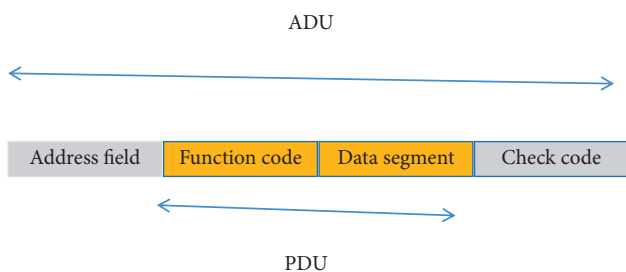

FIGURE 13: Modbus general frame format.

slave station, sends information, and so on. The slave receives the information sent by the master and sends a response to the master. Figure 12 shows the comparison of the connection mode between the point-to-point communication and the multipoint communication mode of the Modbus protocol using the serial port [31].

The general frame format structure of the Modbus protocol is shown in Figure 13.

The Modbus protocol consists of 4 types of registers and multiple function numbers, each function representing a different function of data in different registered entities. The
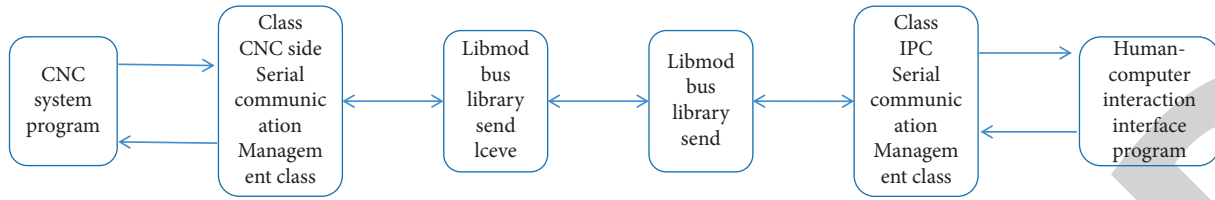
FIGURE 14: The realization process of communication between a CNC system and an industrial computer.

master-slave command response process according to the general statement of the Modbus model is as follows: the master sends a command according to the slave product created in the initial command and requests to read or write the record in the registration area. This time, after each slave device receives the statement, it compares the device address in the statement with its own address. If similar, it will accept the post and respond accordingly. If it is different, it discards the message frame and continues to wait for the command from the master [32].

In using this software, in order to facilitate the communication between computerized business and digital management, two types of communication based on computerized and digital business were developed. At the same time, the serial communication control class of the CNC terminal also provides a connection for receiving CNC system information and sending commands to the CNC system. The software implementation process of the communication between the CNC system and the industrial computer is shown in Figure 14.

After completing the absent initialization and the files required for Modbus communication, the communication class of the CNC terminal starts to patrol the serial port to check whether the Modbus frame is issued by the owner and whether the frame file is available. Then, it will receive the frame data and store it in the specified array, parse the data in the array to get data such as function code and offset address, and then determine what to do according to the function code. These operations include reading CNC system parameters and retrieval, and providing CNC system commands so that the CNC system can complete corresponding tasks according to the commands and responses. Figure 15 shows the flow chart of serial communication on the CNC system side.

Since the computer can be used as a proprietary device, the computer only needs to determine the slave address of the received data when sending the actual data. The serial communication class on the computer side sets the Modbus communication address of the CNC system through macro definitions. Each function module of the software provides the communication function with the CNC system and encapsulates the parameters and user operation commands obtained from the interface [33].

The kinematic model of the ultrafast laser CNC machine tool needs to verify the algorithm of the control strategy of the rotary axis, so it is necessary to simulate the tool attitude and attitude error of the three interpolation methods, respectively. The attitude error corresponding to the improved vector interpolation method is the smallest., the linear
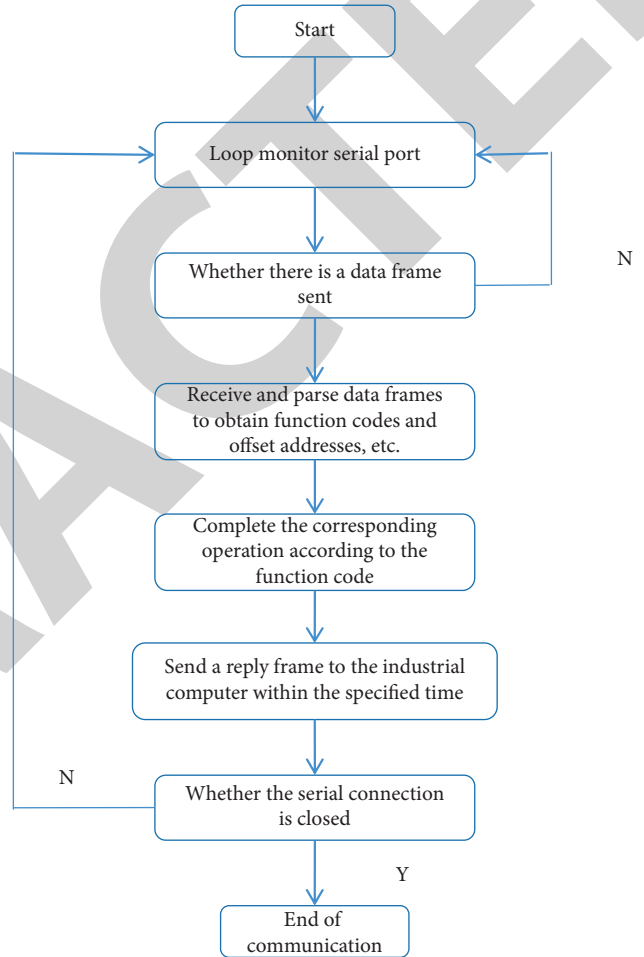

FIGURE 15: Flowchart of serial communication on the CNC system side.

interpolation mode is the largest, and the error is 44°, which meets the requirements of the system error, as shown in Figure 16.

As can be seen from Figure 16, during the interpolation process of vector interpolation, the speed of the C-axis will change drastically at the singular point, far exceeding the maximum acceleration performance of the machine tool. The linear interpolation method produces a larger tool attitude error. The advantages are proposed in this research.

In the interpolation process, the speed change is relatively gentle and meets the requirements of machining accuracy.

It is important to note that when assembling a Modbus frame, the internal computer industry determines the
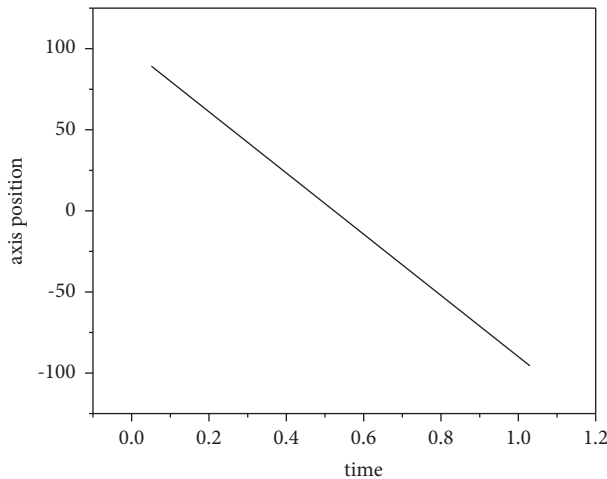
Figure 16: Schematic diagram of AC axis position curve.

location in the Modbus frame based on the type of operations registered and invoked. In the above rule, since the final call is to record multiple registry functions, the base functions are assembled in Modbus. When framing, the job number is set to 16 (multiple names assigned). The software application process of other functions and control signal communication in the computer software industry is similar to the communication process using the optical modification process and will not be explained one by one.

5. Conclusion

The combination of CNC technology and laser processing technology is a new direction for the development of CNC machine tools in the future. Through laser processing, CNC machine tools can further improve the power addition accuracy and processing efficiency and make it possible for CNC machine tools to complete finer processing. The research results show that this electrical collaborative control system scheme has strong practicability and feasibility. With the help of system upgrades and optimization, the efficient integration of laser processing technology and numerical control technology can be better achieved. It should be noted that the machining process of the machine tool is also required. In-depth improvements should be made, which can maximize the operating efficiency and machining accuracy of the electrical system of the CNC machine tool. Although CNC technology and laser technology are still relatively mature at present, there are still many problems in the development of more general laser CNC machine tools, and further exploration and research are needed. Compared with general machine tools, the research and development of laser CNC machine tools are still in the preliminary stage. There is no relatively unified manufacturing standard. More research and development are carried out to meet specific processing needs. The experience and results will provide a certain reference for further in-depth research and development in the future.

This research focuses on the research and implementation of electrical system cooperative control in ultrafast laser CNC machine tools, mainly from three aspects:

(1) Research and design of the overall control scheme. By analyzing the equipment composition and functions of the laser CNC machine tools, combined with the processing requirements and the control relationship between the equipment, in order to better meet the processing requirements, a collaborative control scheme for the electrical system of the machine tool based on the industrial computer is proposed, and this collaborative control scheme is used as a guide for machine tool hardware structure design and software design.

(2) Hardware structure design, based on the control relationship between laser numerical control machine tool equipment analyzed in the first part and the proposed collaborative control scheme to complete the overall hardware structure design of the machine tool, and introduce the hardware structure design of the numerical control system and collaborative control unit in detail, and finally complete the machine tool equipment intercommunication design.

(3) The software management department was informed. As the basis for the hardware components of the machine tool, an integrated control unit integrated with the computer was developed, including the main control unit. The integrated control system consists of two parts: the industrial computer control software and the digital control system. Among them, the CNC system software is famous for controlling the movement of the machine tool axis, and the industrial computer software is used for real-time operation and comprehensive control. Finally, the realization of the main function modules of the control system software and the software realization of the communication between the numerical control system and the industrial computer are introduced in detail.

The laser CNC machine tool researched and developed verifies the rationality and feasibility of the collaborative control scheme through practical experiments, which can meet the processing requirements and realize the integration of laser processing technology and numerical control technology. There are high machining efficiency and machining accuracy. In general, although the machine tools studied in this topic are highly specialized, they still have certain reference value for future related research. The main development trend of the laser industry in the future is as follows: ultrafast laser will become the future development trend of the laser industry, the industry will continue to develop in the direction of high precision, and the industry will continue to develop in the direction of flexibility. The laser processing control system is the brain of the laser processing equipment. With the continuous development of the laser processing equipment, the performance requirements of the laser processing control system are increasing day by day. In the future, the application of the laser processing control system will develop in the direction of high precision.

Data Availability

The labeled data set used to support the findings of this study is available from the corresponding author upon request.

Conflicts of Interest

The author declares that there are no conflicts of interest.

Acknowledgments

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