International Journal of Innovative Computing, Information and Control
Volume **20**, Number **3**, June **2024**

ICIC International ©2024 ISSN 1349-4198
pp. 857–873

RESEARCH ON AUTOMATIC MACHINING OF CYLINDER BASED ON IMPROVED PROGRAMMABLE LOGIC CONTROLLER

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Received May 2023; revised September 2023

Abstract. *With the rapid development of traditional mechanical technology, the level of automation in the production and processing of products is also increasing to meet the higher requirements for product quality and performance. In order to solve the problems of low machining efficiency and high product failure rate in the existing automated machining system, this study designs an automated cylinder body machining system that combines a Programmable Logic Controller (PLC) and an industrial computer. The study firstly optimized the machining trajectory of the machine tool in the automatic machining system, and designed a method of controlling the machining trajectory of the CNC machine tool based on PLC and computer technology, and on the basis of which the automatic machining process of the engine cylinder body was designed. The experimental results show that the machining error of the CNC machine tool under PLC control can be controlled within 0.03, and the trajectory control accuracy is between 0.81 and 0.95. In addition, it is found that the longest time taken by the machining system under PLC control is only 1.1 min, which is much lower than other control systems. In conclusion, the automatic production and machining system with PLC control can reach stability faster and the control time is shorter. The automatic machining system designed in this research can effectively improve the machining efficiency of the traditional machining system and provide a new control method for the optimization of automatic machining system.*

Keywords: Programmable logic controller, Cylinder, Industrial computer, Automation, Production and processing

1. **Introduction.** With the increasing degree of industrial automation, Programmable Logic Controller (PLC) has become an important device in the field of modern industrial control [1]. In the field of machine tool processing, PLC is widely used in the control of machine tool trajectory. PLC can realize efficient and accurate machining process by precise control of machine tool trajectory to improve productivity and product quality. Machine tool is one of the most important equipments in manufacturing industry, and its machining quality and efficiency directly affect the benefit of the whole production line. The traditional way of controlling machine tools mainly relies on manual operation, and this way has problems such as complex operation, low precision and low productivity [2]. In addition to the study of machine tool manufacturing, the current automatic production and processing system has also become an indispensable part of modern industrial production. With the continuous development of science and technology, the mechanical automated production system is also constantly upgraded and improved [3,4]. However, there are still some problems with the current mechanical automated production system.

DOI: 10.24507/ijicic.20.03.857

First, the cost of mechanical automation production system is high. Although mechanical automation can improve production efficiency and quality, its equipment price is high and maintenance cost is also high. Secondly, mechanical automation requires specialized personnel for maintenance and operation. Due to the complexity and specialization of mechanical automation technology, it requires professional personnel for maintenance and operation, which also increases the enterprise's labor cost. Further, mechanical automation has limited adaptability to product types and specifications. Finally, accidents are also prone to occur during operation due to the high speed, force and noise of equipment operation. Based on this background, this research innovatively will start from the application of PLC in machine tool motion trajectory control to introduce the role PLC plays in the field of machine tool machining. At the same time, the study also designs an automatic engine cylinder body machining system and introduces the main functional modules in the system, aiming at proposing some feasible solutions in the field of automated production and machining, and providing a new reference method for automated control in the field of machine tool machining.

This research is divided into seven parts, the first part is a brief introduction to the research content of the article, the second part is an analysis and summary of the related research of others, the third part is an introduction to the specific methodology of the article, the fourth part is a test of the performance of the model, the fifth part is a discussion of the results of the research, the sixth part is a summary of the results of the article, and the last part is a presentation of the future work.

2. **Related Work.**

Due to the development of intelligent machinery technology and the gradual increase in automated production standards, PLCs are widely used in industrial and machinery control, etc. Many experts have conducted a series of studies on them with the aim of improving machinery automation production [5]. Dai [6] proposed a design methodology for the conversion from IEC function blocks to PLC event-driven architectures, applying it to IEC 61131-3 PLC to IEC 61131-3 PLC to IEC 61499 function block application, providing a novel set of conversion steps and rules. Experimental results show that the method can be used for different designs of PLC source code to improve data processing efficiency. Jiang et al. [7] proposed a numerical model of a cylinder block based on elastomeric lubrication for the analysis of its microscopic motion, a simplified lifting model based on the Greenwood design, and a discussion to analyze the relationship between its motion and sealing of a cylinder block under different conditions. The experimental results show that the tilting due to discharge pressure can be alleviated by increasing the rotation rate and increasing the sealing degree, etc. The model provides a better theoretical reference for the optimization of cylinder blocks in practice. Garrido et al. [8] proposed an information model structure aimed at simplifying the use of mechatronic methods in response to the current lack of models for collecting basic general data in the automation industry. The structure can contain information about the machine operating tools and the motion logic associated with their objects, and is layered according to its structure. Experimental results show that the structure can visualize a series of dynamic behaviours such as machine movements. Aiming at the problem that the currently existing structure synthesis methods cannot effectively handle real-time specifications and loop-dependent specifications, Xie et al. [9] proposed a structure synthesis method for programmable logic controller programs. Experimental results show that the PLC-based synthesis approach can be applied to cyclic-dependent specifications with better interpretability. Joo and Shin [10] constructed a framework for formalizing human-machine manufacturing systems for the human-machine interaction aspect of manufacturing systems. It consists of a supervisor, a cell operator and a machine, and an interface. The model constructs ideal specifications, which include confusion conditions in the human-machine system, accessibility of task goals and exception handling supportability. Experimental results confirm that the proposed framework can be effectively adapted to automation at different information levels, demonstrating the applicability of the formal model and automation. Ko and Choi [11] proposed a novel unsupervised learning technique for modulators that exploits learning features in multidimensional wireless parameter changes to predict in real time the multidimensional modulation pattern for the next transmission. Simulation experiments confirm that the results obtained by the technique are above the basic standard based on the most common offline training. Kempegowda et al. [12] proposed an Automatic Guided Vehicle (AGV) based on PLC and magnetic tape guidance, which was designed and experimented in a mass material production environment. In the study, the PLC was combined with different sensors for handling the movement of the vehicle during travel, and the study constructed an infrared sensor system based on the AGV for detecting obstacles in the path. The experimental results show that the AGV, when combined with PLC and tape guidance, uses less power, is more efficient and durable when combined with a lithium-ion battery charging system, and is more productive and reliable compared to existing systems.

In summary, PLC is widely used in automated machinery, automated production and other fields due to its high integration and fast running speed [13]. In response to the current problems of slow system running time, low processing accuracy and high failure rate of processed products that exist in most automatic production and processing systems, the study adopts the mode of combining PLC and industrial computer, and firstly designs a CNC machine tool processing trajectory control method, based on which a set of automatic production and processing process is designed, aiming to achieve high efficiency of the production system through this automatic production and processing system, so as to reduce labour costs and maximize production benefits.

3. PLC and Computer Technology Based Automatic Engine Cylinder Body Machining Process Design.

3.1. **Design of CNC machine tool machining trajectory control method based on PLC and computer technology.** To achieve a high degree of automation and precision in the automatic machining process of engine cylinder bodies, it is first necessary to combine programmable logic controllers and computer-related technology to precisely control the machining trajectory of the machine tool in the automatic machining process, and then to build an automatic machining system [14,15]. In the automatic machining system, in addition to PLC error control of the CNC machine tool trajectory, the machining centre, robot arm, loader, tilting mechanism and downcomer need to be set up to minimize all trajectory errors and ensure that all subsequent high precision machining requirements are met.

Figure 1 shows the structure of the automatic production machining system. The entire automatic production machining system consists of two machining centres, robotic arms, loaders, tilting mechanisms and unloaders. Since the trajectory of the CNC machine tool conforms to a linear law during operation, the study first uses mathematical modelling to model the trajectory of the machine tool. The CNC machine is assumed to have its tool rotating and translating around the axes in the 3D spatial coordinate system N.

$$F = [R(X, A), R(Y, B), R(Z, C)] \tag{1}$$

Equation (1) is a mathematical model for the change of motion of a CNC machine tool in a three-dimensional spatial coordinate system. X, Y and Z represent the axes of the three-dimensional spatial coordinate system, respectively. A, B and C represent the vector

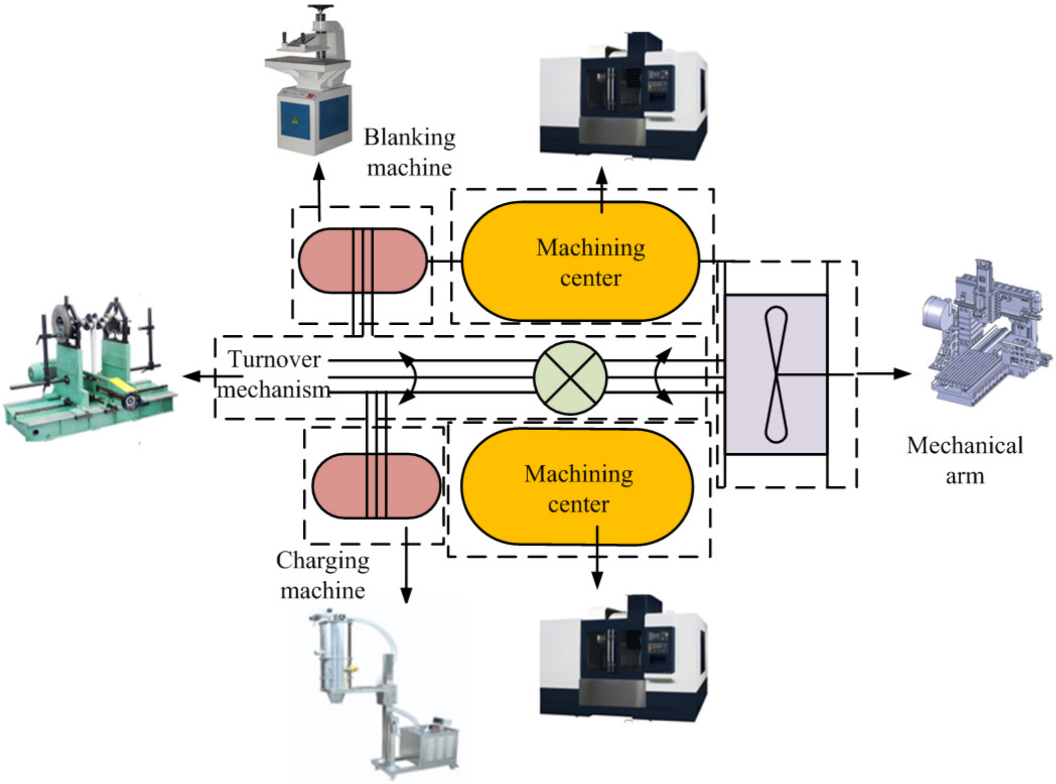


FIGURE 1. Automatic production and processing system

translation distance of the CNC machine tool along each axis in the three-dimensional spatial coordinate system, respectively.

To further describe the machining trajectory of a CNC machine tool, the kinematic model is transformed positively and inverted, respectively. The inverse transformation usually refers to the equivalent transformation of the displacement pulse of the CNC machine tool in the spatial coordinate axes [16]. The position of the tool in the 3D spatial coordinate system is assumed to be m and this position information includes not only the specific coordinates of the tool, but also its angular magnitude. When the tool swing angle of the CNC machine tool is 0, the CNC machine tool can be equated to a 3-axis machine tool at this point, and the tool displacement changes as shown in Equation (2).

$$q(t) = \sqrt{(x + x_w)^2 + (y + y_w)^2 + (z + z_w)^2} \tag{2}$$

In Equation (2), $q(t)$ represents the expression for calculating the drive displacement of the tool at the time of t. x, y and z represent the horizontal, vertical and oblique coordinates in the three-dimensional spatial coordinate system, respectively. x_w, y_w and z_w represent the horizontal, vertical and oblique coordinates of the tool offset vector, respectively. When the NC machine tool swing angle is not zero, the Euler angle can be used to describe the tool position and thus find the value of the tool drive displacement.

$$q'(t) = \|r + a - b\| + [x_0 - (x + x_w)] + [y_0 - (z + z_w)] \tag{3}$$

In Equation (3), $q'(t)$ represents the drive displacement of the tool at the moment t when the swing angle is not 0. r represents the orientation vector of the tool in a fixed coordinate system. b represents the attitude vector of the tool. a denotes the Eulerian angle of the 3D coordinate system compared to the fixed reference coordinate system. x_0 and y_0 indicate the horizontal and vertical coordinate values of the tool in the fixed coordinate system, respectively.

In addition to the inversion, a positive transformation of the tool is also required. Positive transformation means that the tool is displaced along the direction of the position of the rotating axis of the three-dimensional spatial coordinate system with respect to the swing angle. Assuming that in CNC machine tools, the rotation angle of each branch chain rotation sub is α, according to Newton-Raphson numerical theory can be obtained CNC machine tool swing angle calculation formula as shown in Equation (4).

$$\beta = \arcsin(-\alpha) \tag{4}$$

In Equation (4), β represents the swing angle of the CNC machine tool. With this numerical theory, the kinematic positive transformation equation for the CNC machine tool is also obtained as shown in Equation (5).

$$q''(t) \begin{cases} x = x - x_w \\ y = y - y_w \\ z = z - z_w \end{cases} \tag{5}$$

In Equation (5), $q''(t)$ represents the kinematic positive transformation displacement of the CNC machine tool, and the mathematical model of the CNC machine tool motion is constructed by Equations (1)-(5).

$$Q \begin{cases} q(t) & \beta = 0 \\ q'(t) & \beta \neq 0 \\ q''(t) \end{cases} \tag{6}$$

Equation (6) is a mathematical model of the motion of the CNC machine tool, which enables the calculation and control of the motion machining trajectory of the CNC machine tool. In order to achieve accurate control and reduce the operating error, further prediction of the machining trajectory error is required.

Figure 2 shows a schematic diagram of the error of the linear motion trajectory of a high precision CNC machine tool during automatic machining. As can be seen from Figure 2, γ indicates the ideal trajectory of the CNC machine tool and the angle of the horizontal coordinate. T indicates the designated position point reached by the tool movement of the CNC machine tool. G denotes the actual position point reached by the tool movement of the CNC machine tool. m denotes the actual point of tool movement of the CNC machine tool. According to the geometric relationship between the points in the figure,

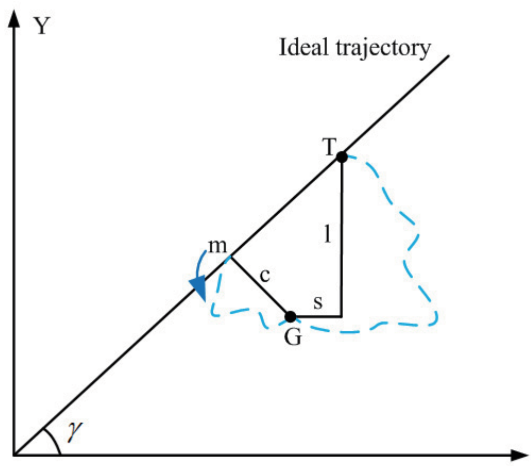


Figure 2. Schematic diagram of motion trajectory error of CNC machine tools

the formula for calculating the linear trajectory error of the CNC machine tool shown in Equation (7) can be derived.

$$c = s\cos\gamma - l\sin\gamma \tag{7}$$

In Equation (7), c represents the linear trajectory error and s and l represent the following error of the horizontal and vertical axes, respectively.

$$c' = \sqrt{(\rho x^* \sin\delta - e_x)^2 + (\rho\cos\delta - e_y)^2} - \rho \tag{8}$$

Equation (8) is the formula for calculating the curve trajectory error. ρ represents the curve trajectory. Assume ε is the centre of the circle and x^* is the horizontal coordinate of ε. δ represents the angle between the tangent line and the horizontal axis of the curve past the desired machining point. e_x and e_y represent the horizontal and vertical coordinates of the actual machining point, respectively. The error values of the linear and curved trajectories are added together to give the total error of the machining trajectory of the high precision CNC machine.

In order to provide accurate control of the machine tool trajectory, the study introduces PLC for real-time interpolation control of the machine tool trajectory [17]. It is assumed that P is the tool coordinate system fixed to the workpiece, L is the machine coordinate system fixed to the fixed axis and J is the position vector of the origin of the coordinate system in P. The centre of the workpiece is set as the origin and the error point in the P coordinate system is calculated in the 3D spatial coordinate system of the CNC machine P according to Equation (8).

$$C = \sin\varpi\sin\upsilon - (J - x_C - y_C) \tag{9}$$

In Equation (9), C represents the corresponding value of the error point position in the three-dimensional spatial coordinate system of the CNC machine tool. ϖ denotes the corresponding rotation angle of the tool axis vector in the three-dimensional coordinate system. υ denotes the rotation angle of the error point around the horizontal coordinate of the three-dimensional coordinate system. x_C and y_C indicate the horizontal and vertical coordinates of the error point position, respectively.

$$C' = (x - x_C) + (y - y_C) + C \tag{10}$$

Equation (10) is the adjustment formula for turning the error point position into the ideal point position. C' indicates the coordinates of the tool in the conversion coordinate system. The PLC enables the mathematical model of the movement of the CNC machine tool to output the set of movement points and form the tool trajectory, and when the coordinates of the tool movement are wirelessly close to the coordinates in the conversion coordinate system, the PLC is able to interpolate and control it.

$$Z = \sum C'(\vartheta) P_i K \tag{11}$$

Equation (11) is the fitting formula for the interpolation control using the fit command for the curve. Z denotes the fitted curve. K denotes the weight value, which is generally defaulted to 1 to simplify the operation. ϑ denotes the node vector. P_i denotes the curve parameters. The above program is coded and then the PLC is used to complete the control instructions.

3.2. **Automatic engine cylinder body machining process design.** After combining PLC and computer technology to control the machining trajectory of CNC machine tools in the automatic machining process, the study attempts to design a system for the automatic machining of engine cylinder bodies using PLC and industrial computers, aiming to replace traditional manual operations with PLC control and computer operation to complete efficient and automatic industrial production machining [18]. The feeder and unloader are combined with an overturning mechanism to automate the processing of the industrial production line, with the feeder filling the material and the unloader outputting the material. During the operation of the loader and unloader, robots are used as actuators to automatically load, unload and unload the material.

Figure 3 shows the flow diagram of the entire automatic processing system. When the staff starts the automatic production operation of the line, the user can select the processing mode according to their needs. There are two types of processing modes: automatic and manual [19,20]. When automatic machining operation is selected, the equipment needs to be home returned using the industrial computer before it can be started. In Figure 3, the first project wait and the second project wait refer to the two machining centres waiting for a machining command to be executed, respectively. When the first machining centre receives a machining signal, the robot arm will carry out that machining centre and place the machined part into the turning mechanism for turning and cleaning, and then place it into the waiting position for the loading operation. When the system has completed the loading operation, the robot arm transports the machined part to the second machining centre for deep machining and places the machined workpiece in the unloader to complete the automatic stacking and loading of the workpiece. When the robot arm has completed the above operation, it will automatically move to the No. 1 machining centre to repeat the above processing steps, thus achieving the purpose of fully automated production of the entire processing line.

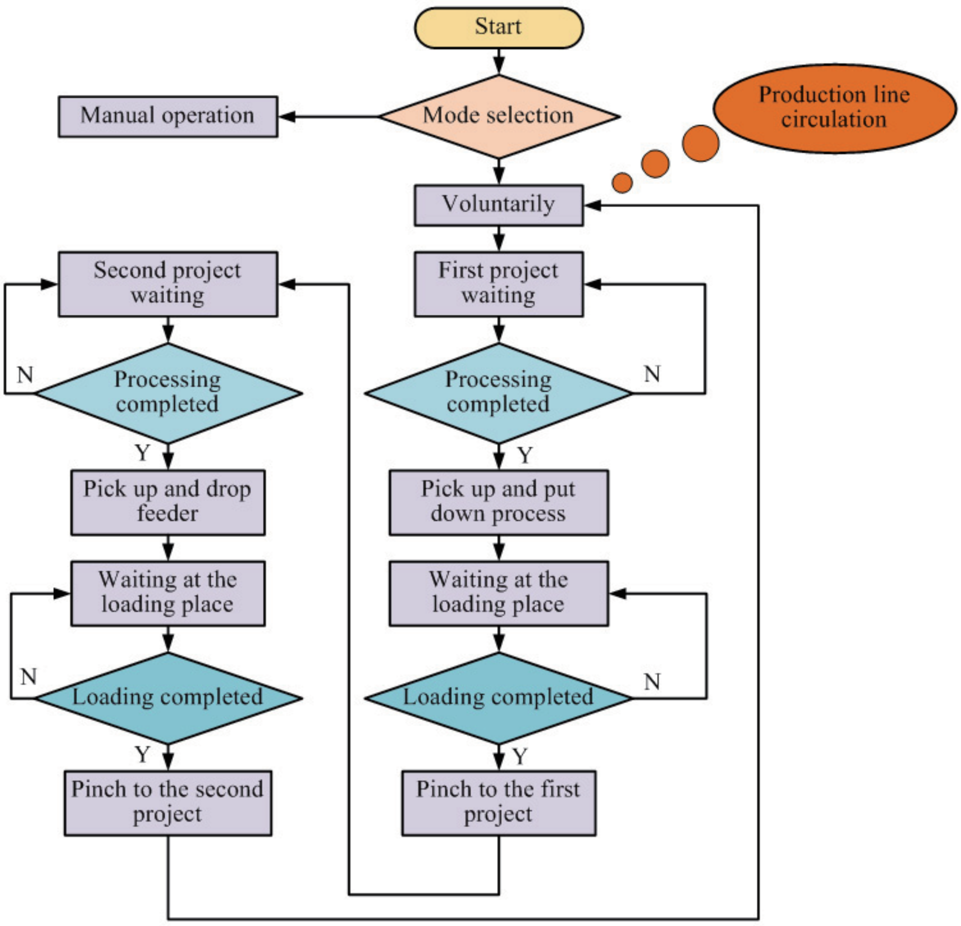


FIGURE 3. Automatic processing flow chart of engine cylinder body

Figure 4 shows the specific operation flow diagram of the loader in the automatic processing system, whose main function is to complete the automatic loading of material in the processing system. The action of the loader is determined by a signal from the robot arm as the robot arm will cause a conflict with the loader operation when the loader is operated on machining centre number two. When the robot arm sends a blocking signal, the loader does not perform the loading operation. When the blocking signal is lifted, the robot arm in the loader starts to grasp the target object and completes the loading through a series of operations such as gripping the jaws, ascending and descending, and positioning [21].

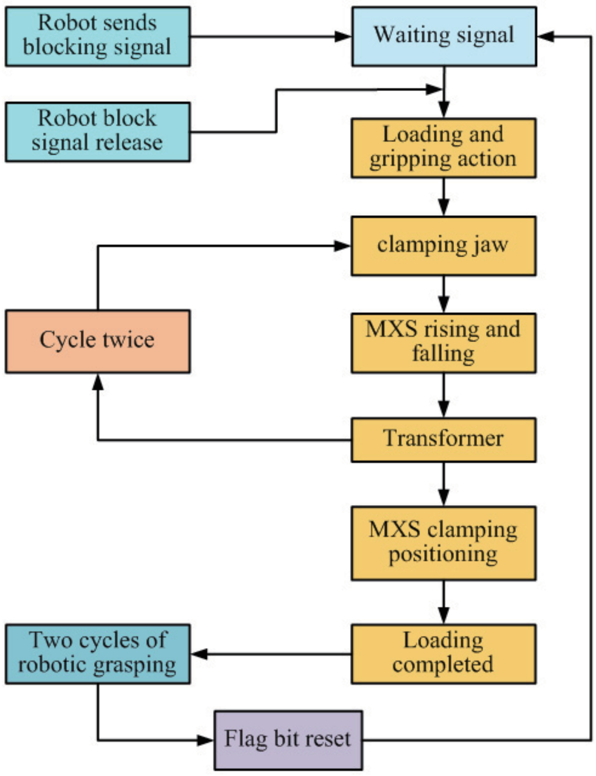


Figure 4. Operation flow chart of feeder

Figure 5 shows the operation flow diagram of the turning mechanism. When the robot sends a signal, the turning mechanism first receives the signal and then takes out the target workpiece from machining centre No. 1 and moves it to the lower feeder of the turning mechanism [22,23]. At this point the robot arm sends a signal to the turning mechanism, which receives the signal and then starts to turn the target workpiece. the MRHQ cylinder will first tighten the workpiece and then rotate it, during this process the cleaning pump is switched on at the same time and the CY cylinder will clean the workpiece. When the cleaning is complete, the CY cylinder moves the workpiece to a waiting position and the MXS cylinder pushes the workpiece into a fixed position for the robot arm to pick it up. When the robot arm has finished picking up the workpiece, it returns to the initial position and repeats the above operation.

Figure 6 shows the operation flow diagram of the downcomer. When the robot receives a downfeed notification from machining centre two, it will send a work signal to the downfeeder to inform the downfeeder robot arm to start the downfeed operation [24,25]. When the robot arm has finished unloading, the unloading cylinder CY will perform a push operation, pushing the workpiece in the unloader to the unloader flip clamping position,

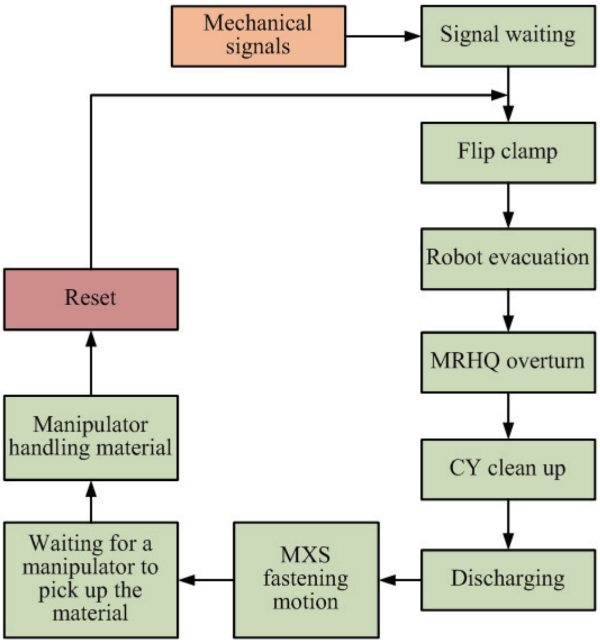


FIGURE 5. Operation flow chart of the turning mechanism

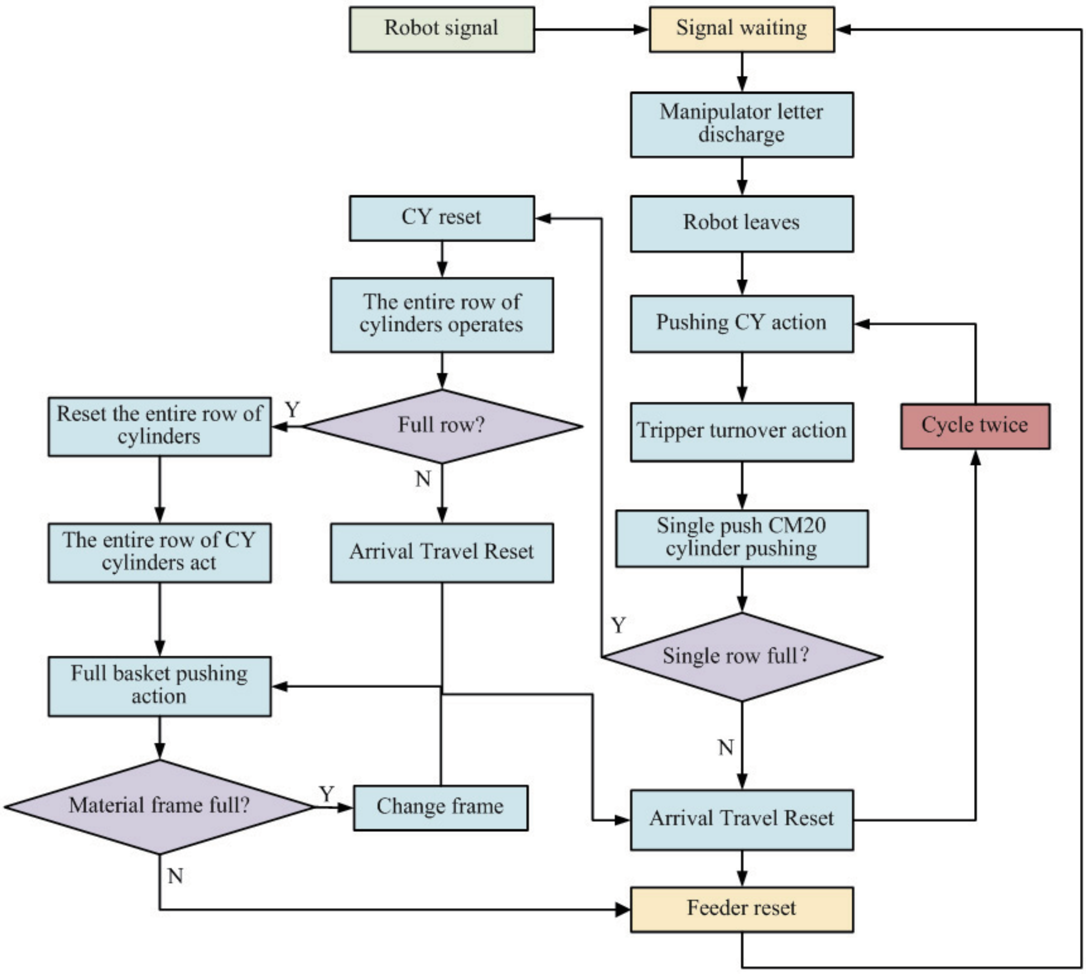


FIGURE 6. Operation flow chart of feeder

using the cylinder CM20 to complete the push operation of the individual workpiece. If the cylinder meets the single row full status, then CY reset is carried out; if not, then the CY pushing step needs to be repeated. Once the CY reset has been completed, the whole row of cylinders will be pushed, if the cylinders are full, then the whole row of cylinders will be reset and the CY cylinders will be pushed into the lower frame. Once the frame has been filled, the staff will be reminded to provide a new frame to keep the whole downcomer cycle running. By presenting a flow chart of each part, the study will then use the relevant software to automate the operation of each part and test the performance of the automatic production and processing system built for this study.

4. **Simulation Experimental Setup and Analysis of Results.** In order to test the performance of the final designed automatic production and processing system, the study used Delta Electronics' DVP programmable control software ISPSoft to build a simulation experimental environment to realize the performance testing of the system. The parameter settings for the entire experimental environment are shown in Table 1.

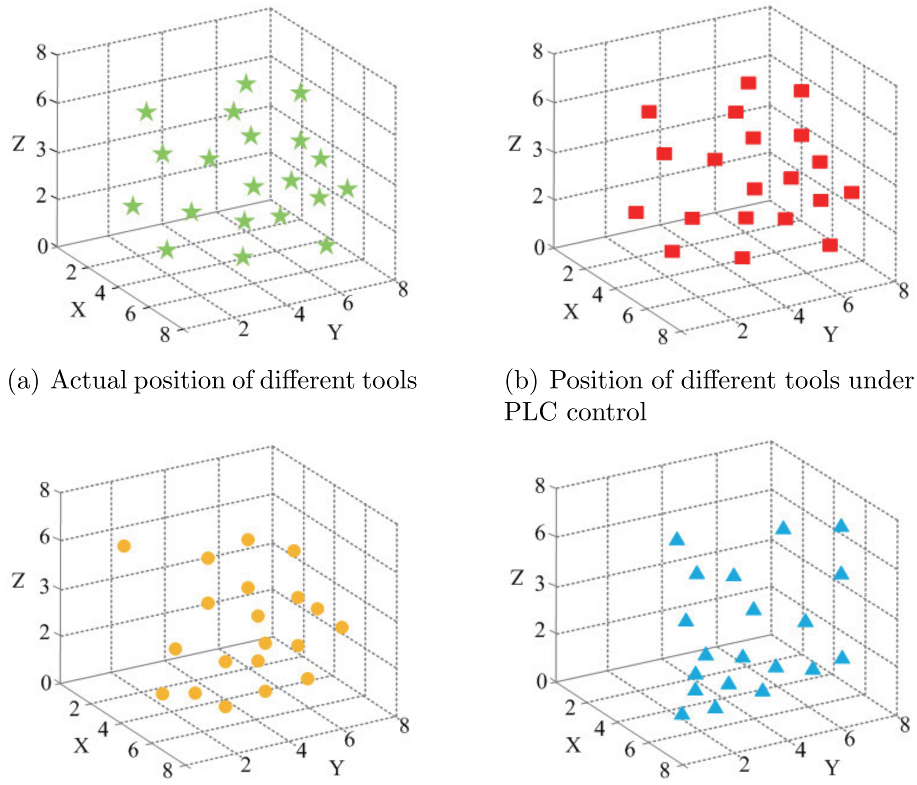
Table 1. Experimental environment parameter settings

Target	Parameter value
Working voltage	220 V
Operating current	80 A
Operating frequency	60 Hz
Operating system	Windows 10
Programming language	C++
Programming software	ISPSoft

The specific parameters taken for the experimental environment of this study are given in Table 1. The operating voltage, operating current and operating frequency are 220 V, 80 A and 60 Hz, respectively. The programming software used for the system is ISPSoft, the programming language is C++ and the operating system is Windows 10. To prove the effectiveness and rationality of the automatic production machining system, the study first analyzes the effect of controlling the machining trajectory of the CNC machine tool under the use of PLC control and computer technology.

Figure 7 shows the coordinate positions of the tool models of the CNC machine tool under different control schemes. Among them, Figure 7(a) shows the coordinates of the motion trajectory of any ten tool models in the actual motion trajectory of the CNC machine tool, while Figure 7(b), Figure 7(c) and Figure 7(d) show the coordinates of the motion trajectory of the tool models under PLC control, Distributed Control System (DCS) control, and FieldBus Control System (FCS). Comparing the tool trajectory coordinates of the three control methods with the actual trajectory coordinates, it can be seen that the tool trajectory coordinates of the PLC-controlled model almost coincide with the actual situation, while the other two control methods have some deviations. This shows that the PLC control is more effective than the other two traditional mechanical control methods and that the tool model under PLC control is able to move according to the actual trajectory.

Figure 8 shows the machining error of CNC machine tools under different control methods. A total of three machine control systems, PLC, DCS and FCS, were selected to compare the machining error performance. As can be seen from Figure 8, the machining error value of the CNC machine tool controlled by PLC is much lower than the other two control methods. With the increase in the number of processing tools, the machining



(a) Actual position of different tools

(b) Position of different tools under PLC control

(c) Position of different tools under DCS control

(d) Position of different tools under FCS control

Figure 7. Coordinate positions of the CNC machine tool model under different controls

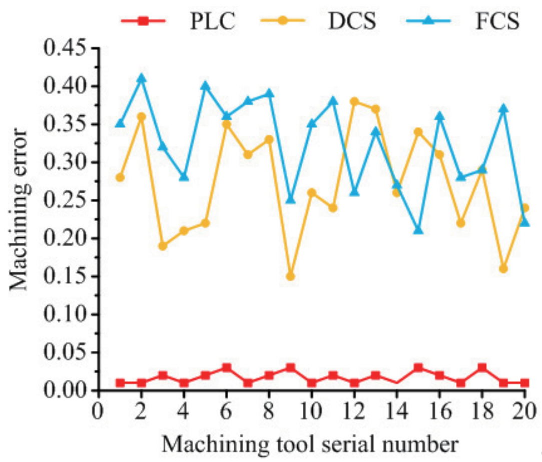


Figure 8. Machining error of CNC machine under different control methods

error of CNC machine tools under PLC control is controlled within 0.03, the machining error of CNC machine tools under DCS control is controlled between 0.15 and 0.38, and the machining error of CNC machine tools under FCS control is controlled between 0.21 and 0.41. It can be seen that the use of PLC control of CNC machine tool machining error value is much lower than the other two control methods under the error value, indicating the control method of control better.

Figure 9 shows the machining trajectory control accuracy of CNC machine tools under different control methods. As can be seen from Figure 9, the machining trajectory control accuracy of CNC machine tools controlled by PLC is much higher than the other two control methods. With the increase in the number of processing tools, PLC control of CNC machine tool machining trajectory control accuracy is in 0.81-0.95, DCS control of CNC machine tool machining trajectory control accuracy between 0.72-0.85, FCS control of CNC machine tool machining trajectory control accuracy is controlled between 0.65-0.84. It can be seen that the CNC machine tool processing trajectory accuracy value using PLC control is much higher than the other two algorithms, and the trajectory accuracy control effect is better.

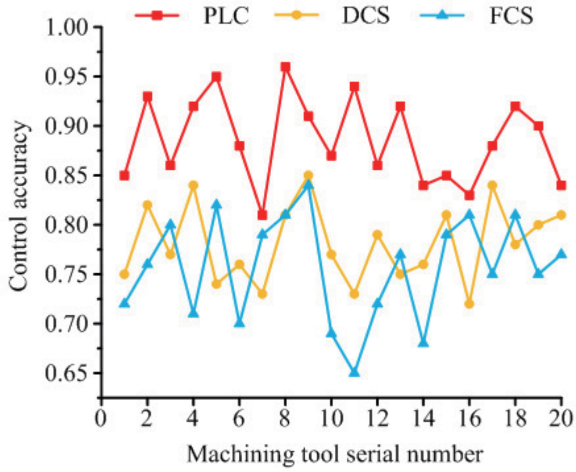


FIGURE 9. Control accuracy of machining trajectory of CNC machine tool under different control methods

Figure 10 shows the time consumption of the automatic production processing system with the different control methods. As can be seen from Figure 10, despite increasing the number of experiments, the time consumption level of the automatic production machining system with PLC control was within 1 min, much lower than the other two control methods. A total of ten experiments were repeated and the longest time consumed by the automatic production machining system under PLC control, DCS control and FCS control was 1.1 min, 5.2 min and 5.9 min, respectively. It can be seen that PLC control

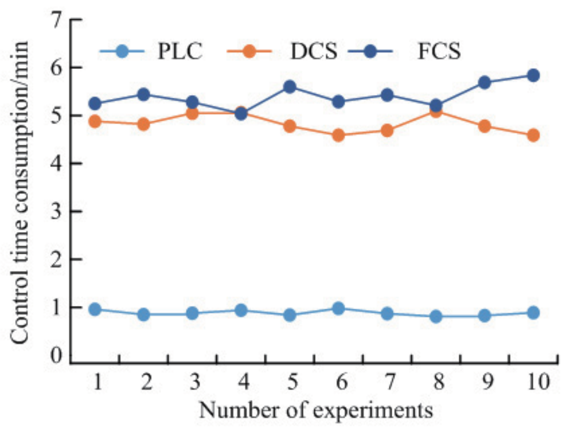


FIGURE 10. Time consumption of automatic production and processing system with different control methods

enables the automatic machining system to complete the machine automation production machining tasks faster.

Figure 11 shows the stability results of the automatic production and processing system under different control methods. As can be seen from Figure 11, with the increase in the number of experiments, the automatic production and processing system under the three control methods eventually reached a stable state, in which the PLC-controlled automatic production and processing system began to reach a stable state after about 55 experiments, the DCS-controlled automatic production and processing system began to reach a stable state after about 75 experiments, and the FCS-controlled automatic production and processing system began to reach a stable state after about 95 experiments. The system under FCS control reached steady state after about 95 experiments.

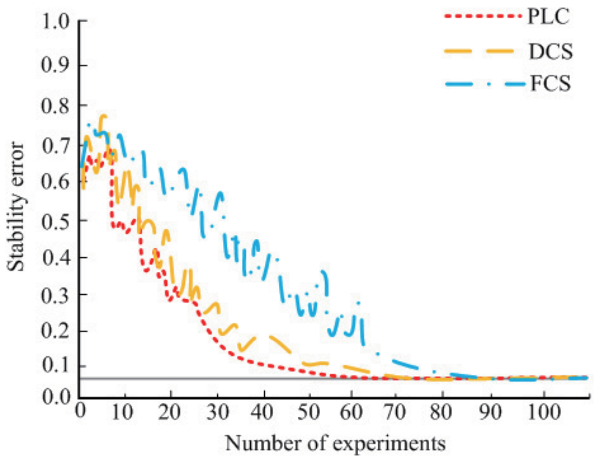


Figure 11. Stability results of automatic production and processing system with different control methods

In summary, comparing the results of the above-mentioned performance tests, it can be seen that PLC control enables CNC machine tools to have a better trajectory, with individual machine tools able to move to the specified position in accordance with the established task. In addition, PLC control of the CNC machine tool machining error value is smaller, in 0.01 to 0.03 or so floating, machining trajectory control accuracy is higher, up to 0.95. PLC control will be used in automatic production processing system, the system can be faster to achieve stability, and the control time consumed is also shorter.

5. **Discussion.** In this study, the optimization of CNC machine tool machining trajectory control method is carried out by using programmable logic controller and industrial computer technology. Meanwhile, the experimental results also verify the effectiveness and superiority of such optimization scheme. First, the PLC was verified through comparative experiments to exhibit high performance in the motion trajectory, machining error and control accuracy of the CNC machine tool. Figure 7 shows that the coordinates of the tool model motion trajectory under PLC control almost coincide with the actual situation, verifying its accuracy in trajectory control. This is further confirmed in Figure 9 at the same time, the machining trajectory control accuracy of CNC machine tools under PLC control can reach up to 0.95, which is much higher than that of DCS and FCS control. Secondly, the PLC control system not only improves machining accuracy, but also shows advantages in system stability and time consumption. As shown in Figure 10 and Figure 11, the time consumption required for PLC control and the number of experiments to reach a stable state are significantly less than the other two control methods, even though

several experiments were conducted. However, the environment of this experiment was conducted under specific voltages, currents and frequencies, and was implemented under the ISPSoft programming software and Windows 10 operating system, which somewhat limits the ability to generalize the results. In addition, the programming language used in the experiments was C++, but it was not explored whether the system performance would be different when other programming languages were used.

This study not only demonstrated the superiority of PLC control in the machining trajectory control of CNC machine tools, but also clearly presented the significant advantages of PLC control over DCS and FCS control in terms of machining error, machining trajectory control accuracy, system stability, and time consumption through the specific data of simulation experiments. At the same time, these findings provide strong empirical support for the widespread adoption of PLC control in industrial production, and are of great significance in guiding the optimization and control of machining trajectories in actual production. In conclusion, the implementation and optimization of PLC control and the comparison with other control methods in this study bring new research directions and possibilities of practical applications in the field of CNC machine tool machining, provide empirical evidence base and trigger insights for further research. Future research could delve deeper into the performance of PLC control in different environments and conditions, and the effects of additional variables could be investigated to more fully understand and utilize the potential of PLC control.

6. **Conclusion.** With the development of science and technology, the human society demands more and more functions and quality of products, the cycle of product renewal is getting shorter and shorter, and the complexity of products is also increasing. In this context, the study uses a programmable logic controller combined with an industrial computer to optimize the machining trajectory control method of a CNC machine tool and to design an automatic machining system for the cylinder body on this basis. The experimental results show that the coordinates of the tool model trajectory under PLC control are more realistic than those under DCS and FCS control. The machining error value of the CNC machine tool with PLC control is much lower than the other two control methods, with an error control range of 0.01 to 0.03. The machining trajectory control accuracy of the CNC machine tool with PLC control is within 0.81 to 0.95, with a maximum of 0.95, which is much higher than the other two control methods. Comparing the machining time consumption and stability results of the three methods, it was found that the longest time taken by the machining system under PLC control was only 1.1 min, and the system was able to reach a stable state before the other two control methods under this control method. In summary, the automatic machining system designed in this research has good machining performance and can be applied to actual production, but this research has only studied a few important structures in the machining system, there are still certain shortcomings, and the subsequent can be deeply optimized to further reduce the system error.

7. **Future Work.**

7.1. **Contribution of this research.** In this study, in response to the real demand for high functionality and high quality requirements of modern products and rapid replacement, a Programmable Logic Controller (PLC) combined with an industrial computer was used to optimize the machining trajectory control method of a CNC machine tool, and a cylinder body automatic machining system was designed accordingly. The experimental results verify that the system shows superior machining accuracy, lower error value and higher stability under PLC control, especially its error control range and machining trajectory control accuracy are far more than DCS control and FCS control. In addition, the time for the system to reach a stable state under PLC control is also significantly shortened.

7.2. **Shortcomings of the study.** Although this study has achieved a series of positive results, there are still some shortcomings. Firstly, this study mainly focuses on the automatic machining of the cylinder body, which is relatively narrow in scope and needs to be further expanded to more types of product machining. Secondly, the study mainly compares three control methods, PLC, DCS and FCS, and more control methods should be considered in future work to evaluate the superiority of PLC control more comprehensively. Finally, this study mainly focuses on the examination of machining accuracy and stability, and its performance in terms of energy saving, cost control and sustainability can be further explored in the future.

7.3. **Future research directions.** Based on the above contributions and shortcomings, future research directions can be developed in the following areas.

Expanding the scope of application: Further study and test the adaptability and efficiency of the automatic machining system under PLC control in the processing of different types of products, and expand its application in a wider range of fields.

Explore a variety of control methods: Join more types of control methods for comparative analysis, in order to comprehensively evaluate the performance and feasibility of PLC control in various aspects.

In-depth study of other performance indicators: Conduct an in-depth study of the automated machining system under PLC control in terms of energy saving, cost, sustainability, etc., with a view to discovering more optimization possibilities.

Optimization algorithm study: In-depth study and optimization of PLC control algorithms to further improve the stability, accuracy and efficiency of the machining system.

User-friendliness research: Optimize the PLC control interface and operation process, in order to improve the operator's experience and reduce the difficulty of operation.

Through in-depth research in these directions, we aim to understand and optimize the automatic machining system under PLC control more comprehensively and promote its wide application in industrial production.

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