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# Program Design of Mechatronics Intelligent Knitting Machine Based on CAD Data Structure

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**Abstract.** In order to improve the automation level of 3D knitting machine, the author proposes a control system of mechatronics intelligent knitting machine based on CAD data structure. The control system adopts the AS-49PC-4 motion control card to design the "PC + motion control card" control scheme, and introduces the connection between the AS-49PC-4 motion control card and the driver and the stepping motor, and the specific realization of the control motor. Experimental results show that the motion control card performs the best linear interpolation at the pulse rate of 0.0023×10-6. The smooth acceleration generated by the high-speed resolution and the 2-level stop by the deceleration setting function to control the vibration measures to prevent vibration, it meets the control requirements for the motor-driven air valve to move to the position of the machine tool, reduces the positioning error, and ensures the positioning accuracy. In the weave test, when the theoretical braiding angle is 60°, 45° and 30° respectively, the maximum error is less than 1°, and the maximum error of coverage is about 1.3%. The braiding parameter control is accurate and effective. Using this scheme, the development cycle of the system can be shortened, the interpolation accuracy can be improved, and the knitting error rate can be reduced.

**Keywords:** Motion control card; three-dimensional braiding machine; computer control system; stepping motor.
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## 1 INTRODUCTION

In a broad sense, weaving refers to the movement of multiple fibers (or yarns) arranged along the fabric forming direction according to a certain law, so that the fibers (or yarns) are intertwined with each other at a certain angle to form a fabric. Three-dimensional weaving belongs to the category of textile technology. In the three-dimensional braid, the braided fibers (or yarns) are oriented at a certain angle along the fabric forming direction, the thickness of the braid is more than three times the diameter of the participating braided yarns or fiber bundles, and the yarns are interwoven in the thickness direction. In the three-dimensional weaving process, the yarns are individually controlled, so it is not suitable for weaving fabrics with large widths; Fibers (or yarns) are intertwined in the fabric thickness direction, and theoretically, the fabric thickness can be infinite; The yarn arrangement can be distributed according to the cross-sectional shape of the product, which is suitable for the weaving of special-shaped components [1]. Different from woven fabrics, woven fabrics are two yarn systems of warp and weft yarns, and weft yarns are fed during weaving; Different from knitted fabrics, knitted fabrics have a yarn loop structure.

According to the type of weaving, 3D weaving techniques can be divided into square weaving and circular weaving [2, 3]. Square three-dimensional weaving means that the knitting yarns are arranged in a rectangular shape on the machine chassis, weaving fabrics with a rectangular cross section or a combination of rectangles; Circular three-dimensional weaving means that the knitting yarns are arranged in a circular pattern on the machine chassis, and weaving a fabric with a circular cross section or a combination of circles. According to the different movement modes of knitting yarns, three-dimensional weaving technology can be divided into angle wheel three-dimensional weaving and determinant three-dimensional weaving. Angle wheel knitting equipment can be woven at high speed, while determinant knitting equipment has compact structure, low cost and good versatility [4, 5]. According to the forming length of the braid, three-dimensional braiding can be divided into continuous braiding and fixed-length braiding. Continuous knitting means that the knitting yarn is fed continuously; Fixed-length knitting means that the knitting yarn is of fixed length.

## 2 LITERATURE REVIEW

With the development of science and technology and the progress of the textile industry, textile composite materials have been widely used in various fields. Due to the composite material woven by the three-dimensional special-shaped whole, it overcomes the disadvantage that the traditional composite material is easy to delaminate because there is no yarn passing between the layers, its appearance has attracted great attention from the scientific and technological circles of various countries, some developed countries such as the United States, France, Germany, and Russia have invested a lot of manpower and material resources in research and development. Many researchers took the lead in realizing the CAD/CAM system of large-scale knitting machines, and applied it to actual production in the following year [6].

Vasantha, G. et al. define the Universal Design Structure (CDS) as a set of frequently occurring features with common parameter values in a CAD database and demonstrated how to effectively calculate CDS for hundreds of 3D CAD models. It is also explained that how prototype implementation successfully mines CDS and identifies replaceable hole features in industrial valve design datasets [7]. Baldacchini, T. et al. used an in vitro experimental platform for delayed imaging of cancer cell dynamics during angiogenesis in microvascular networks, which directly writes laser into cell printing and combines it into a rat mesenteric culture model; Simulate a 3D in vivo culture model. The laser 3D printing method has important prospects in the 3D printing of tissue engineering scaffolds, microstructure medical devices, and other medical related structures. [8].

Andhyal, P. et al. used a 5D model to store spatial data, such as project schedules, 3D models of itemized element costs and quantities, and structures. The conclusion of this study indicates that the GIS model can serve as a real-time database for all parties involved in various stages of the project [9]. Brahmi, R. et al. proposed a method that allows for interoperability between system specifications and CAD models of the product being designed. System engineers use the data collected from the SysML model to check and validate product requirements based on the V model. Taking the bicycle pedal as an example, the effectiveness and efficiency of the proposed method were demonstrated and demonstrated [10].

During the weaving process, the basic structural unit cube of the prefab can change the ratio of length, width and height with the change of the shape and size of the part, the weaving process is extremely flexible and can be arbitrarily changed to meet the requirements of different weaving shapes, realize direct overall weaving. The special-shaped three-dimensional braiding machine is the key equipment for three-dimensional braiding technology. Compared with developed countries, the automation level of 3D braiding equipment in my country is relatively low, which is a key problem to be solved urgently [11,12]. The author designs the control scheme of "PC + motion control card", and systematically studies the application of the four-axis motion control card AS-49PC-4 in the computer control system of the special-shaped three-dimensional knitting machine.

## 3 RESEARCH METHODS

### 3.1 The Working Mechanism of the Special-shaped Three-dimensional Braiding Machine

The special-shaped three-dimensional braiding machine uses a four-step braiding process to weave preforms of various shapes [13], as shown in Figure 1.

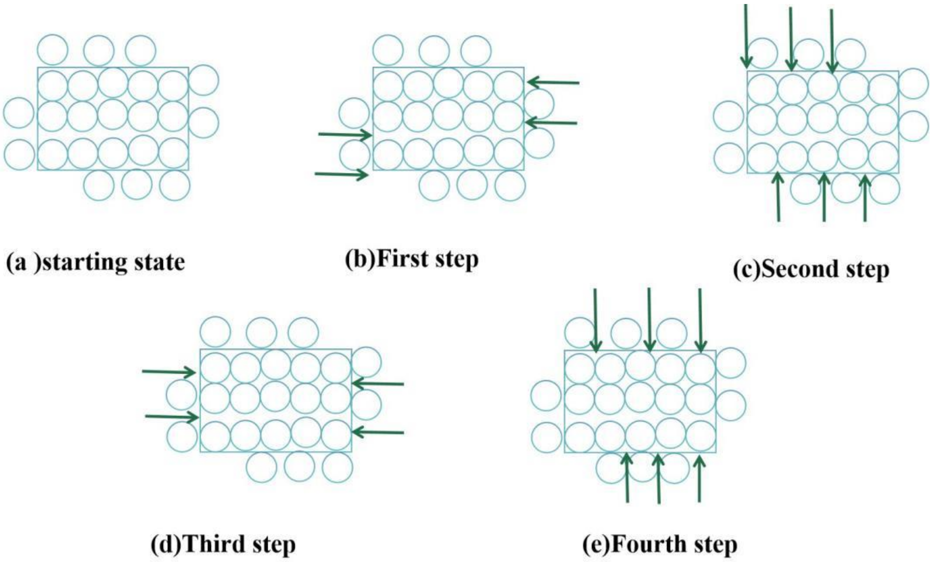


**Figure 1**: Schematic diagram of the four-step knitting process of rectangular knitting.

The knitting yarn is carried by the yarn carrier, and arranged according to the cross-sectional shape of the preforms, the yarn carrier carries the knitting yarns to move along four directions of the knitting machine, so that the knitting yarns are interwoven with each other. A knitting cycle is divided into 4 steps, each step of the yarn carrier can only move in the horizontal or vertical direction. Step 1, the yarn carrier is staggered in row direction; Step 2, the yarn carrier is staggered in column direction; Step 3, the stepping direction of the yarn carrier is opposite to the first step. Likewise, the movement of the yarn carrier in step 4 is reversed from that in step 2. After 4 steps, the arrangement of the yarn carriers is the same as the initial one. Typically, after each knitting cycle, both have a process of tightening the yarn to make the braided structure more compact [14].

After a knitting cycle, the arrangement of the yarn carriers on the machine chassis returns to the initial arrangement, completing a machine cycle. During the cycle of the machine, the row and column in which the edge yarn is located remains stationary in the movement of the corresponding row and column. After several machine cycles, the individual yarn carriers return to the starting position. By repeating the above weaving steps, the yarns will be intertwined to form a preform of a certain length. The arrangement pattern of the yarn carriers on the chassis indicates the cross-sectional shape of the preform, a square preform is usually represented in the form of $m \times n$, where $m$ is the number of rows of the main yarn that the yarn carriers are arranged on the machine chassis, $n$ is the number of columns of the main yarn. The total number of braided yarns in the preform is the following equation (3.1) [15]:

$$N = m \times n + m + n \tag{3.1}$$

## 3.2 Control System Design

Motion control is a subject of the automation discipline, which is based on a certain servo drive (such as motor, linear controller, etc.), under complex conditions, using pre-designed control schemes and instructions; it can perform precise position control, speed control or torque control on the mechanical movement of the production machine. Motion control is widely used in packaging machinery, medical equipment, printing machinery, and textile machinery, semiconductor manufacturing and integrated industries. A typical motion control system is mainly composed of a controller, a power drive device and an electric motor [16], its structure is shown in Figure 2.

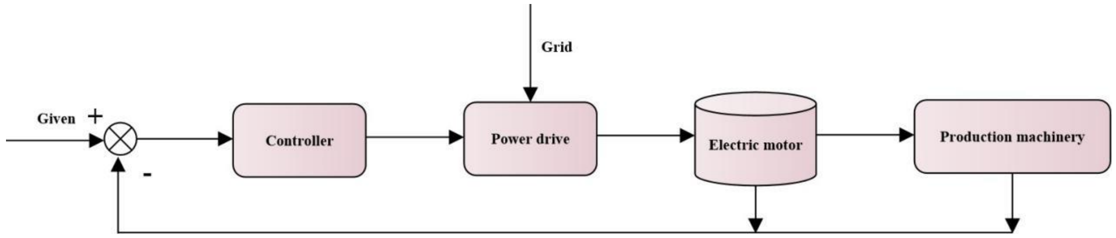


**Figure 2**: Basic structure diagram of motion control system.

Motion control cards have unique advantages. The library functions of the motion control card include two-dimensional linear interpolation functions, circular interpolation functions, and multi-axis linkage functions, speed control can provide S- and T-shaped acceleration. Based on the motion control card, develop automated products and robot control systems, you can directly use the library functions attached to the motion control card, which saves the development of the underlying driver, reduced development cycle and development costs. And the openness of its library functions provides a convenient condition for developing an open motion control system. Due to its advantages of convenient control and fast programming, motion control cards are widely used in the field of automation control, and in position control systems that require precise positioning or fixed length. Motion control cards are also widely used in CNC systems, such as engraving machines [17].

The upper control system of the special-shaped three-dimensional braiding machine adopts the scheme of "PC machine + motion control card", which realizes the automatic production process of three-dimensional special-shaped overall braiding, and can automatically weave a variety of preforms with different cross-sectional shapes [18], the structure of the control system as shown in Figure 3. The system adopts the motion control card model AS-49PC-4, and its basic parameters are shown in Table 1.

In the four directions of the special-shaped three-dimensional knitting machine, a stepping motor is designed to be installed in each direction, drive the steam valve to move according to the movement steps of the yarn carrier [19], open the valve at an appropriate position, and push the yarn carrier to carry the knitting yarn [20]. The stepper motor in 4 directions is only moving in two directions at a certain moment.

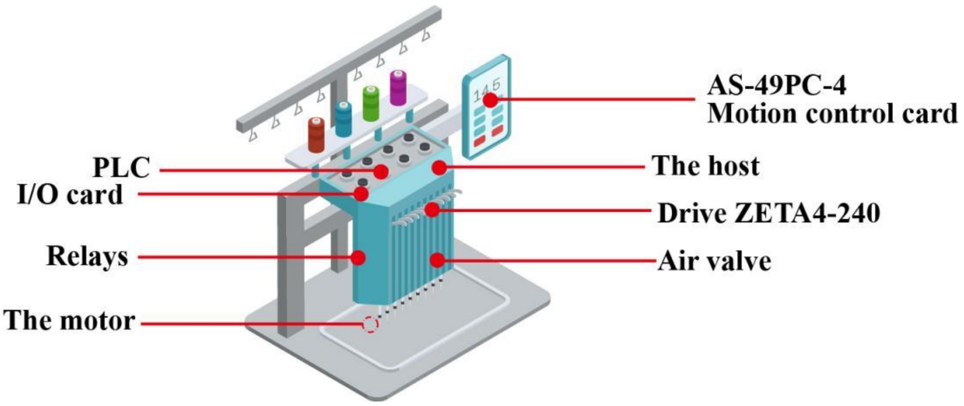


**Figure 3**: Structure diagram of the control system of the special-shaped three-dimensional braiding machine.

| *Order number* | *Project* | *Specific parameters* |
|---|---|---|
| 1 | Drive way | Dual pulse mode / single pulse mode |
| 2 | Maximum step size per command | ±16777215 steps |
| 3 | Speed | 1 - 400 kpps |
| 4 | Pulse output type | The collector opens the way，100 mA/ch, Vmax = 30 V DC |
| 5 | Input voltage of the limit switch | DC +12V- 24V |
| 6 | Digital input | 8 Channel isolation input |
| 7 | Digital output | DC +12V- 24V |

**Table 1**: Basic parameters of AS-49PC-4.

That is, when the stepper motor in the east-west direction is running, the stepper motor in the north-south direction does not work; The opposite is true. Therefore, the design adopts two drivers to drive 4 stepper motors, and the relay is used as steering control between the driver and the motor. After 4 steps, a knitting cycle is completed, the motor returns to the original position, and the arrangement of the yarn carrier is the same as the initial one, and then executes in sequence. The switching action of the air valve is controlled by a programmable logic controller (PLC), and through the front position sensor and the rear position sensor on each steam valve, it is detected whether the steam valve is in place, and whether the air valve is reset in place [21].

Stepper motor can be used as a special motor for control, using its characteristics of no accumulated error, widely used in various open-loop controls. Stepper motors include permanent magnet stepper motor (PM), reactive stepper motor (VR) and hybrid stepper motor (HB)[22]. Permanent magnet stepping motors are generally two-phase, with small torque and volume, and the stepping angle is generally 7.5° or 15°; Reactive stepping motors are generally three-phase, which can achieve large torque output, and the stepping angle is generally 1. 5°, but the noise and vibration are very large; The hybrid stepping motor combines the advantages of the permanent magnet type and the reactive type, and is divided into two-phase and five-phase, the two-phase stepping angle is generally 1.8°, while the five-phase stepping angle is generally 0.72. Hybrid stepper motors are the most widely used [23-24].

The motion control card completes the management and control of the stepping motor, and is the interface between the host and the mechanical device. The AS-49PC-4 motion control card introduced by Japan SEEK Company is selected in the system control. AS-49PC-4 card is a 4-axis

PC I bus motion control card, designed and manufactured with professional motion control chip AS-49F, suitable for the positioning and speed of servo, stepping and DC motors controlled by pulse signal, and can be directly The CPU implements control. The movement of each axis is controlled by a separate AS-49F chip, with a trapezoidal acceleration and deceleration curve, and the maximum output frequency can reach 4.9MHz. Using the synchronous start function, the optimal linear interpolation can be performed at a pulse rate of 0.002 3×10-6. Each AS-49PC-4 card can control 4-axis servo, stepper and DC motors, and each axis can output pulse and direction signals to control the operation of the motor; At the same time, external switch signals such as origin, pre-origin, deceleration, and limit can be connected to realize the functions of returning to the origin and protection [25-26], these switch signals are automatically detected and responded by the AS-49PC-4 card.

## 4 RESULT ANALYSIS - WEAVING PROCESS CONTROL

In the control system of the special-shaped three-dimensional knitting machine, the knitting process is controlled by the PC command AS-49PC-4 card. AS-49PC-4 card is used as motor upper control unit, form master-slave control structure with PC machine: The PC is responsible for the management of the human-computer interaction interface and the real-time monitoring of the control system, including the management of the keyboard and mouse, the display of system status, the sending of control commands, and the monitoring of external signals; The AS-49PC-4 card completes all the details of motion control, including the output of pulse and direction signals, the processing of automatic acceleration and deceleration, the detection of signals such as origin and limit, and so on. Developed in VB language, using the motion function library of AS-49PC-4, through programming, it controls the forward and reverse running and rotation speed of the motor in 4 directions, and completes the weaving action of prefabricated parts of various shapes [27].

### 4.1 AS-49PC-4 Connection with Driver and Stepper Motor

In the control system of the special-shaped three-dimensional knitting machine, the AS-49PC-4 motion control card is connected with the driver and the stepping motor. The main task is to generate pulse and direction signals, control the operation of the stepper motor, and make the knitting machine perform the knitting action according to the knitting process file. Its connection diagram is shown in Figure 4.

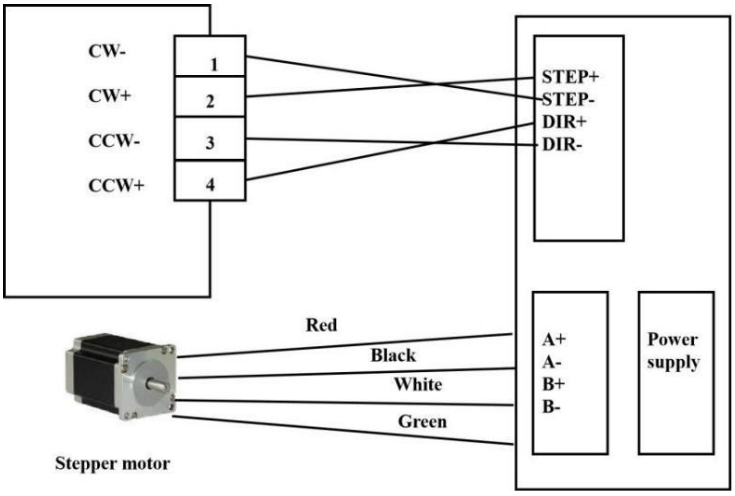


**Figure 4**: The connection between AS-49PC-4 and the driver and stepper motor.

In Figure 4, CW +/CW - is the forward running pulse, CCW + /CCW - is the reverse running pulse, they are respectively connected with the STEP signal (input signal of stepping pulse) and D IR signal (controlling the running direction of the motor) of the driver. In addition, the AS-49PC-4 motion control card must be supplied with DC 24 V input. Pulses are input to the driver from STEP +, STEP -, the pulse frequency controls the rotation speed of the motor, and the number of pulses controls the angular displacement of the motor. The direction signal is input to the driver from DIR + and DIR -, and the high and low levels control the direction of the stepper motor.

### 4.2 AS - 49PC - 4 Cards Control Motor Operation

In this system, AS-49PC-4 card according to the requirements of the weaving process file, control the stepper motor to move in 4 directions of the knitting machine [28].

When driving the south motor and the north motor, the relay switch is off, and the two drivers drive the north and south motors. First give the reset command to the two drivers, stop the motor running, and then give the relay disconnection signal; Then give the driver CCW signal to control the running direction of the motor; Give the driver a start command to make the motor end the suspension state; Give the driver CW signal again to form positive and negative pulse currents to drive the motor to run. Since the driver is adjusted to 200 steps, the motor runs for one week, after calculation, after the north-south motor runs for 2.5 weeks, the north-south steam valve passes through the distance of a position point of the machine tool, and finally stops the motor operation.

The operation process of the east-west motor is similar, except that the east-west motor runs independently according to the weaving requirements, and the relay is turned on; And due to the mechanical structure of the machine tool, after the east-west motor runs for 1.8 weeks, the east or west steam valve passes through the distance between a position point of the machine tool.

When the stepper motor drives the air valve, the speed curve of starting, running and ending of the motor is mainly considered, as shown in Figure 5. By setting the speed data to the 16-bit speed register of the AS-49PC-4 motion control card, the starting, running and ending of the stepper motor can be controlled. The maximum transfer time is 600 ns, and the data will be held until the end or reset signal is input.

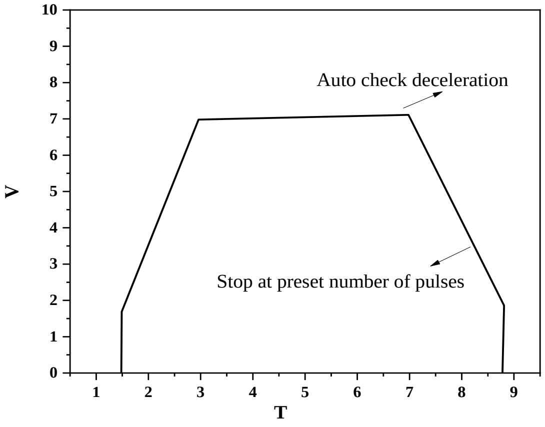


**Figure 5**: Speed curve

### 4.3 Realization of Stepper Motor Speed and Steering

Use the function AxSpeedSet() to set the speed data to AS49F, including low-speed lsp, high-speed hsp, acceleration acr, etc., the steps are:

(1) Set the low speed; (2) Set the high speed; (3) Set the acceleration, use the functions AxReSet() and AxModeSet() to reset the AS49F and initialize the settings, AxSpeedSet() and AxStartSet() Set the speed and start Pulse data to AS49F. Call the function AxIndex() to execute the moving process; (4) Forward running; (5) Reverse running; (6) Deceleration stop

The AS-49PC-4 motion control card can perform the best linear interpolation at the pulse rate of 0.0023×10-6, with a high degree of subdivision. The smooth acceleration generated by the high speed resolution and the 2-level stop control of the deceleration setting function prevent vibration, meet the control requirements for the motor-driven air valve to move to the machine tool position, reduce the positioning error, and ensure the positioning accuracy, accuracy can effectively reduce the knitting error rate.

### 4.4 Weaving Test

To verify the control effect, the braiding angle and coverage test data of the braiding object are shown in Table 2 and Table 3 respectively.

| ***Woven core mold flat*** | ***Theoretical weaving Angle*** | ***crest value*** | ***least value*** | ***mean value*** | ***maximum error*** |
|---|---|---|---|---|---|
| **The cylinder core mold** | 30 | 30.833 | 29.160 | 29.906 | 0.840 |
| | 45 | 45.864 | 44.180 | 45.037 | 0.864 |
| | 60 | 60.685 | 59.166 | 59.976 | 0.835 |
| **Cross section change core module** | 45 | 45.875 | 44.065 | 44.968 | 0.935 |

**Table 2**: Knitting angle (°) test data table.

| ***Woven core mold flat*** | ***Theoretical weaving Angle*** | ***crest value*** | ***least value*** | ***mean value*** | ***maximum error*** |
|---|---|---|---|---|---|
| **The cylinder core mold** | 75 | 75.602 | 74.883 | 75.236 | 0.601 |
| | 85 | 85.785 | 84.441 | 85.097 | 0.785 |
| **Cross section change core module** | 85 | 86.310 | 83.780 | 85.080 | 1.310 |

**Table 3**: Weaving the physical coverage test data sheet (%).

In the weaving industry, due to the different environmental humidity and the different tension of the weaving spindle spring, the friction force of the yarn during weaving is different, which will cause certain errors. It is generally believed that if the braiding angle error is within ± 3 °, the control is accurate and effective. It can be seen from the data in Table 2 and Table 3 that the maximum error is less than 1° and the maximum error of coverage is about 1.3% when the control theoretical braiding angle is 60°, 45° and 30° respectively. Therefore, it can be seen that the parameter control of the control system is accurate and effective.

## 5 CONCLUSION

The control system of the special-shaped three-dimensional knitting machine adopts the control scheme of "PC machine + motion control card", which makes the knitting algorithm easy to realize, the overall control is flexible, can be modified at any time, and it is easy to control the knitting machine to knit according to the needs, and the adaptability is relatively strong, it is convenient to expand the system functions, improve the control efficiency, and shorten the development cycle of the control system. At the same time, the AS-49PC-4 card is used in the control system to realize the management and control of the stepper motor, as the interface between the host computer and the mechanical device, the AS-49PC-4 motion control card is used in the execution efficiency of the interpolation algorithm and the motion function using a more efficient method, the interpolation accuracy, interpolation speed and real-time performance are improved. The best linear interpolation and smooth acceleration and deceleration functions of the card are used in the system to prevent the vibration from being stopped, ensure the positioning accuracy, and effectively reduce the knitting error rate.

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