Journal of Research in Science and Engineering (JRSE)
ISSN: 1656-1996 Volume-7, Issue-3, March 2025
DOI: 10.53469/jrse.2025.07(03).10

Design of a Fully Automatic Three-Dimensional Loom Control System Based on PLC

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Abstract: ***This study proposes a PLC-based fully automatic control system for 3D flat looms to address the limitations of current domestic 3D textile production equipment. First, the shortcomings of existing control systems (e.g., low efficiency and mechanical instability) are analyzed. Subsequently, the hardware and software designs of the proposed system are elaborated, including the selection of key components such as the Haoxin H226IM PLC and Sqeldt CS1-U magnetic switches. Experimental results demonstrate that the system achieves a weaving efficiency of 120 mm/h for shallow crossbend fabrics under fully automatic operation.***

Keywords: 3D textile, 3D loom, PLC, Control system**.**

1. Introduction

In recent years, China's textile industry has experienced rapid growth, leading the world in fiber processing volume, chemical fiber production, and textile exports. Three-dimensional woven materials have garnered significant attention due to their diverse preparation methods, simplicity in manufacturing, and superior mechanical properties such as high specific strength, modulus, and impact resistance compared to 2D materials. These advantages make 3D textiles ideal for aerospace, automotive, and military applications [1], [2].

However, current domestic 3D weaving processes predominantly rely on manual or semi-automatic methods, resulting in low efficiency, poor product quality, and unstable workflows. Existing 3D looms face challenges such as excessive hardware complexity, frequent mechanical failures, and limited adaptability to diverse fabric structures. Additionally, energy waste and equipment wear further hinder their practicality [3]. To address these issues, this paper proposes a PLC-based fully automatic 3D flat loom control system. The system integrates warp lifting, weft insertion, beat-up, and fabric take-up mechanisms, offering advantages such as rapid response, operational simplicity, stability, precision, and versatility.

2. Overview of the 3D Loom Control System

The control system comprises the following subsystems:
Section headings come in several varieties:

2.1 The Main Circuit

The main circuit consists of various electrical components such as air switches, contactors, 24V DC power supplies, etc. It links all the control systems together and enables the entire system to operate fully automatically by transmitting signals.

2.2 PLC

PLC (Programmable Logic Controller) is an electronic system designed for digital computing operations in industrial environments. It uses programmable memory to store instructions, perform functions such as logic, sequence, timing, counting, and arithmetic, and control various mechanical working procedures through digital or analog input and output modules.

2.3 Heddle Lifting Control System

The heddle lifting control system is responsible for raising the heddle frames to create an opening in the warp yarn layer, allowing the interlacing of the weft yarns with the warp yarns to form fabric. This system consists of 18 cylinders that control the movement of the heddle frames, electromagnetic valves, and magnetic switches. During the weaving process, fabric production parameters can be adjusted by altering the sequence of heddle lifting motions.

2.4 Weft Insertion Control System

The purpose of the weft insertion system is to guide the position of the weft yarn, drawing it from one side of the loom into the warp yarn layer. This system is composed of a weft insertion sword, vertical needles, water nozzles, auxiliary vertical needles, and cylinders controlling the movement of the sword and vertical needles, as well as magnetic switches. The weft insertion control is realized through the integration of magnetic switch signals and the control program of the PLC.

2.5 Beating-Up Control System

The function of the beating-up system is to push the newly inserted weft yarn toward the reed to form the fabric. This system consists of a beating-up plate, beating-up cylinders, and magnetic switches. Beating-up control is achieved through the reception of magnetic switch signals and the control program of the PLC.

2.6 Winding Control System

The winding system is responsible for drawing the fabric, which has been partially formed at the shedding point, away from the weaving area and transporting it for further processing. This function is achieved using a stepper motor to drive the clamping device for automatic winding.

2.7 Touchscreen Interaction System

The touchscreen interfaces with the control program, enabling parameter settings and machine operation. Below is the configuration of the control system for the fully automatic three-dimensional loom (see Figure 1).

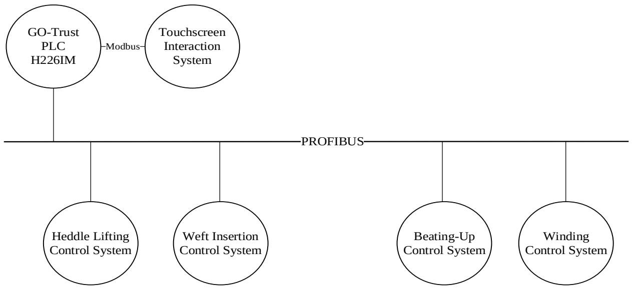

Figure 1: Composition diagram of the control system

3. Hardware Design of 3D Weaving Machine Control System

3.1 Selection of PLC

The fully automatic 3D flat loom requires real-time signal acquisition and the corresponding signal output to drive the motion of various systems. The systems are connected to a large number of external components, which necessitates the PLC to have rapid computational capabilities [4]. After threading, the loom needs detailed debugging, which requires the PLC to have easy maintenance features. Based on these requirements, this system selects the H226IM PLC and corresponding expansion modules from the Haoxin CTH200 series. The operating voltage of this PLC is 24V, which matches the operating environment of the loom. The user program of the H226IM PLC includes instructions for bit logic, counters, timers, complex mathematical operations, and communication with other intelligent modules, allowing it to monitor input statuses and change output statuses to achieve control objectives [5]. The control system uses the PROFIBUS protocol for communication through the DP communication module SM277.

3.2 Selection of Sensing Components

As the fully automatic 3D flat loom adopts an electric signal control pneumatic scheme, in order to ensure the stability and safety of the loom system, it is necessary to detect the status of the cylinders. The CS1-U magnetic switch from the Sqeldt brand (see Table 1) was selected. This switch is a two-wire type with contacts, featuring advantages such as long switch life, high pressure resistance, and a wide operating range.

Table 1: Magnetic switching parameter

Name of index	*Specification*
Model	CS1-U
Sensor type	2-wire type
Voltage	5～240V AC/DC
Output current	100mA Max
Operating temperature	-20～80℃

3.3 Selection of Touch Screen

The use of a touch screen can reduce the operational and debugging difficulties of the fully automatic 3D flat loom. The touch screen can display machine parameters and monitor machine status, greatly reducing the complexity of machine operation. This design utilizes the MT8106IE touch screen from Weintek (see Table 2).

Table 2: Touch screen parameters

Name of index	*Specification*
Model	MT8106IE
Display size	2-wire type
Resolution	1024*600
Boundary dimension	271×213×36.4 mm
Voltage	DC24V

3.4 Design of the Main Circuit

To connect all the electrical components, the main circuit of the entire system was designed (see Figure 2). The main circuit enables signal transmission and the fully automatic operation of the loom. In this design, QF represents the air switch, K represents the contactor, H represents the indicator light, X represents the terminal, and V represents the 24V DC power supply. The touch screen is powered by 0L+ and 0N, the curling stepper motor is powered by 1L+ and 1N, and the PLC input/output is powered by 2L+, 2N, 3L+, and 3N. The 4L+ and 4N are reserved.

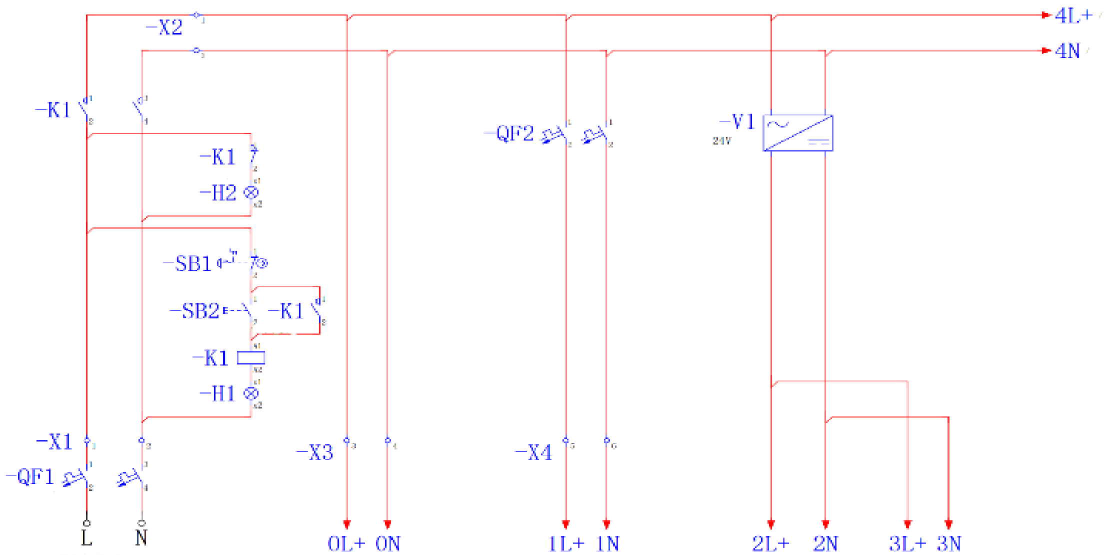

Figure 2: Main circuit design drawing

Table 3: The I/O definitions of PLC

input	*function*	*output*	*function*
I0.0-I0.1	Emergency stop button/switch knob	Q0.0	Automatic/single step indicator light
I0.2-I0.3	Control off/on button	Q0.1	Running indicator light
I0.4	Automatic/single step mode knob	Q0.2	Stop indicator light
I0.5	Start/click button	Q1.0-Q1.7	Heald frame 1-8
I1.0-I1.7	Heald frame positions 1-8	Q2.0-Q2.7	Heald frame 9-16
I2.0-I2.7	Heald frame positions 9-16	Q3.0-Q3.1	Heald frame 16-17
I3.0-I3.1	Heald frame positions 16-17	Q3.4-Q3.5	Left and right sword extension
I3.4-I3.5	Left and right sword	Q3.6-Q3.7	Left and right vertical needle extension
I3.6-I3.7	Left and right vertical needle	Q4.0-Q4.1	Left and right horizontal needle extension
I4.0-I4.1	Left and right horizontal needle	Q4.2-Q4.3	Left and right secondary vertical needle extension
I4.2-I4.3	Left and right secondary vertical needle	Q4.4-Q4.5	Beating
I4.4-I4.5	Beating-up	Q4.6	Winding motor rotation

4. Equations

4.1 PLC Hardware I/O Device Addresses

The operation of the fully automatic 3D flat loom requires detecting the current machine status. The I/O ports on the PLC are defined as shown in Table 3.

4.2 Program Flow Design

Since the fully automatic 3D flat loom uses the Haoxin CTH200 series H226IM PLC, the official Haoxin software MagicWorksPLC is used to write the PLC program. Ladder diagram language is employed as it is simple, easy to understand, and convenient for debugging and modification.

A cycle consists of multiple weft insertion cycles. Within each weft insertion cycle, a process will be executed once (see Figure 3).

A complete cycle is divided into the upper half-cycle and the lower half-cycle. Additionally, during each half-cycle, we perform a weft insertion and winding. Before each weft insertion cycle, the harness frame distribution is adjusted to change the weaving process, thereby altering the fabric's weaving technique. Once the weaving is complete, the control "ON" and "OFF" buttons are clicked again to reset the machine, marking the end of one cycle. During system debugging, the shallow interlaced fabric technique is used.

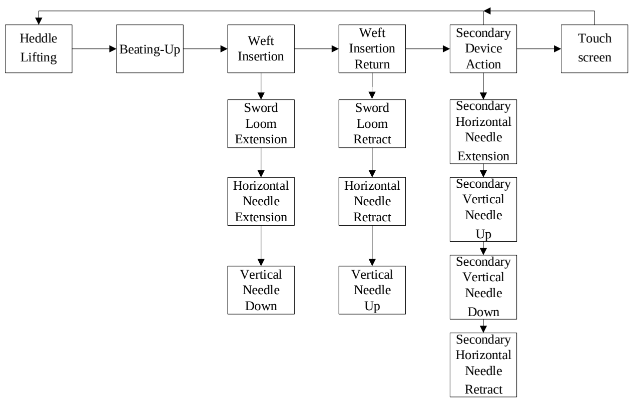

Figure 3: Flow chart of weaving procedure

The fully automatic 3D flat loom has three working modes: automatic mode, single-step mode, and jog mode. The switching between these modes is done through the touchscreen and buttons on the human-machine interface. Regardless of the mode, the control "ON" button must be activated to operate.

In automatic mode, the loom weaves according to the weaving process shown in Figure 3. The shuttle count is calculated after each weft insertion, and based on this count, the loom executes either the upper or lower half-cycle. Once a cycle is completed, the system automatically resets and begins the next cycle. The purpose of this mode is to automatically weave 3D fabrics. If the loom's operation is paused, the "Automatic/Single-step" knob is rotated to switch the loom to single-step mode.

In single-step mode, by pressing the jog button, the loom moves step-by-step according to the automatic mode's movement pattern. The switch between movement steps is controlled by the jog button. The purpose of this mode is to test the 3D fabric weaving process. By running the loom step-by-step, we can verify whether the shedding, picking, and weft insertion systems can operate stably after the loom is threaded. Once the debugging is stable, the "Automatic / Single-step" knob is rotated to return to automatic mode.

Jog mode is accessed through the human-machine interface's touchscreen. In this mode, each movable mechanism can be controlled individually. The purpose of this mode is machine debugging. If a malfunction occurs during the loom's operation, this mode allows for detailed troubleshooting and fault elimination. Additionally, through the touchscreen, the pulse amount for the winding system's stepper motor can be adjusted, enabling the winding system to function. This increases the yarn tension and enables passive warp feeding.

4.3 Human-Machine Interface (HMI) Design

The human-machine interface is composed of three parts: buttons, indicator lights, and a touchscreen. The button section consists of an emergency stop button, a switch knob, control on/off buttons, an automatic/manual mode knob, and a start/manual jog button. The indicator light section includes automatic/manual mode indicator lights, running indicator lights, and stop indicator lights.

The touchscreen section uses the Weintek MT8106IE touchscreen. The HMI configuration and interface design is done using the Utility Manager software. This software allows data transfer between the PLC and the touchscreen.

During the weaving process, the control and debugging page is shown in Figure 4.

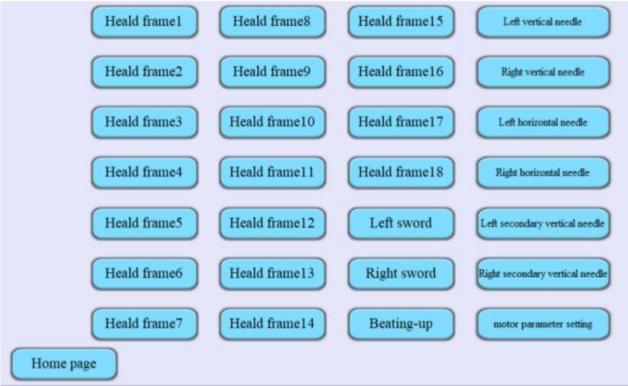

Figure 4: Touch screen debugging interface

By clicking the motor parameter setting button, the page for debugging the winder motor is accessed (see Figure 5).

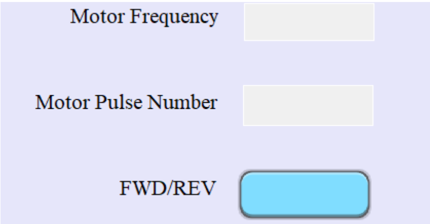

Figure 5: Touch screen winding motor debugging interface

4.4 System Debugging Results

Figure 6: Finished fabric

The control system that has been completed is now undergoing debugging. The fabric material used for the debugging process is quartz fiber. All control systems are connected, the program is downloaded into both the PLC and the touchscreen, and all magnetic switches are placed in position. After powering on and pressing the control on button, the loom is debugged in both single-step mode and manual jog mode. Once everything is functioning properly, the system is switched to full automatic mode, all parameters are set, and weaving can begin. The system is now running stably, and the fabric being woven is shown in Figure 6. After optimization, the production speed can reach 120 mm/h.

5. Conclusion

Through system debugging, it has been proven that the design of this control system can run stably. The requirements for a fully automatic loom have now been mostly achieved:

By using a PLC in the control system, the problems of numerous electrical components and complex wiring have been solved. This significantly simplifies the circuit design, increases integration, and improves operational reliability and safety.

The PLC-based control program allows for fast and efficient modification of the heddle sequence. By changing the heddle sequence within the cycle, various fabric structures can be woven. Additionally, the PLC operates at a voltage of 24V, which offers advantages such as low power consumption and a safe operating environment.

In conclusion, the PLC-based fully automatic three-dimensional flat weaving loom control system has achieved the automatic weaving of three-dimensional fabrics and provides a reference for the design of future three-dimensional loom control systems.

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