Design of the Motion Control Hardware System of The Geotextile Paving Trolley for Tunnel Construction

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Abstract: The tunnels mostly use geotextile and waterproof board laying for waterproof construction. At present, most of the geotextile laying uses simple bench and manual laying method, which has many potential safety hazards, and the construction quality and construction efficiency are not high. This paper analyzes some tunnel structures and waterproof construction methods in our country. Based on the tunnel geotextile laying trolley, the hardware system of the trolley motion control system is designed. This system includes controller, HMI, actuator drive device and sensor device. Finally, experiments and debugging were carried out with the software system, which verified the completeness and reliability of the system functions.

Keywords: Tunnel construction; Geotextile; Trolley; Motion control

1. Introduction

Waterproof construction is an important link in tunnel construction, and waterproof laying is the top priority in waterproof construction\cite{1}. The technology of using waterproof boards and geotextiles in tunnel waterproofing facilities is a common construction method in tunnel engineering. According to data, 34\% of tunnel linings have water seepage\cite{2}. The waterproofing of tunnels in my country is mainly faced with the problems of unclear tunnel waterproofing level, insufficient design engineering, and irregular construction process\cite{3}. At present, most of the tunnel waterproof construction adopts manual laying methods, and the laying efficiency and quality are low, which is the main reason for the leakage of the tunnel lining surface.

With the development of construction machinery, manual paving methods can no longer meet the current construction quality requirements. In recent years, many tunnel construction units have begun to develop waterproof paving trolleys to improve the efficiency and quality of tunnel waterproof construction. In 2015, the FS-GL11 new automatic waterproof layer paving machine developed by Sichuan Hao Desi New Material Technology Co., Ltd. realized the laying of the ring frame and can walk automatically, reducing the use of manpower and improving the construction efficiency\cite{4}; 2018 In the year, the geotextile paving trolley developed by China Railway First Bureau Group Construction Machinery Co., Ltd. added a hoop paving trolley on the basis of the traditional trolley, which speeded up the construction efficiency and also reduced the use of labor\cite{5}. In 2019, the tunnel geotextile paving trolley developed by the Fourth Engineering Co., Ltd. of China Railway First Bureau Group adopted a method in which the electric motor drives the track trolley to lay the geotextile in the circumferential direction\cite{2}. In the multifunctional waterproof paving trolley developed by the First Engineering Co., Ltd. of China Railway 12th Bureau Group, the electric motor drives the traction mechanism for geotextile laying\cite{6}. However, most of the waterproof paving trolleys that have been designed currently still use relay control circuits. The circuit is complicated, the action is unreliable, and the control cabinet
takes up a large space, which is not conducive to the use of the trolley in tunnels with harsh construction conditions. Aiming at the various deficiencies of the existing trolleys, this paper designs a hardware system based on the motion control of the tunnel geotextile paving trolley, which integrates modern control equipment into the tunnel waterproof construction link, which greatly improves the work efficiency and construction quality of tunnel construction.

2. Hardware system structure

According to the structure and characteristics of the tunnel, the tunnel construction geotextile paving device is installed on the track trolley, and the trolley motion control system needs to drive the track trolley to move horizontally and circularly to complete the entire laying process. The motion control system is divided into a lateral motion system (hereinafter referred to as Y axis) and a circular motion system (hereinafter referred to as X axis). The horizontal track span of the trolley is 12m, and the circumferential track span is 5m. In order to ensure that the trolley does not deform when it is traveling, this paper uses two servo motors[7] to control the horizontal track and the circumferential track simultaneously.

The motion control system includes X-axis servo system and Y-axis servo system and related limit devices. The X-axis servo system includes two servo motors, namely X-axis servo 1, X-axis servo 2, and Y-axis servo system includes two servo motors, Y-axis servo 1, Y-axis servo 2, and two for each motion axis. A limit position switch limit+, limit- and a home position switch home. The system structure is shown in Figure 1.

![Figure 1. Structure diagram of motion control system](image)

3. Control system hardware design and analysis

According to the system function and the task requirements of the tunnel laying system, the hardware design includes the power supply system of the laying platform, one Siemens s7-1200 PLC and one Weiluntong HMI for control; four Huichuan motors drive system actuators; use six A limit sensor detects the position of the motion control system.

3.1. Controller and human-computer interaction system

3.1.1. Controller. In engineering, PLC (programmable controller) is generally used as the control core of the automatic control system. PLC is a digital operation controller with microprocessor for automatic control, which can load control instructions into memory at any time for storage and execution. The programmable controller is composed of functional units such as CPU, instruction and data memory, input/output interface, power supply, digital-analog conversion, etc., and can complete various functions such as logic control, timing control, analog control, and multi-machine communication. According to the requirements of the control system, the used controller has at least configure as follows:

1) With more than seven digital input interfaces;
2) With more than eight high-speed pulse output interfaces;
3) With more than four digital output interfaces;
4) With more than two Ethernet communication interfaces;
Based on the above configuration requirements, this article uses the SIMATIC S7-1200 series 1215c (DC/DC/DC) CPU module as the controller of the motion control system. Siemens S7-1200 series PLC has the characteristics of small equipment size, fast running speed and stable communication performance[8]. In the complex working environment of the tunnel, the stability of the equipment operation can be effectively guaranteed.

3.1.2. Human-computer interaction system. According to the system's functional requirements, in order to make the workers' operation more convenient and intuitive, this design uses a touch screen as the system's monitoring and operating equipment. The touch screen is an inductive liquid crystal display device that can receive input signals such as contacts. When the graphic buttons on the screen are touched, the tactile feedback system on the screen can drive various connection devices according to pre-programmed programs, which can be used to replace mechanical The button panel, and through the liquid crystal display screen to create dynamic audio and video effects. According to the requirements of the control system, the touch screen used needs to have the following configuration:

1) With Ethernet communication interface;
2) Screen size above 10 inches;
3) Has a good screen resolution;
4) With more than 128M memory;
5) Compatible with Siemens s7-1200 PLC;

Based on the above needs, this article chooses Weiluntong MT8071iE touch screen as the human-computer interaction device of the control system. The touch screen uses DC 24V power supply, the screen size is 10 inches, the resolution is 800*400; it supports MPI 187.5K connection, and the built-in memory size is 128M , Supports RS485, RS232 and Ethernet communication[9], strong compatibility, high stability, resistive touch screen, and the surface has been hardened, not afraid of dust, oil, friction and scratches, suitable for the harsh interior of the tunnel working environment.

3.2. Actuator drive

The motion system of the geotextile paving trolley for tunnel construction includes two motion axes, each of which is driven by two servo motors. Servo motors can control the controlled output of the object's state, position, etc. with the change of the given value, which is closely related to modern digital control technology. Stepper motors or all-digital AC servo motors are mostly used as motion control systems The executive motor[10]. Due to the different loading conditions of the horizontal track and the circular track, the servo motors used in the two tracks have different specifications. The specific usage conditions are shown in Table 1.

| Equipment name | Model | Rated power (W) | Rated torque (N·m) | Rated speed (rad/min) |
|----------------|-------|-----------------|--------------------|----------------------|
| X-axis servo   | ISMH4-75B30CB-U234Z-234Z (Driver IS400) | 400               | 11.5               | 3000                 |
|                | ISMH4-75B30CB-A331z-234Z (Driver IS620P) | 750               | 6.36               | 3000                 |

The X-axis is a circular track. Due to the large weight of the trolley, when the trolley runs to the edge of the ring, the vertical component of gravity is large, which is likely to cause the servo system to alarm. After many experiments, adding a 100W, 1kΩ braking resistor to the X-axis servo system has solved this problem well.
3.3. Hardware system wiring diagram

The wiring of the hardware system is divided into the main loop, control loop and servo amplifier wiring in strict accordance with the installation specifications of the electrical control system. The main loop and other loop wire specifications are shown in Table 2.

| Circuit name       | Maximum current (A) | Wire type | Conductor cross section (mm²) |
|--------------------|---------------------|-----------|-------------------------------|
| Main circuit       | 10.4                | BVR       | 2.5                           |
| Other circuits     | 5                   | BVR       | 1.5                           |

### Table 2. Hardware system line type

3.3.1. Main circuit wiring diagram. The main circuit wiring is shown in Figure 2. The four servo systems are powered by a single-phase power supply[11]. The servo amplifier and the motor connected to it are connected through the power cord and the signal cord slot CN2.

![Figure 2. Main circuit wiring diagram.](image)

3.3.2. Controller wiring diagram. Siemens s7-1200PLC uses DC 24V power supply, and each sensor is NPN connection. Controller wiring is shown in Figure 3.

![Figure 3. Controller wiring diagram](image)
3.3.3. Servo amplifier wiring diagram. Servo system, as the actuator of the entire motion control system, is the power source of the entire equipment. Take one of them as an example, the definition of each terminal in the CN1 slot of the servo amplifier is shown in Table 3.

**Table 3. Servo amplifier CN1 slot terminal**

| Terminal name | P- | P+5V | P+24V | D- | D+5V | D+24V | S11 | S12~14 | +24V | S01~02 | COM |
|---------------|----|------|-------|----|------|-------|-----|--------|------|--------|-----|
| Paraphrase    | Pulse signal- | Pulse signal+ | Pulse signal+ | Direction signal- | Direction signal+ | Direction signal+ | Enable signal | Undefined | Signal power+ | Undefined | Signal power- |

According to the control requirements, set the servo system to the position control mode of "pulse + direction", using 24V pulse signal, the specific wiring is shown in Figure 4.

**Figure 4. Wiring diagram of servo amplifier CN1**

4. Conclusion
Aiming at the shortcomings of the existing geotextile paving trolley, this paper designs a hardware system based on the motion control of the geotextile paving trolley for tunnel construction, and introduces the hardware system in detail. According to the experimental results, the motion control system can cooperate with the automatic paving device, which reduces the use of labor, saves labor expenses and reduces the incidence of tunnel construction safety accidents; improves the work efficiency and quality of waterproof construction.

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