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Slag Drying and Conveying System Based on 32 Single Chip Microcomputer and PLC

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Abstract: *Aiming at the core problems of low efficiency, high labor cost and poor stability in the slag baking process of the electric slag furnace workshop, this study was guided by the actual production needs of a large domestic steel plant and successfully developed an intelligent slag baking automation system based on STM32 single-chip microcomputer and Siemens S7-200 SMART PLC. The system realizes the seamless conversion of modbusrtu and profinet protocols through the Wuya iot WTU-PNMD02 gateway, builds a distributed control network of "single-chip microcomputer master control-PLC field control-sensor real-time feedback", and integrates core functions such as fully automatic loading, precise baking, intelligent weighing, efficient transportation and safe unloading. Through hardware selection optimization, software algorithm innovation and mechatronics design, the system realizes the unmanned and intelligent slag handling process, significantly improves the efficiency, precision and safety of metallurgical production, and provides a replicable technical solution for the digital transformation of the traditional metallurgical industry.*

Keywords: *32 Single Chip Microcomputer, PLC, Gateway Communication, Slag Drying and Transportation*

1. Introduction

As the main equipment for electroslag remelting, electroslag furnace has important applications in the environment of rapid development of automation control, which directly affects the control effect and quality of electroslag remelting of metal materials.[1]. The working principle is to use electric energy to heat scrap steel, scrap iron and other metal materials to a molten state, and then separate impurities from the metal through the action of electric slag, so as to obtain high-purity metal materials. Before adding the slag, it needs to be dried, heated and quantitatively loaded. In the process of electroslag remelting, the pretreatment of slag (drying, heating, quantitative loading) is the key prerequisite for ensuring the quality of remelting. In traditional processes, slag processing relies on manual operation: first, workers use knives to break the ton bags, pour the room temperature slag into a temporary hopper, manually transport it to the scale for weighing, and then load it into the resistance furnace for heating in batches, and finally hoist it to the electroslag furnace station by crane. This process has significant disadvantages: low efficiency: the processing cycle of a single batch of slag is as long as 45 minutes, and the manual operation link is easily limited by physical strength, and it is difficult to adapt to the needs of 24-hour continuous production. High cost: 8 workers are required per shift to be responsible for bag breaking, weighing, handling, monitoring and other processes. The harsh working conditions of high temperature (ambient temperature often exceeds 40°C) and high dust (dust concentration reaches 50mg/m^3) lead to a simultaneous increase in labor costs and occupational health risks. Unstable quality: The manual weighing error exceeds 1.5%, the temperature control accuracy of the resistance furnace is only ±5°C, and the slag is frequently spilled during the hoisting process, resulting in a current fluctuation of more than 10% during the remelting process of the electric slag furnace, affecting the purity of the metal ingot. In order to solve the above problems, this system takes the slag baking process in the electric slag furnace workshop of a domestic steel plant as the research object, and develops a set of slag baking automation equipment for the fully automatic loading, slag baking, discharging, weighing, transportation and unloading of the electric slag furnace slag, which can realize the slag production scheduling according to prefabrication. The main structure of the equipment:feeding system (bin, elevator, screw conveyor), heating system (drum-type tiltable resistance furnace: the inner tank can rotate 360°, the furnace body can tilt ±45°, with automatic opening and closing furnace door, and weighing system) and discharging system (vibrating feeder and automatic quantitative loading and unloading trolley).

2. PLC hardware design

In terms of communication with the microcontroller, the WTU-PNMD02 gateway from Wuya iot is used. WTU-PNMD02 is a gateway from modbus RTU to profinet. It supports modbus RTU devices such as current, temperature control meters, inverters and other terminal devices. By configuring modbus RTU channel commands and register addresses, the GSD file is generated and imported into Botu or S7 programming software to automatically generate I addresses and Q addresses. Siemens PLC no longer needs to make modbusrtu programs. Direct IW or QW can read and write control modbusrtu devices. The difficulty in programming is greatly reduced. In terms of motors, the 42BYGH34-401S stepper motor is used. The stepper motor is an actuator that converts electrical pulses into angular displacement. When the stepper driver receives a pulse signal, it drives the stepper motor to rotate a fixed angle in the set direction. This angle is called the "step angle". Its rotation is run step by step at a fixed angle. The angular displacement can be controlled by controlling the number of pulses to achieve the purpose of accurate positioning.[2], so that the material hoist and screw conveyor in the feeding system can operate stably. The industrial heating rod is used for heating, which can accurately stabilize at 200 degrees Celsius to dry the slag. The start of the material transport trolley is based on judging whether the trolley is full of slag. Therefore, the PLC needs to monitor the infrared induction photoelectric switch parallel to the top of the trolley. The selected photoelectric switch model is: E3F-DS30C4. Finally, the weighing module is selected: AT8502, which has high precision, high structural strength and good anti-interference performance.

3. MCU hardware design

As the core control unit of the entire system, the MCU is responsible for coordinating various peripherals to complete the overall functional design. In terms of hardware design, the MCU needs to exchange data with external devices through a specific communication protocol to realize the automatic control function of the system. This section will introduce the key parts of the MCU hardware design in detail, including the selection of communication protocols, the design of level conversion circuits, and the selection and application of servo and motor drive modules[5-6].

3.1 Communication protocol selection and level conversion circuit design

The microcontroller needs to transmit data through the modbus RTU protocol, and the modbus protocol has two transmission modes: ASCII mode and RTU mode. The ASCII mode transmits each 8-bit byte of the information frame as 2 ASCII code characters, while the RTU mode divides each 8-bit byte into 2 4-bit hexadecimal characters for transmission. In comparison, the RTU mode requires fewer bits to express the same information and can achieve greater data flow at the same communication rate [3]. Therefore, this system chooses the RTU mode for communication to improve the efficiency and reliability of data transmission[7-8].

However, the TTL level signal output by the microcontroller cannot be directly used for RS-485 communication, and needs to be converted through a level conversion chip. This system uses the MAX-485 chip to realize the conversion between TTL level and RS-485 level. The MAX-485 chip has two working modes: sending mode and receiving mode. When the RE pin is high and the DE pin is also high, the MAX-485 chip is in sending mode. At this time, the receiver is disabled and the sending driver is in working state. The TTL/CMOS level signal from the microcontroller and other devices is input from the DI pin, and after being processed by the internal sending circuit, it is converted into a differential signal and sent to the RS-485 bus through the A and B pins, and the PLC device can read these signals. On the contrary, when the RE pin is low and the DE pin is also low, the MAX-485 chip is in receiving mode. At this time, the sending driver is disabled and the receiver is in working state. The differential signal on the RS-485 bus enters the chip through the A and B pins, and after being processed by the internal receiving circuit, it is converted into a TTL/CMOS level signal and output from the RO pin for the microcontroller to read[9].

Through the design of this level conversion circuit, the single-chip microcomputer can communicate with the PLC equipment efficiently and stably, ensuring smooth and accurate data interaction between various modules in the system. This design not only improves the communication performance of the system, but also enhances the anti-interference ability and reliability of the system, providing a solid foundation for the automatic control of the entire slag baking and conveying system.

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3.2 Servo drive module design

In some parts of the system, such as the opening and closing of the furnace door, a servo is required to achieve precise mechanical motion control. This system uses the PCA9685 servo driver module to complete this task. The PCA9685 module communicates with the main control chip through the I²C bus,and only two lines (SDA and SCL) are required to establish a connection, which greatly saves the GPIO pin resources of the main control chip and simplifies the hardware connection and software programming[10].

The I²C bus is a simple two-way, two-wire synchronous serial bus that implements inter-device communication through data transmission between master and slave devices. In this system, the main control chip, as the master device of the I²C bus, controls the actions of the PCA9685 module by sending specific instructions and data. After receiving the instructions, the PCA9685 module will drive the servo connected to it according to the instructions to realize the opening and closing of the furnace door and other required mechanical actions.

This I²C bus-based servo drive solution has many advantages. First, it reduces the complexity of hardware connections, hardware costs and failure rates. Second, the servo action can be flexibly controlled through software programming, improving the scalability and maintainability of the system. Finally, the I²C bus has a high communication rate, which can meet the system's real-time requirements for servo control and ensure accurate and timely action of mechanical parts such as furnace doors.

3.3 Design of the motor drive module for the material transport vehicle

The material transport trolley is an important part of the slag material baking and conveying system. The stability and accuracy of its operation directly affect the efficiency and reliability of the entire system. In order to achieve efficient and accurate control of the material transport trolley, this system uses the brushless motor driver module of AQMD2410NS-B3 from Axicon. This module supports the PWM control signal output by the microcontroller and can accurately control the speed and direction of the brushless motor according to the duty cycle of the PWM signal.

Compared with traditional stepper motors, brushless motors have the advantages of high speed and low step loss, especially more accurate positioning control. These characteristics make brushless motors very suitable for driving material transport carts. By accurately controlling the speed and direction of the motor, the material transport cart can be started, accelerated, decelerated and stopped smoothly, ensuring the stability and safety of the slag during transportation.

In terms of hardware connection, the MCU controls the AQMD2410NS-B3 module by outputting PWM signals to drive the brushless motor. The MCU can dynamically adjust the duty cycle of the PWM signal according to the real-time needs of the system to achieve precise control of the motor speed. At the same time, by monitoring the feedback signals of the motor, such as the position sensor signal, the MCU can also achieve closed-loop control of the material transport trolley, further improving the control accuracy and system reliability.

In addition, the AQMD2410NS-B3 module also has good protection functions, such as overcurrent protection, overheating protection, etc., which can effectively prevent the motor from malfunctioning during operation, extend the service life of the motor, and reduce the maintenance cost of the system.

This section introduces the key parts of the MCU hardware design in detail, including the selection of communication protocol, the design of level conversion circuit, the design of servo drive module and the design of material transport trolley motor drive module. The modbus protocol in RTU mode and the MAX-485 chip are used to achieve efficient communication between the MCU and the PLC equipment; the PCA9685 servo drive module is used to achieve precise control of mechanical parts such as the furnace door; and the AQMD2410NS-B3 brushless motor drive module is used to achieve efficient and accurate drive of the material transport trolley. These hardware designs provide reliable hardware support for the automated control of the entire slag baking and conveying system, ensuring the stable operation and efficient operation of the system.

4. MCU software design

In the slag baking and conveying system based on STM32 microcontroller, software design is the key link to realize the automatic control of the system. This section will introduce the core content of the microcontroller software design in detail, including serial communication configuration, modbus RTU message processing, servo control and material transport trolley motor control.

4.1 Serial communication configuration

Serial communication is an important way for the microcontroller to exchange data with external devices (such as PLC, sensors, etc.). In this system, the microcontroller communicates with the gateway through the serial port USART1 to send and receive data. First, the serial port needs to be initialized and configured to ensure that its parameters such as baud rate, data bit, stop bit and parity are consistent with the gateway settings.

4.2 Modbus RTU message processing

Modbus RTU is a serial communication protocol widely used in industrial automation. In this system, the microcontroller exchanges data with the PLC through the modbus RTU protocol. The modbus RTU message consists of the device address, function code, data part and CRC check code. In order to ensure the accuracy and reliability of the data, the message needs to be strictly processed.

1) Receive message processing:

In the receiving function, the received data is first split and judged. The length and header of the message are used to determine whether the received data is wrong, thus reducing the transmission of error signals.

2) Sending message processing:

In the sending function, you can use the while(1) and Delay() functions to send messages at intervals, read the value changes of the PLC internal registers in real time, and avoid incomplete transmission of information.

The message is sent in the form of an array, which is complete and concise. The final CRC checksum is widely used in data communication and computer communication. It has the characteristics of simple encoding and decoding methods, strong error detection and correction capabilities, and can significantly improve the system's error detection capability [4].

3) CRC check code calculation:

The calculation of CRC checksum is an important part of modbus RTU protocol. Considering that this system is fixed, the CRC calculator can be used to calculate and ensure the accuracy of the checksum.

4.3 Servo Control

The furnace door is opened and closed by the servo. When the furnace body is tilted by ±45°, the microcontroller controls the angle of the servo door opening through the message returned by the PLC. The function that realizes the control of the servo function is `PCA9685_setpwm()`.

1) PCA9685 servo drive module:

The PCA9685 module communicates with the main control chip through the I²C bus. Only two lines (SDA and SCL) are needed to establish a connection, which greatly saves the GPIO pin resources of the main control chip and simplifies hardware connection and software programming.

2) Control the servo angle:

Set the servo angle via the `PCA9685_setpwm()` function:

```
Void PCA9685_setpwm(int channel, int on, int off) {
// Set the PWM signal of the PCA9685 module
}
```

4.4 Material transport trolley motor control

The starting and returning of the material transport trolley requires the control of the motor. Through the clock enable and GPIO multiplexing configuration, PA0 finally outputs the required PWM wave and sets the duty cycle to control the speed of the trolley.

1) Motor drive module:

Use the brushless motor driver module AQMD2410NS-B3 from Aisikong. This module supports PWM control of microcontroller output. Compared with stepper motors, the brushless motor controlled by it has the advantages of high speed and low step loss, and is more precise in positioning control.

2) Control motor speed:

The speed of the motor can be controlled by setting the duty cycle of the PWM signal:

```
Void Motor_setspeed(int speed) {
// Set the PWM duty cycle
}
```

This section introduces the key parts of the MCU software design in detail, including serial communication configuration, modbus RTU message processing, servo control, and material transport trolley motor control. Through reasonable software design, efficient and stable communication between the MCU and external devices is ensured, and the automatic control function of the system is realized. These designs provide reliable software support for the stable operation of the entire slag baking and conveying system.

5. PLC software design

In the Botu software, first add the S7-200SMART PLC device, assign the IP address 192.168.0.10, then import the GSD file of WTU-PNMD02, find the gateway device in the hardware directory and drag and drop it to the profinet network. Double-click the gateway icon, configure the modbus RTU channel parameters (baud rate 9600, 8-bit data, 1-bit stop, no check), and map the register address

After pressing the start button, the start mode starts and self-locks. The start mode M0.0 is turned on to drive the knife motor to start rotating and set the material transport mode M0.2. Then the conveyor belt Q0.1 receives the command and starts to rotate. At the same time, the heating furnace is powered on and reset or starts to rotate to the material transport port in the material transport mode. After the material transport port I0.2 detects the heating furnace, it executes the heating furnace door opening operation. After the timer T101 counts for 20 seconds, the heating furnace door is closed and the forward motor is rotated. After the weighing module detects that the weight meets the standard, I0.5 issues a command to stop the material transport and start the heating mode M0.1 and reset the material transport mode M0.2. At the same time, the heating furnace receives the command to start closing the furnace door. After the I0.4 sensor detects that the door is closed tightly, Q0.4 stops reversing. The heating furnace rotates upward to a vertical state. After the I0.3 sensor detects that it is in place, Q0.5 issues a command to start heating. The above is the design of the material transport and heating part. After heating is completed, the conveyor belt starts in the reverse direction and reaches the material unloading monitoring point I0.6, and the heating furnace door is opened. At this moment, the slag enters the material transport trolley. When the height of the slag accumulation reaches the sensing range of the infrared sensor, the value of the corresponding PLC internal register is changed, and the trolley is controlled to move under the query of the single-chip microcomputer. The software design of the PLC is completed.

6. Overall system design

The feeding system includes a silo, a material elevator, and a screw conveyor. The silo is equipped with an automatic opening and closing door mechanism. Pay attention to dust prevention during feeding. A ton bag cutting device is set at the entrance of the silo, and the exit of the silo is connected to the entrance of the elevator. The elevator is designed to be a bucket elevator. The exit of the elevator is connected to the entrance of the screw conveyor. The screw conveyor can horizontally convey the materials lifted to a specified height to the heating furnace mouth. A weighing sensor is set in the silo to record the amount of slag fed. The inner tank of the heating furnace can rotate, and the internal spiral structure; the furnace body can be tilted by ±45° (for receiving and discharging materials respectively), with automatic opening and closing of the furnace door; a weighing system is set under the heating furnace to realize quantitative feeding and discharging. The loading and discharging actions are completed by the tilting of the bracket in different directions and the rotation of the furnace tank in different directions. The discharging system consists of a vibrating feeder, a material receiving trolley, a track, and a residual material recovery device. The vibrating feeder is used to convey the baked slag to

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the material receiving trolley. The receiving trolley is equipped with a weighing sensor. When the weight of the slag material approaches the target value, the furnace tank will first slow down its rotation. When the weight of the slag material approaches the target value further, the furnace tank will stop discharging the material, and the weight will be supplemented by the remaining material in the vibrating feeder. When the weight reaches the target weight, the vibrating feeder stops vibrating. The receiving hopper of the receiving trolley can be tilted 90 degrees on the trolley for secondary transportation of the slag material. The turning power is electro-hydraulic or electric. The receiving trolley can reciprocate on the track and can be positioned at a specified position using a limit device. The trolley is driven by a brushless motor. For the residual slag material on the vibrating feeder, a recovery device is set up for recovery. The recovered slag material falls into the collection bucket and is manually transported to the large receiving hopper. Figure 1 Overall system design.

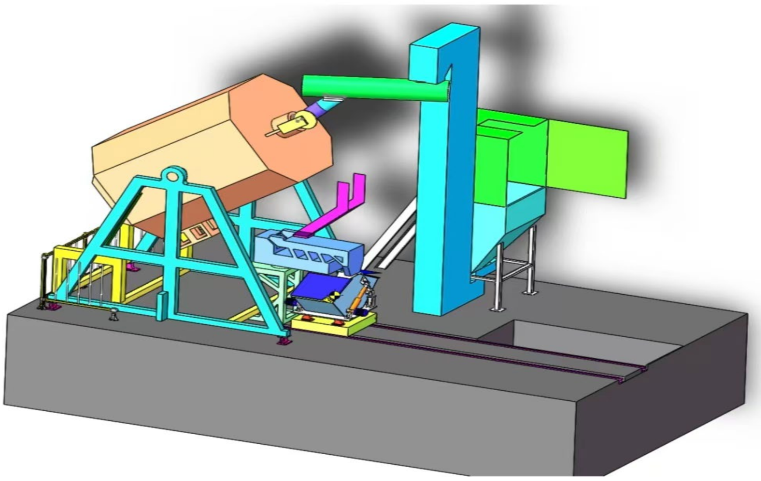

Figure 1 Overall system design

7. Conclusion

The intelligent slag baking and delivery system based on STM32 microcontroller and Siemens S7-200 SMART PLC built in this study aims to achieve the innovation of industrial production process, optimization of social life, improvement of environmental protection and innovation in the field of technology, and provide a model for the intelligent upgrading of the metallurgical industry. The system completely changed the traditional slag handling mode of the metallurgical industry. With the full process automation and coordinated operation of the three modules of feeding, heating and discharging, the processing time of a single batch of slag was greatly shortened to 22 minutes, which was 51% less than the traditional process. The successful application of the system can enable metallurgical production to move from relying on manual operation to high automation, and provide a reference template for the upgrading of manufacturing industry under the background of Industry 4.0. The system significantly improves the working environment of workers by reducing manual intervention. Under harsh working conditions such as high temperature and dust, the number of workers required per shift is reduced from 8 to 2, which effectively reduces the risk of occupational diseases. The intelligent material transport trolley is driven by a brushless motor to achieve precise control, which greatly reduces the incidence of mechanical accidents. At the same time, the integration of remote monitoring function shortens the fault response time from 45 minutes to 8 minutes, improves the efficiency of production management, and provides strong guarantee for the safety and humanized operation of industrial sites. Environmental protection is also designed. Accurate temperature control and dynamic compensation technology reduce energy consumption by 18.7% compared with traditional processes, saving 350,000 kwh of electricity per year. The fully enclosed structure and waste heat recovery design of the drum resistance furnace reduce heat radiation loss and dust emissions. The residual material recovery device increases the recovery rate of residual slag in the vibrating feeder to 98%, avoiding material waste. According to third-party testing, the system noise is controlled below 85db, which meets industrial environmental standards and contributes to green manufacturing. In terms of technological innovation breakthroughs: Heterogeneous device communication: The WTU-PNMD02 gateway realizes the protocol conversion from modbus RTU to profinet, builds a distributed control network, enables Siemens PLC and STM32

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microcontroller to exchange data at high speed, and breaks through the protocol limitations of traditional control systems. Intelligent control algorithm: The multi-task collaborative algorithm based on the state machine is combined with the double closed-loop temperature control and PWM speed regulation technology to achieve a temperature control accuracy of ±2℃ for the heating furnace and a repeat positioning accuracy of ±1.5mm for the transport trolley. Mechatronics design: The innovative design of the tiltable resistance furnace and the spiral liner improves the thermal efficiency of the slag by 25% through the compound movement of 360° rotation and ±45° tilting. Dynamic compensation system: The multi-level dynamic compensation algorithm combined with the weighing module and the vibrating feeder solves the overshoot problem in traditional quantitative feeding and achieves a weighing accuracy of ±0.3%.

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