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Design of control system of sludge rotary kiln drying unit based on PLC

Yuhui Li[1,*] *and Zhongliang Gong*[1]

[1] College of Mechanical and Intelligent Manufacturing, Central South University of Forestry and Technology, Changsha, Hunan, 410004, China

SUMMARY: *In order to realize the high efficiency and environmental protection of sludge drying, improve the automation level of sludge treatment process and reduce the intensity of manual operation, a sludge rotary kiln drying control system based on PLC was designed. Combined with the sludge drying process, the control structure composition and procedure of the rotary kiln equipment were designed in detail. In terms of control system hardware, the control scheme with Siemens 200 Smart series PLC as the core was established, and the design of hardware circuit wiring diagram and I/O distribution table was completed. In terms of control system software, in the STEP 7-MicroWIN SMART and WinCC Flexible SMART V3 environments, the manual automatic control program was written and the touch screen interface was developed. Finally, human-computer interaction and full-process automatic control were realized in system simulation and debugging. The results show that the system is stable and reliable, and the drying efficiency is significantly improved, which can dry the sludge with a moisture content of up to 85% to a moisture content of less than 10%, reduce energy consumption and improve the tail gas treatment effect, and meet the needs of industrial production.*

KEYWORDS: *sludge drying; rotary kiln device; PLC; Automation; System simulation*

1 Preface

With the acceleration of urbanization and the improvement of the living standard of the residents, the capacity of sewage treatment has been significantly increased, accompanied by the generation of a large amount of sludge with high water content [1, 2]. High water content sludge contains bacteria, viruses [3] and heavy metals, which not only brings potential safety hazards, but also increases the difficulty of transportation and disposal. The high water content and complex nature of sludge, if not properly treated, not only occupy a large amount of land resources, but also may lead to secondary pollution. Therefore, sludge reduction, stabilization and harmless treatment has become an important issue in the field of environmental engineering at present [4]. Sludge drying technology, as a key link in sludge resourceization and reduction treatment, evaporates the water in sludge through high-temperature heating to reduce its water content to a lower level [5], which in turn reduces the volume of sludge and improves its physical properties. Among many drying processes, rotary kiln drying process has been widely used in the field of sludge treatment due to its simple structure, high thermal efficiency, and adaptability [6]. However, the traditional rotary kiln drying equipment often relies on manual operation, with low control precision and high energy consumption, making it difficult to realize automation and efficient operation. In order to solve the above problems, programmable logic

*l13100223244@163.com
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controller PLC technology is applied to the sludge rotary kiln drying device system [7].PLC technology has the advantages of high reliability, strong anti-interference, easy maintenance, etc. Through the integration of automation control system, it can realize remote monitoring and control, precise adjustment of the equipment, and adaptive control of multiple working conditions, which can greatly improve the efficiency and stability of the sludge drying system [8]. The sludge drying system can greatly improve the efficiency and stability of the system [8]. In addition, combined with the real-time data acquisition and feedback of temperature, gas, pressure and other sensors, the PLC control system can dynamically adjust the burner block position, inlet and outlet rate, main kettle rotational speed, and the exhaust gas treatment system to ensure the efficient dewatering and energy utilization of the sludge at different stages of drying [9]. Based on PLC automation control technology, the study designed a set of control system applicable to sludge rotary kiln drying process, focusing on the study of the system's structural composition, working principle and automation control strategy. By optimizing the control parameters of the equipment, the intelligent level of the drying process is improved, the intensity of the operators is reduced, the operational energy consumption is reduced, and the efficient drying and harmless treatment of sludge is finally realized.

2 Rotary kiln device overall structure and process flow

2.1 Rotary kiln plant structure

The structure of the main unit of sludge rotary kiln drying is shown in Figure 1. The overall structure consists of combustion chamber, inner and outer kettle, rotary kiln support mechanism, power part, inlet and outlet screw conveyor, exhaust gas discharge pipeline and so on.

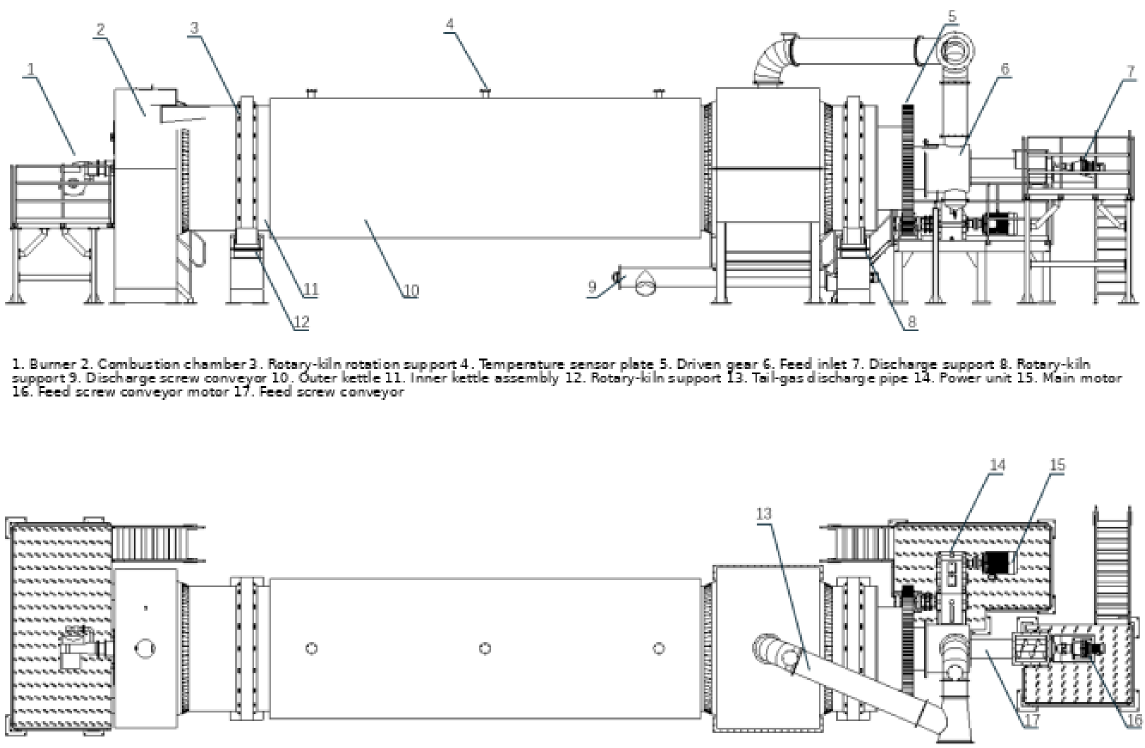


Figure 1: Structural diagram of the main equipment of the rotary kiln

2.2 Drying process of rotary kiln unit

As shown in Fig. 2 and Fig. 3 the rotary kiln drying process can be divided into three parts, Part 1: The sludge with high moisture content is transported from the sludge storage silo pool to the feeding mechanism of the main kettle equipment by means of a screw lifting device and a scraper device, utilizing a sludge loader and sludge feeder for the transport of the untreated sludge to the kettle. This part is controlled by a frequency converter motor to control the feeding rate. The second part: sludge pre-heating section, combustion chamber burner, outer kettle, inner kettle and fuel supply equipment and other peripheral equipment, the main role is to incinerate and heat the sludge that will be incinerated and drying treatment, moisture treatment to increase the temperature of the sludge itself, through the main kettle driven by the motor rotates slowly to carry out the sludge incineration and drying of the three phases, i.e., the low-temperature preheating stage to the medium-temperature bacterial breakthrough stage to the high-temperature depth of dewatering stage. Stage. The third part: there are slag hopper, discharging device, 5 tail gas treatment system, dust collector and so on. The incinerated and dried sludge is transported to the slag storage tank by an inverter controlled motor [10]. The tail gas first passes through a spray tower, which utilizes water spray to reduce the temperature of the hot gas and remove some of the sludge dust particles. After passing through the spray tower, the tail gas is introduced into the electric tar catcher, which utilizes the electrically charged characteristic of tar to collect the tar in the tail gas. The tail gas then passes through the alkaline washing tower to neutralize the acidic substances in the tail gas, such as SO_2, H_2S, NO_x and so on. Bacteria, viruses, and organics in the tail gas are broken and inactivated by UV photolysis device, and some odors are eliminated at the same time [11]. Finally, the exhaust gas is passed through the activated carbon adsorption device to remove the remaining polluting particles and pungent odor to ensure that the exhaust gas meets the national emission standards.

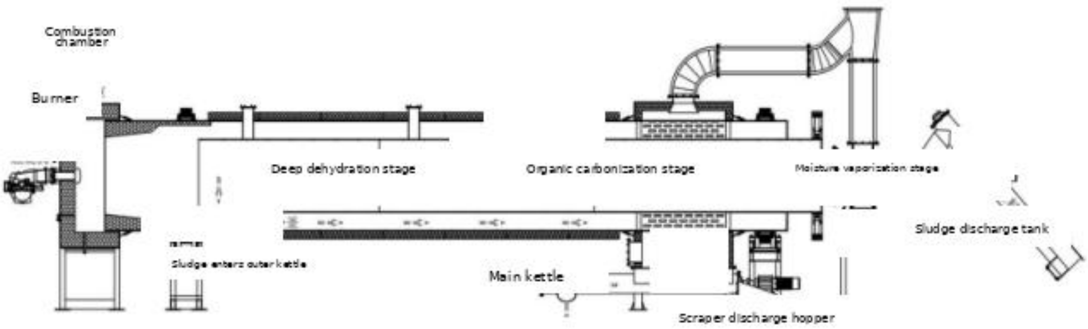


Figure 2: Schematic diagram of the process status of the main equipment

The main equipment has a simple and compact structure, high drying efficiency, the equipment occupies no more than 300m2 of the ground, and adopts the technology of inner and outer kettle suite type sludge dewatering equipment, sludge high-efficiency dewatering and treatment equipment, simplifies the process of drying and treatment of sludge, and can be readily adapted to the sludge residue disposal on the demand for changes in the water content.

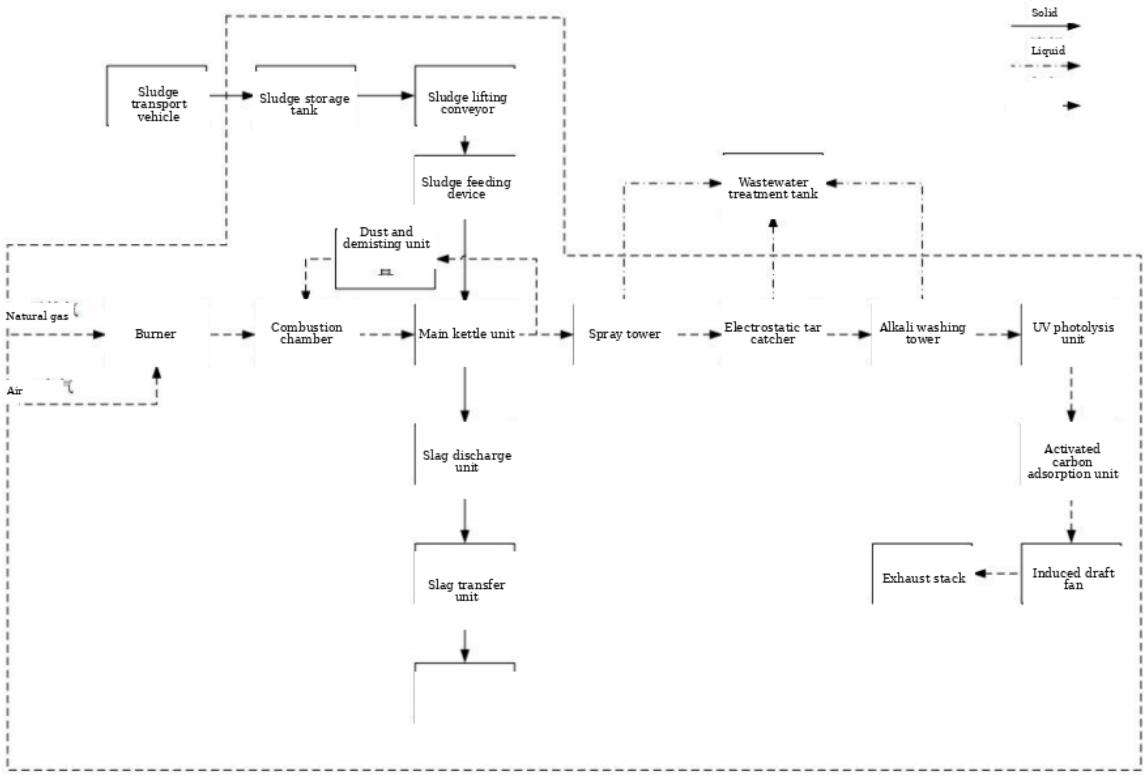


Figure 3: Process flow diagram

3 Hardware design of rotary kiln control system

3.1 Control system structure

The rotary kiln drying control system includes PLC main controller, touch screen, sensor, burner, inverter, inlet and outlet motor, main kettle motor, induced draft fan, air valve, ball valve, safety alarm system, exhaust gas treatment system and other components.

The system adopts Siemens 200 SMART series PLC as the main controller, indirectly controlling the starting and stopping of each moving part through relays and contactors, and at the same time communicating with the touch screen through PLC connecting with the switch to realize the monitoring of the action status of each execution unit and real-time displaying of the information acquired by each sensor. Using PT-type thermocouple sensors for temperature acquisition, connected to the temperature receiver, temperature converter, analog electrical signals into digital signals sent to the main controller PLC to complete the data processing, and then will be collected in different intervals of the temperature display on the touch screen [12]. Differential pressure transmitter and gas detector real-time collection of rotary kiln pressure difference and the concentration of each exhaust gas, when the collected value exceeds the set value, open the induced draft fan, constantly pumping out the exhaust gas inside the equipment to achieve the gas inside the equipment has been in the state of exchange with the outside world and negative pressure. Sludge drying is a dynamic drying environment, different moisture content of sludge drying needs to match different main kettle motor speed, inlet and outlet motor speed, so as to achieve the requirements of sludge drying (Figure.4).

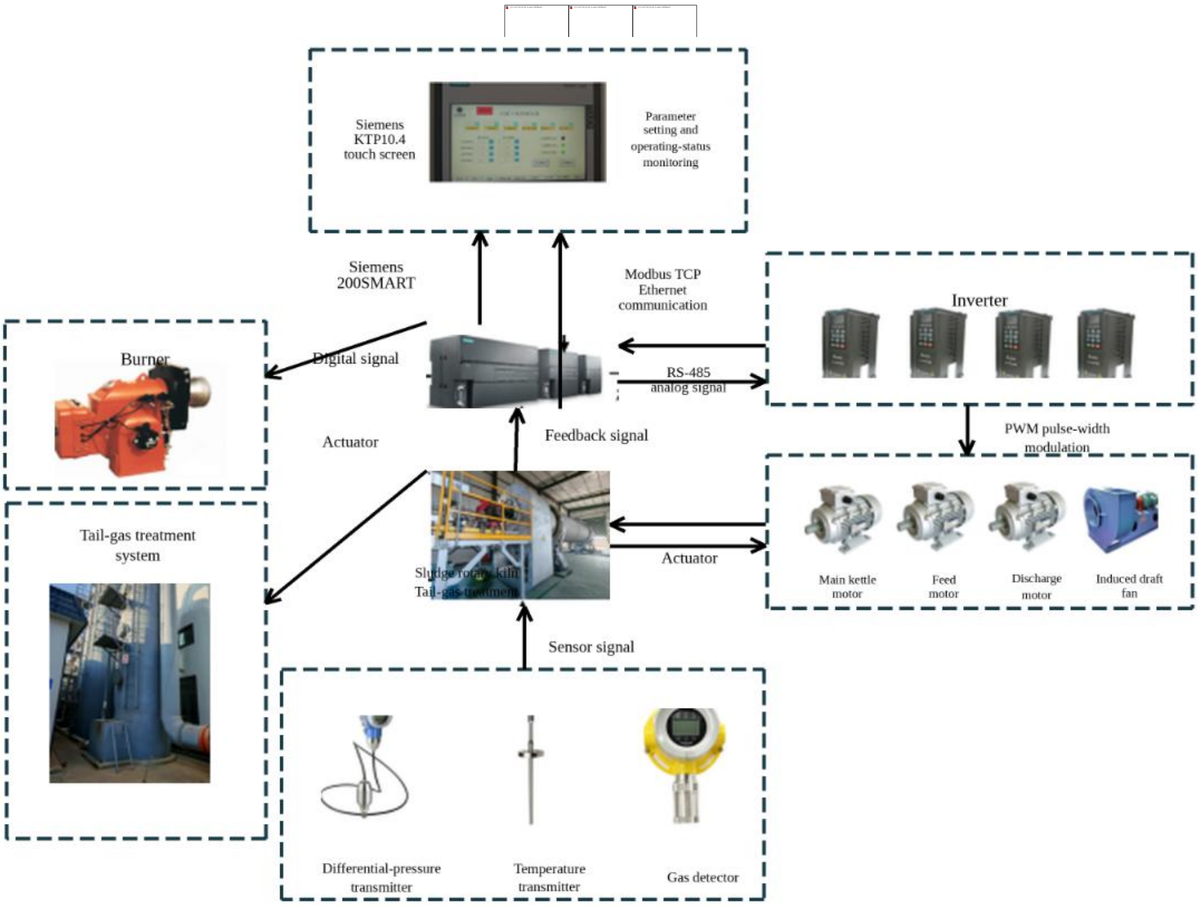


Figure 4: Diagram of the control system block

3.2 General control requirements

The control system is based on the rotary kiln sludge drying treatment system, and combined with the process of rotary kiln drying, the following requirements: (1) touch screen manual mode with the control of inlet and outlet motors, the main kettle motor forward and reverse function, to prevent sludge clogging, the motor current is too large to automatically alarm the shutdown, to regulate the induced draft fan frequency, and the normal switch spraying and alkaline washing tower. The automatic mode meets the sequence of switching on and off of each executive part in the production process. (2) Reasonable selection of control system hardware, including PLC control cabinet power supply modules, hubs, Ethernet switches, I/O cards, terminal blocks and so on. Power supply module should have a wide range of voltage adaptability, equipped with overload protection and surge suppression, through the industrial Ethernet switch to achieve PROFINET communication between PLC and HMI, analog in order to prevent interference with shielded wires, the design of the hardware system wiring diagrams, PLC and frequency converter using RS-485 serial communication and analog input and output to exchange data. (3) Using Siemens STEP7 series software for ladder diagram design, using WinCC configuration software for the upper monitoring interface design, storage and display of field data, and record the alarm information of the entire process system [13]. (4) The principles and functions of the system configuration scheme: to meet the various process control requirements in the sludge drying process; to realize the hand-automatic program function, the touch screen panel operation of the executive parts; to monitor and modify the operating parameters on site; to provide daily production reports, which helps production management.

It has fault alarm function, which is convenient for maintenance and expansion.

3.3 Control system wiring

According to the control requirements of the system, the following wiring diagrams are for the main kettle motor, feed motor, discharge motor, and induced draft fan motor (Figure 5~ Figure 9). PLC control circuit diagram, and Table 1 System I/O address assignment table.

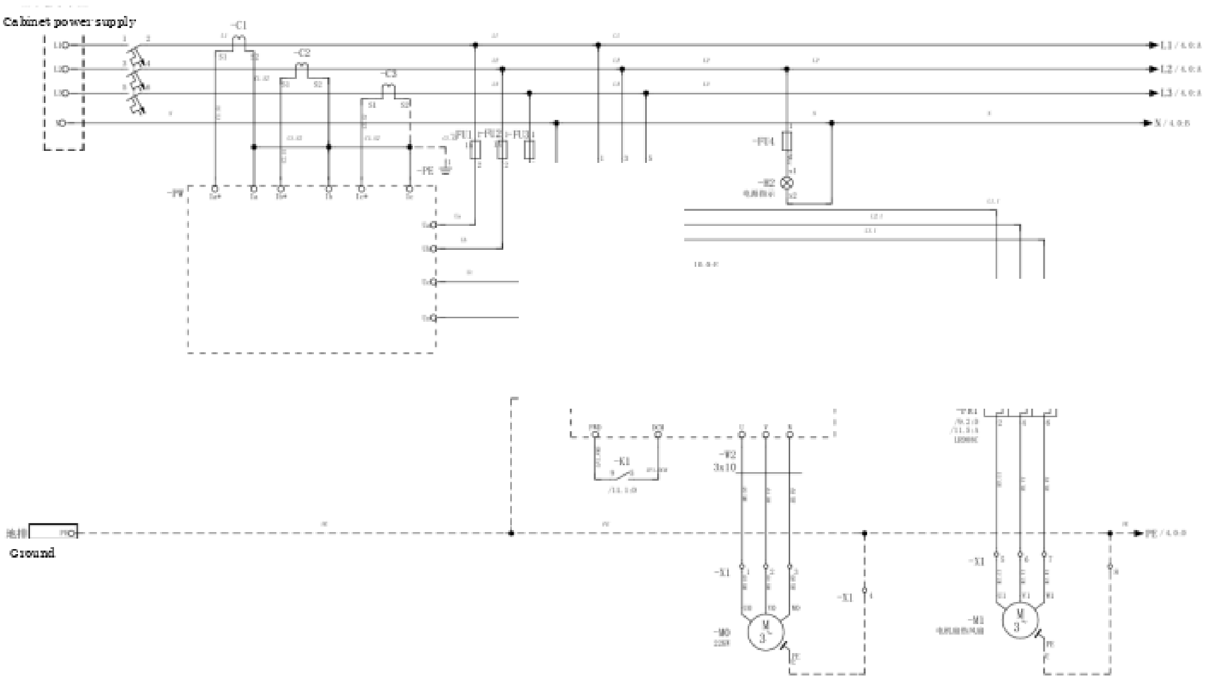


Figure 5: The electrical wiring diagram of the main kettle motor and cooling fan

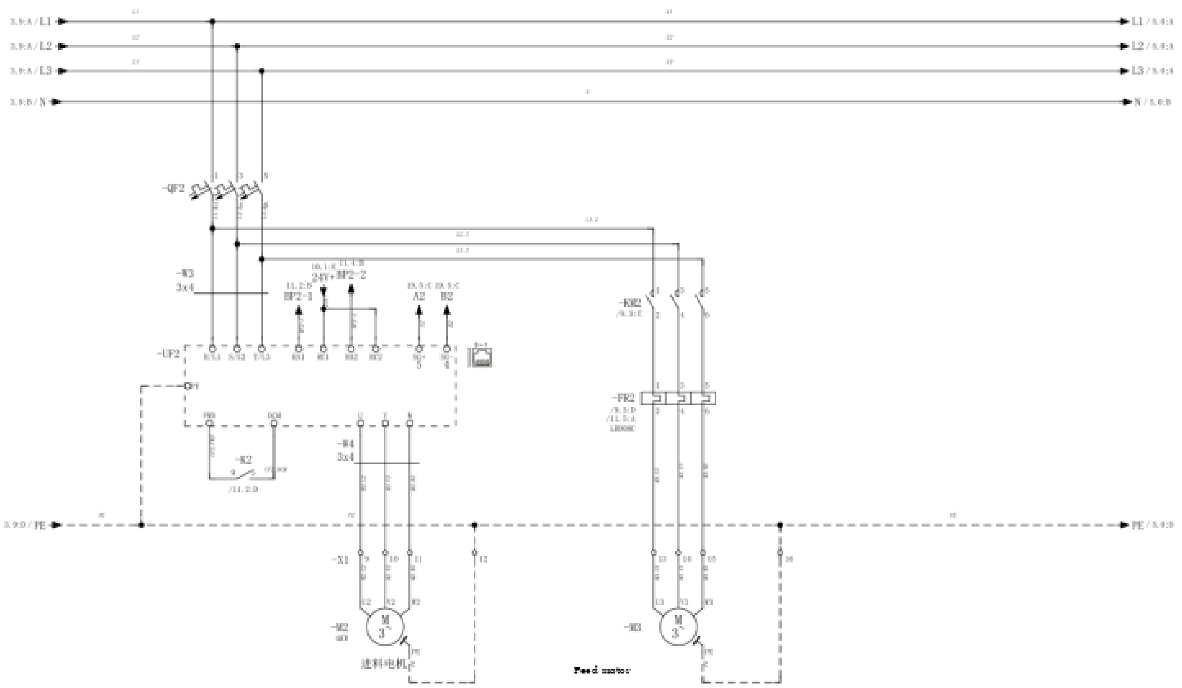


Figure 6: Electrical wiring diagram of feed motor and cooling fan

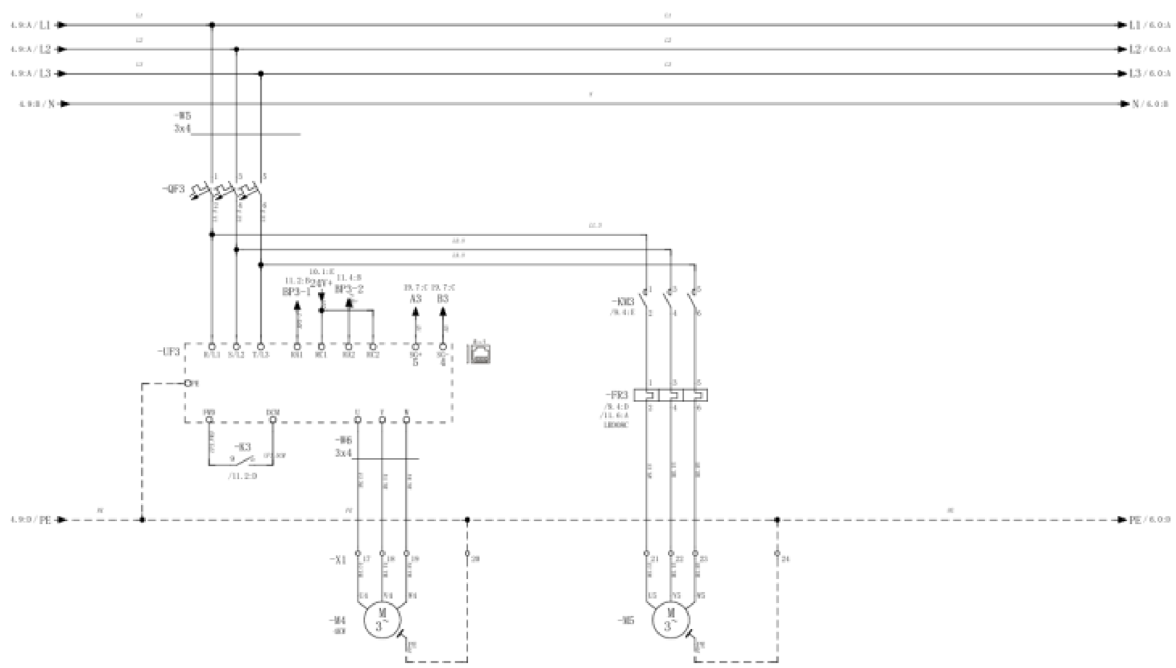


Figure 7: Electrical wiring diagram of discharging motor and cooling fan

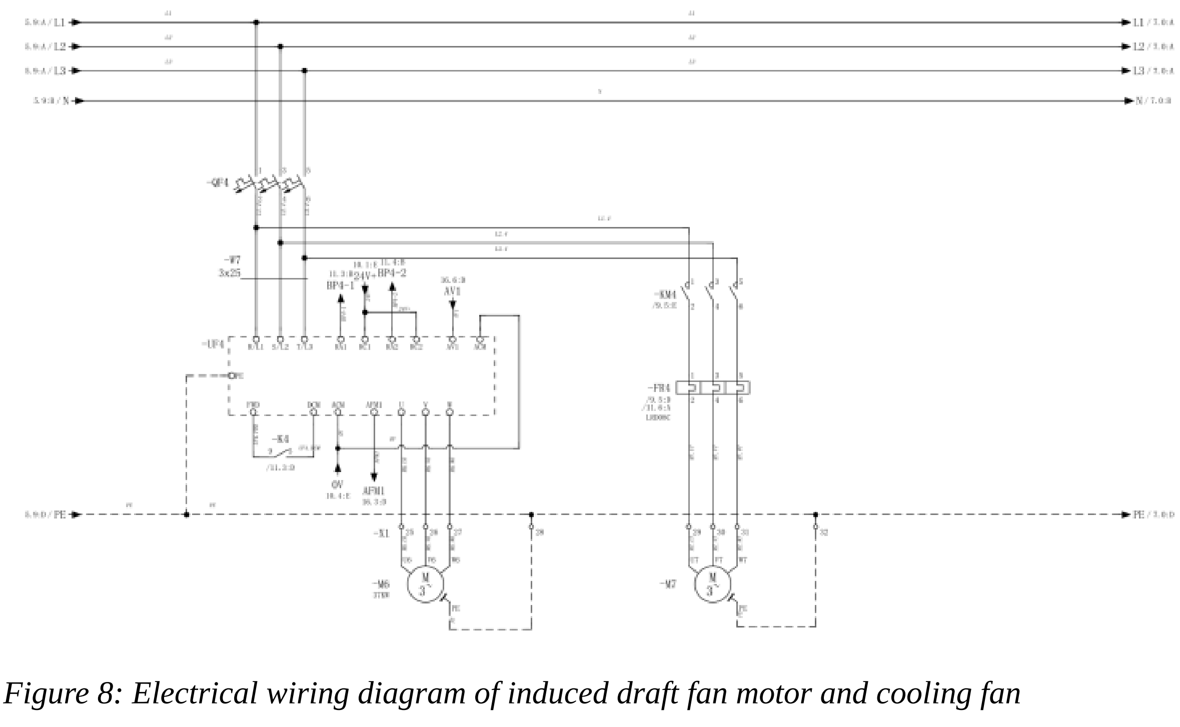


Figure 8: Electrical wiring diagram of induced draft fan motor and cooling fan

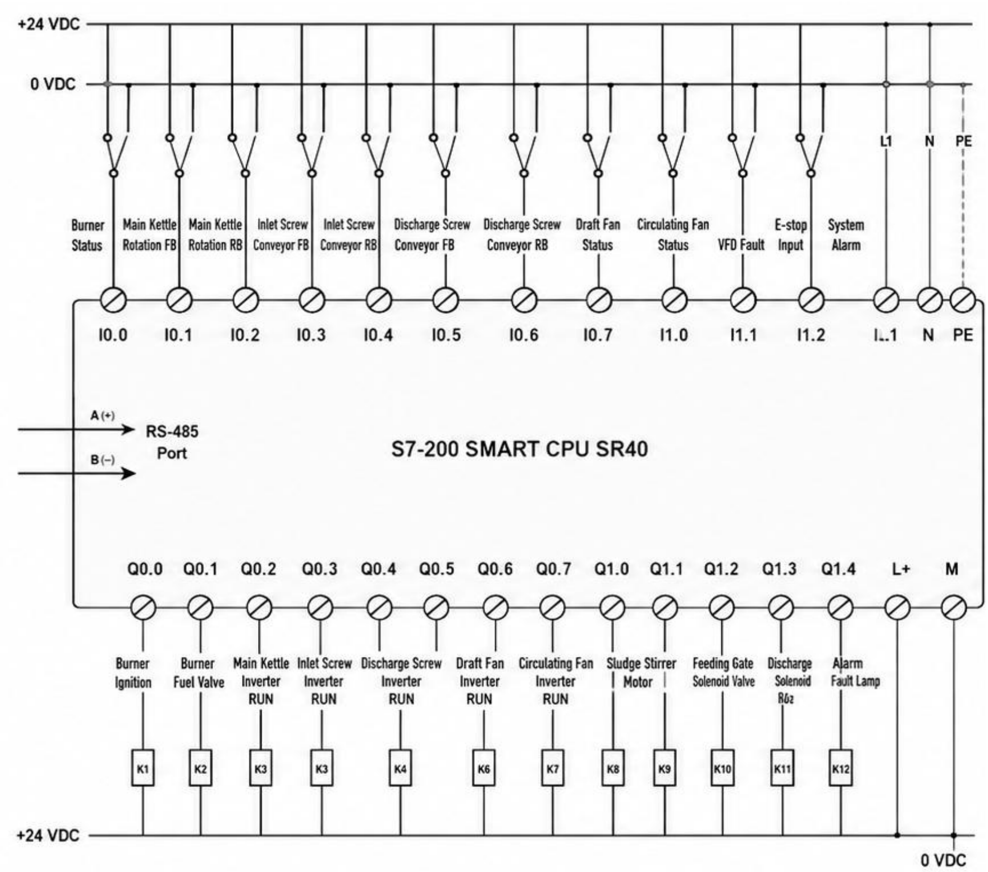


Figure 9: Control circuit diagram

Table 1: System I/O address allocation Table

Input Signal	Input terminals	Output Signal	Output terminals
Emergency stop	I0.0	Main kettle operation	Q0.0
Main kettle fault	I0.1	Feed operation	Q0.1
Feeding fault	I0.2	Discharge operation	Q0.2
Discharge fault	I0.3	Fan operation	Q0.3
Fan fault	I0.4	Main kettle motor cooling operation	Q0.4
Main kettle heat dissipation fault	I0.5	Feed motor cooling operation	Q0.5
Main kettle operation	I0.5	Discharge motor cooling operation	Q0.6
Feed operation	I0.6	System fan cooling operation	Q0.7
Discharge operation	I0.7	Primary spray start	Q1.0
Fan operation	I1.0	Alkaline washing start	Q1.1
Main kettle cooling fan failure	I1.1	Secondary shower start	Q1.2
Feed cooling fan failure	I1.2	Burner operation	Q1.5
Discharge cooling fan failure	I1.3	Burner ignition	Q1.7
Blower cooling fan failure	I1.4	Main kettle motor running indication	Q8.5
Primary shower fault	I1.5	Feed motor running indication	Q8.6
Alkaline washing fault	I1.6	Unloading motor running indication	Q8.7
Secondary shower fault	I1.7	Fan operation indication	Q12.0
Burner operation signal	I2.7	Burner operation indication	Q12.3
Burner fault signal	I16.0		
Shower operation signal	I16.3		
Signal for alkaline wash operation	I16.4		
Secondary Shower Run Signal	I16.5		

4 Rotary kiln control system software design

4.1 Control system flow

The control system flowchart is shown in Figure 10. Start-up phase, start-up: system initialization, check the status of the equipment to ensure that everything is normal. Primary spray (delay 10s): the spray device starts, initially cooling the temperature of the exhaust gas, removing large particles of dust and reducing the load of the exhaust gas on the subsequent system. Secondary spray (delay 10s): further refine the spray, remove fine particles of dust and part of the acidic gas, to ensure that the exhaust gas temperature and quality standards. Electric filter (delayed 10s start), used to remove particles and tar in the tail gas, to ensure the cleanliness of the tail gas and improve the efficiency of the subsequent tail gas treatment equipment. Then delay 10s UV photolysis system start, open the UV photolysis device, for the subsequent purification and disinfection of exhaust gas to prepare. Main system fan start (10s delay): start the fan to form a micro-negative pressure inside the equipment to ensure the stable extraction of exhaust gas. Main kettle startup (10s delay): the main equipment formally enters the standby state, and the main kettle rotary kiln starts to rotate slowly, ready for sludge drying. Burner pre-start: The combustion chamber starts to preheat, gradually increasing the internal temperature of the rotary kiln to provide a heat source for sludge drying. Drying operation stage: When the temperature at the specified position inside the kiln is judged to be higher than 200°C after the burner preheating, the feeding starts and the wet sludge enters into the main kettle through the screw feeding mechanism. In the sludge drying process, the time from feeding to discharging is generally about one hour, and the speed can be changed according to the actual operation requirements. After a delay of 50min, the unloading screw discharging mechanism is activated to convey the dried sludge to the dry sludge storage system. When the stop signal is given: the system detects the operation status and judges whether the feeding needs to be stopped. Delay 2min feeding stop, stop sludge conveying, make sure the equipment is running within the load range. Delay 1min burner stop, shut down the burner, the system gradually cooling. When the kettle temperature drops to 100℃, the system temperature is reduced to the safe range, ready to enter the stop phase. Stopping stage: main kettle stops: stop the main body of the equipment running. Discharging mechanism (delay 20s) stops gradually, fan stops (delay 2s), shut down the fan, stop exhaust extraction. Spraying stop (delay 2s), close the primary and secondary spraying system, stop the tail gas cooling.UV photolysis stop (delay 2s): close the UV photolysis system, stop the tail gas disinfection [14]. Finally, the electric filter stops, completely cutting off the power supply of all executive equipment to ensure the safe shutdown of the system.

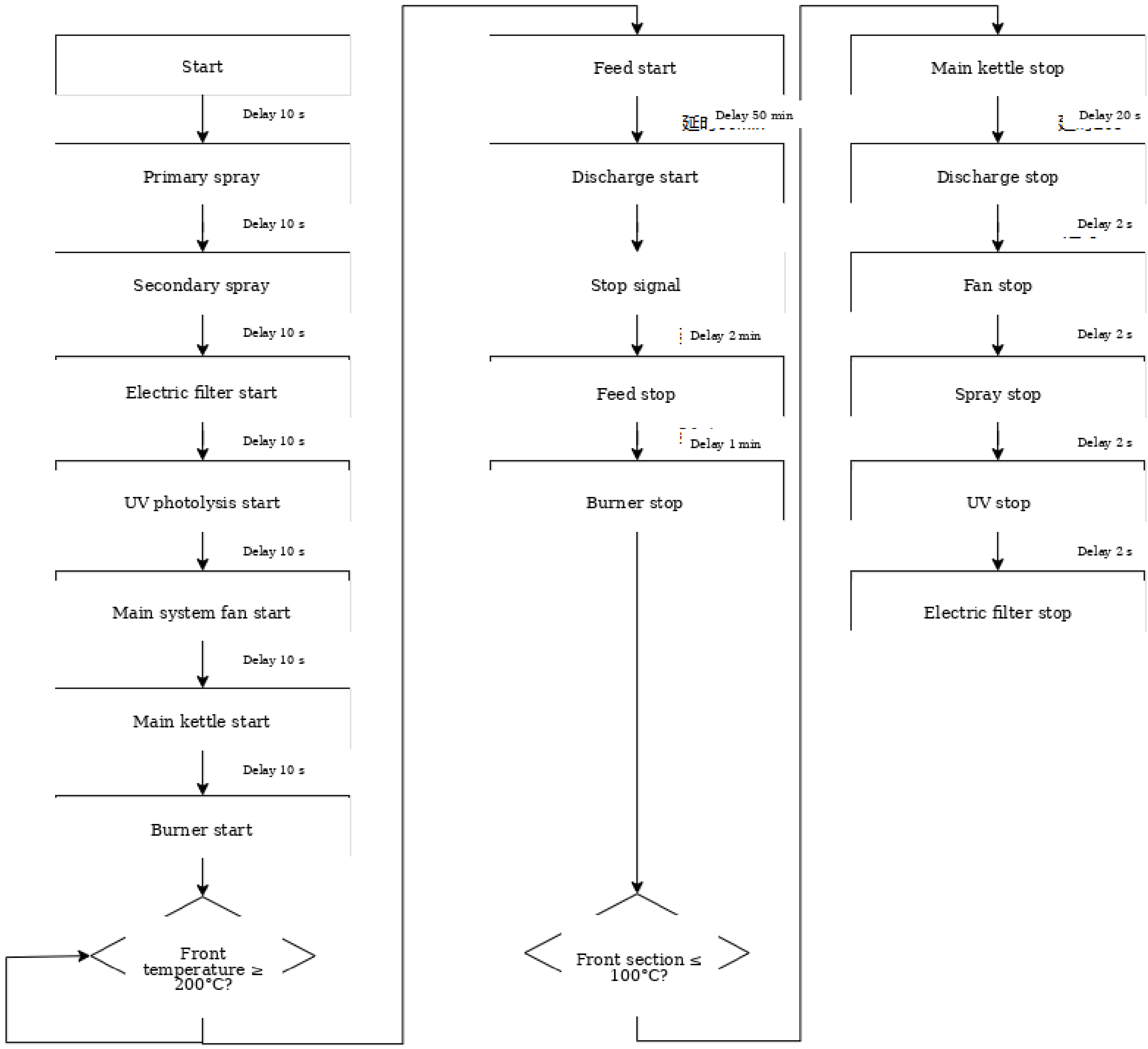


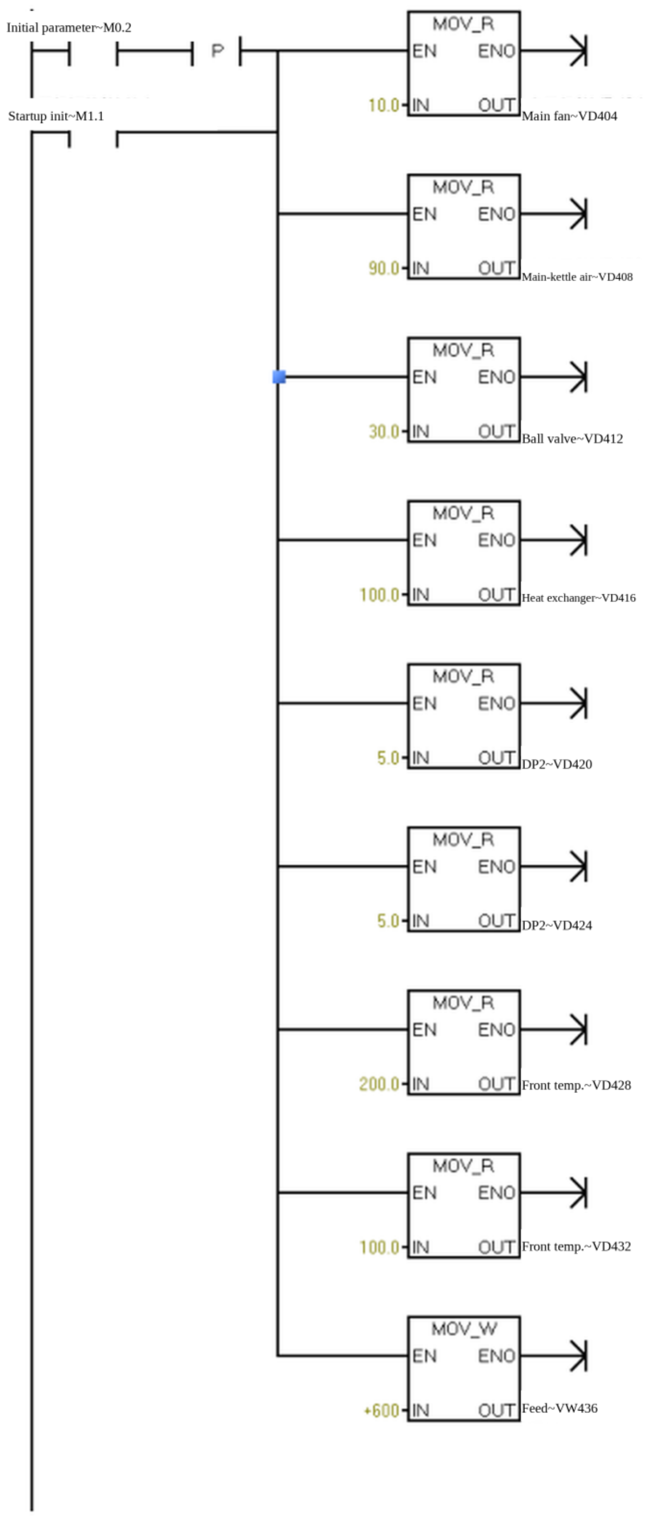
Figure 10: Diagram Control System Flow Chart

Primary shower and secondary shower for gradual cooling of the tail gas and dust removal in the start-up phase, providing stable front-end support for the subsequent tail gas treatment system. Drying operation stage: By controlling the burner and feeding mechanism, the drying process of sludge from low temperature preheating to high temperature deep dewatering is realized. Stopping phase: The system is gradually shut down to ensure safe cooling and shutdown of all components, reducing energy waste and safety risks. The whole process coordinates the operation of each link through the automated control system, realizing the efficient, safe and stable operation of the sludge drying process, and at the same time ensuring that the exhaust gas meets the standard emission.

4.2 Control system program design

The PLC uses logic and sequential control in the form of ladder programs, which are programmed using STEP 7-MicroWIN SMART software, and some of the ladder diagrams are shown below.

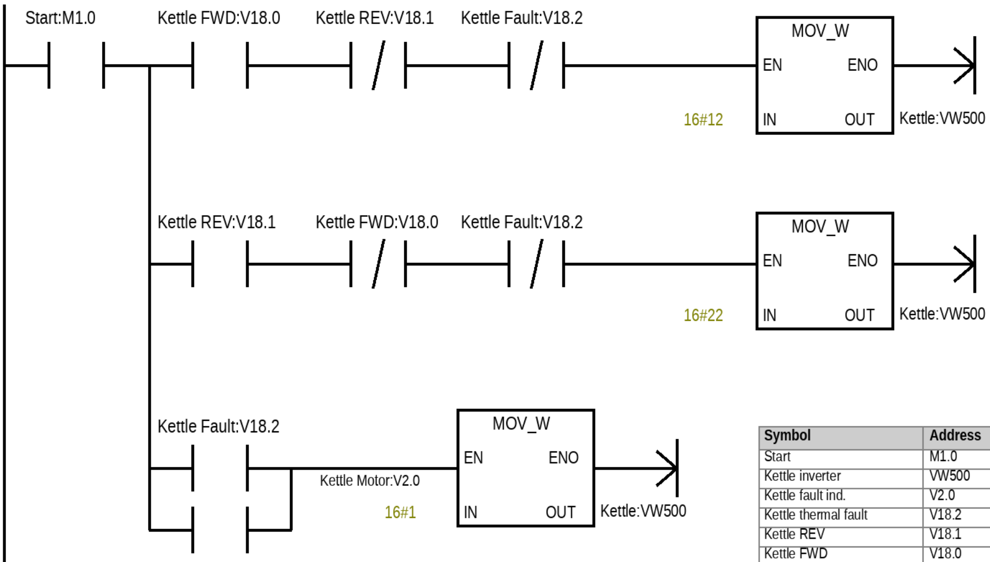
(1) The factory setting initialization process is shown in Figure 11.



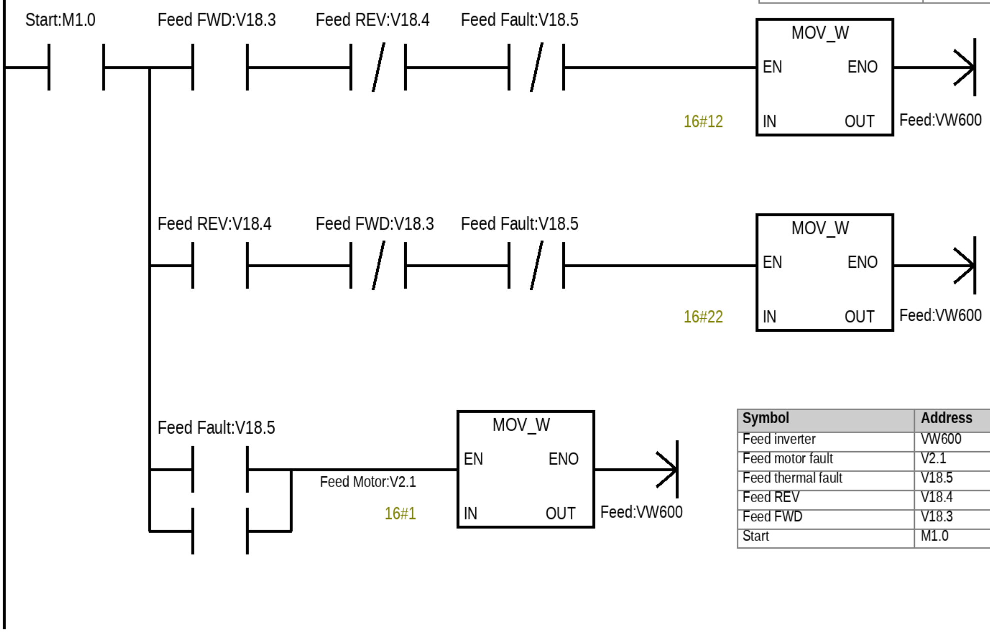
Symbol	Address
Initial parameter reset	M0.2
Feed-delay setting	VW436
Startup initialization	M1.1
Front-temp. compare set 1	VD432
Front-temp. compare set 2	VD428
Ball-valve opening	VD412
Heat-exch. air-valve opening	VD416
DP2 initial value 1	VD424
DP2 initial value 2	VD420
Main-fan set frequency	VD404
Main-kettle air-valve opening	VD408

Figure 11: Ladder diagram of factory setup initialization

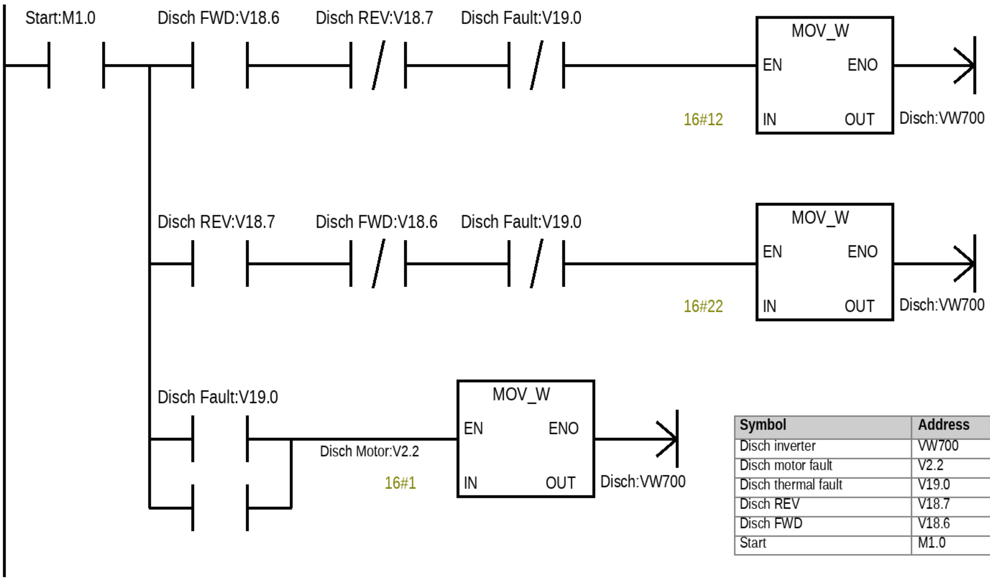
(2) Manual program (Figure 12)



Symbol	Address
Start	M1.0
Kettle inverter	VW500
Kettle fault ind.	V2.0
Kettle thermal fault	V18.2
Kettle REV	V18.1
Kettle FWD	V18.0



Symbol	Address
Feed inverter	VW600
Feed motor fault	V2.1
Feed thermal fault	V18.5
Feed REV	V18.4
Feed FWD	V18.3
Start	M1.0



Symbol	Address
Disch inverter	VW700
Disch motor fault	V2.2
Disch thermal fault	V19.0
Disch REV	V18.7
Disch FWD	V18.6
Start	M1.0

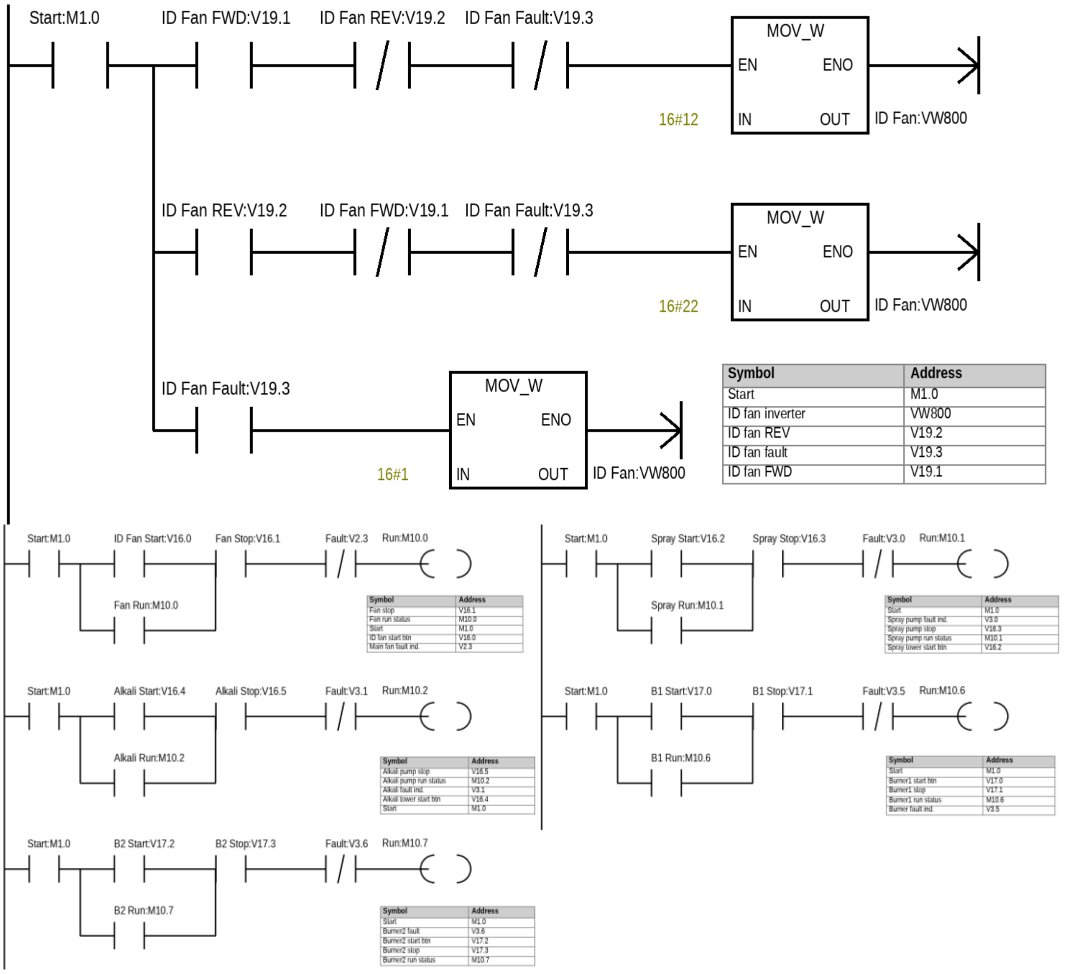
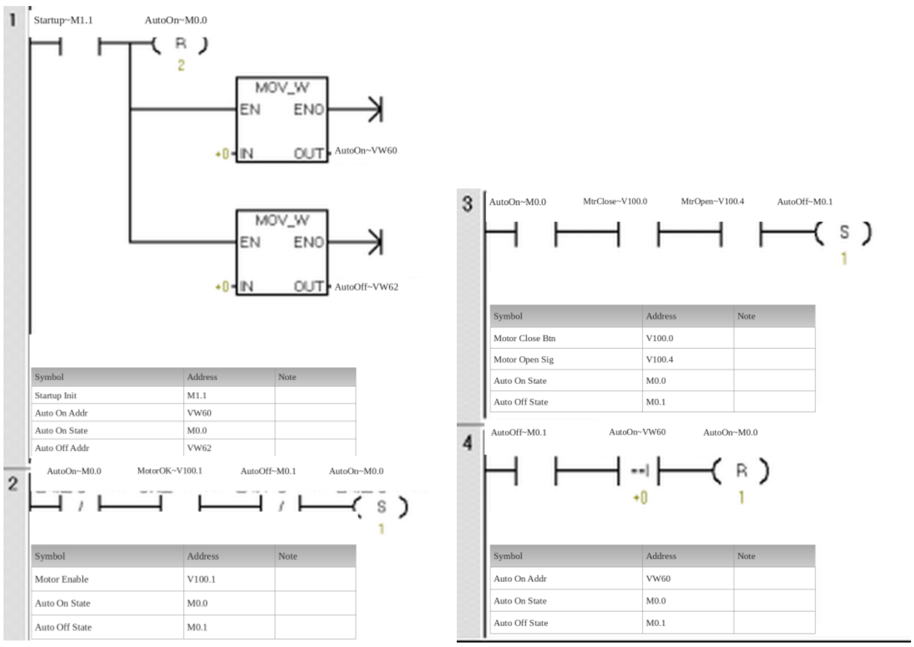
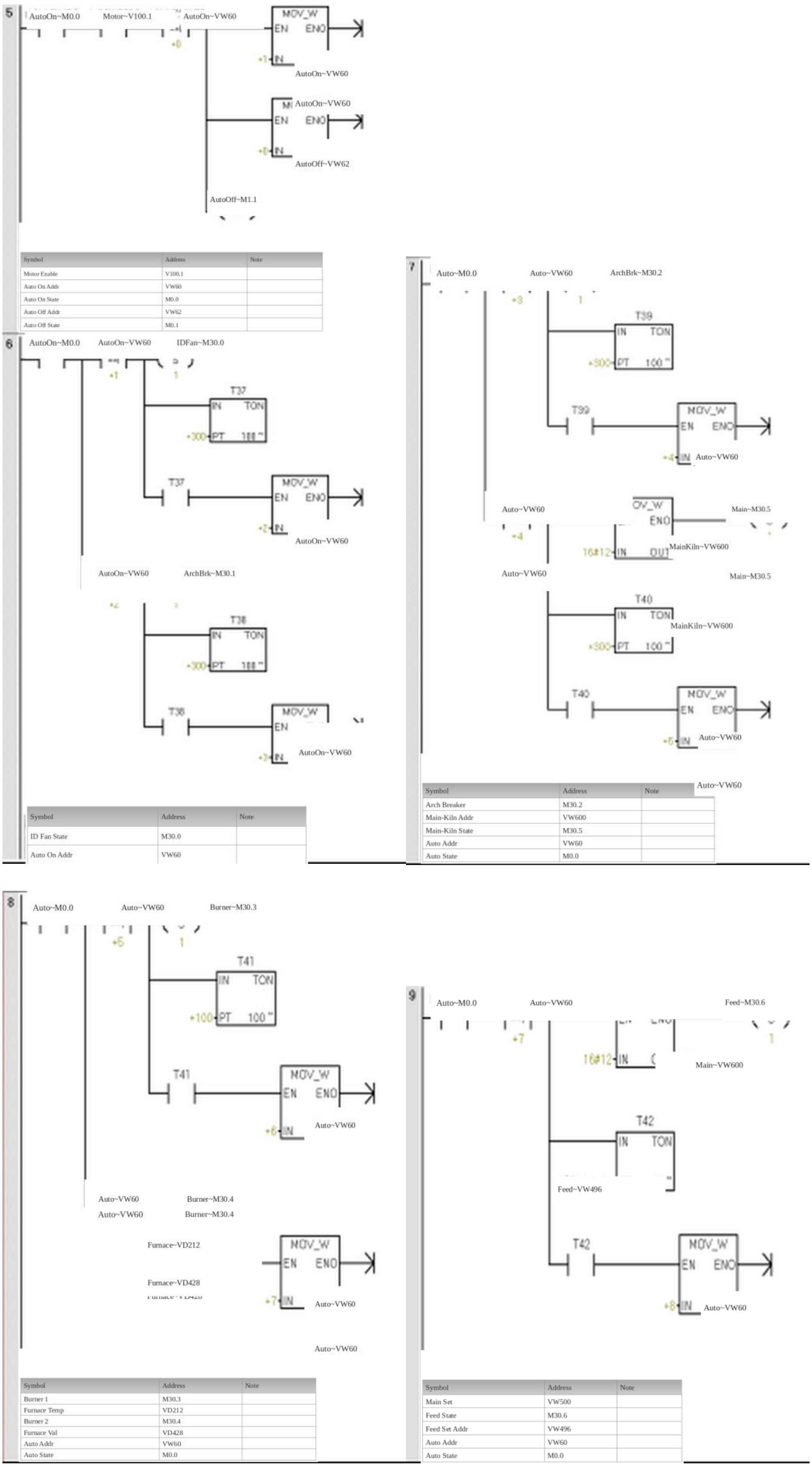


Figure 12: Manually controlled ladder diagram

(3) Automatic program

Part of the automatic ladder program is shown in Figure 13.





Symbol	Address	Note
Motor Enable	V100.1	
Auto On Addr	VW60	
Auto On State	M0.0	
Auto Off Addr	VW62	
Auto Off State	M0.1	

Symbol	Address	Note
ID Fan State	M30.0	
Auto On Addr	VW60	

Symbol	Address	Note
Arch Breaker	M30.2	
Main-Kiln Addr	VW600	
Main-Kiln State	M30.5	
Auto Addr	VW60	
Auto State	M0.0	

Symbol	Address	Note
Burner 1	M30.3	
Furnace Temp	VD212	
Burner 2	M30.4	
Furnace Val	VD428	
Auto Addr	VW60	
Auto State	M0.0	

Symbol	Address	Note
Main Set	VW500	
Feed State	M30.6	
Feed Set Addr	VW496	
Auto Addr	VW60	
Auto State	M0.0	

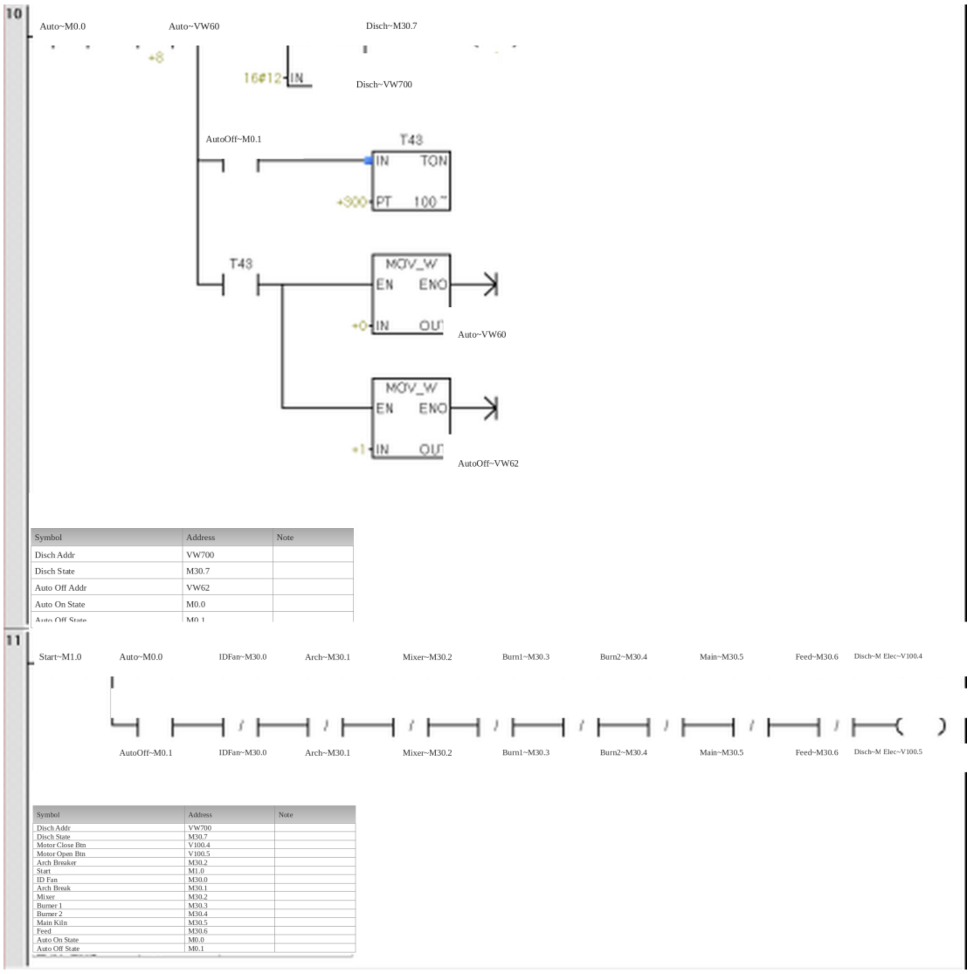


Figure 13: Automatic control ladder diagram

4.3 Program Simulation

The PLC 200SMART program is simulated using Huasheng Yunlian COSAI_S7200_ 200SMART simulation program (Figure 14). Take the automatic control program as an example, import the ladder diagram of the section into the software.

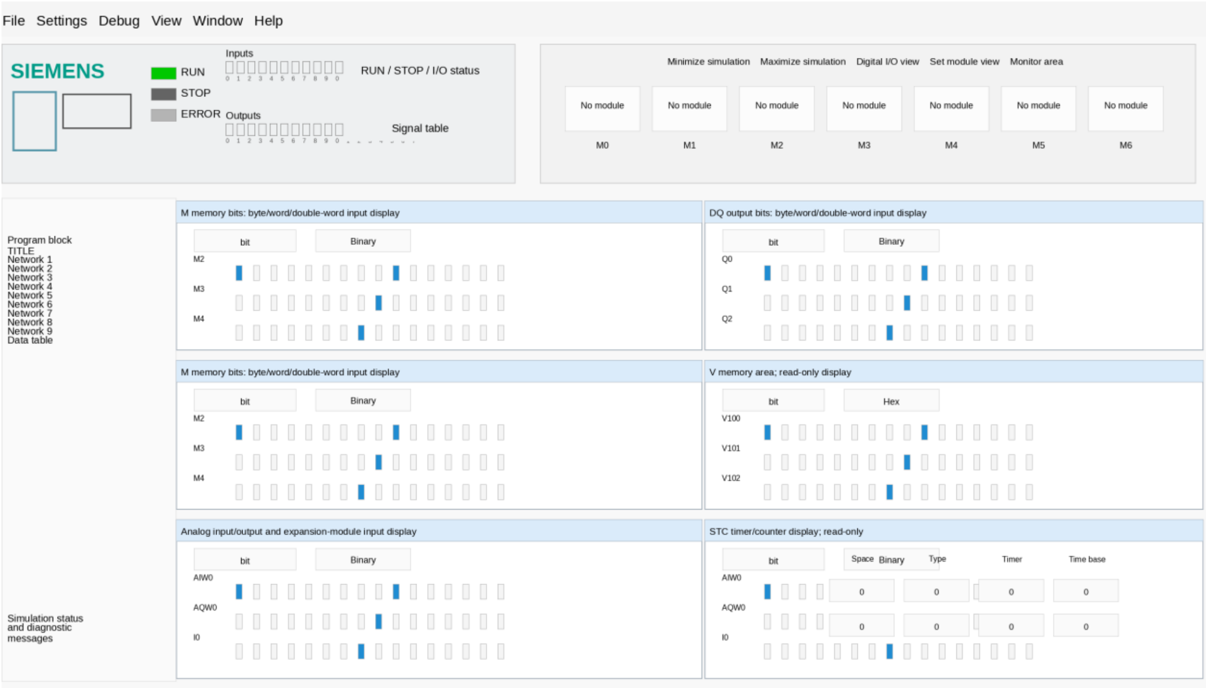


Figure 14: Diagram of program simulation results

As shown in Figure 14 for the simulation results, after importing the ladder diagram in the software, RUN is pressed, at which time the PLC is powered up. Subsequently, the program runs when the power-on button M1.0 is pressed in the register address operation panel, and after the power-on initialization M1.1 is pressed, the MOV_W instruction transmits 0 to VW60 to prepare for the subsequent automatic sequential startup.V100.1 motor full-on button is pressed, at which time the M0.0 automatic power-on state is set to 1, which is illuminated in the simulation diagram, and the M31.1 automatic power-on indication is also illuminated. The program judges that when VW60 is 0, M0.1 automatic power-up state is set to 0, and then VW60 is assigned the value of 1, the induced draft fan M30.0 is lit, the lower right corner of the diagram T37 turns on the delay timer to start timing, the value reaches 300, the spray tower M30.1 is lit. T38-T41 in order to start timing, respectively, the lighting of alkali washing pump M30.2, the main kettle motor M30.5, combustion 1 No. motor M30.3, combustion No. 2 motor M30.4. In the VW60 value of 6, at this time the program to determine whether the VD212 front-end temperature value is greater than the VD428 front-end temperature set to compare the value, greater than the feed motor M30.6 will be energized in the figure is lit. Then T42 timer will read the VW436 feeding delay setting value initialized in the factory setting program, and the discharging motor will start after 50min delay. When M30.0-M30.7 are all illuminated in sequence, the motor full open indication V100.4 is energized and illuminated.

4.4 Touch screen design

The touch screen is developed by WinCC Flexible SMART V3, and the control parameters are realized by adding switch buttons, indicator lights and other controls through the configuration page, with the functions of control process visualization and alarm [15], and part of the interface is shown in Fig.

Its running interface is shown in Fig. 15. Under the running page, the operator can manually adjust the frequency of the main kettle motor, discharge motor, feed motor and system fan. The page also has the ability to display the temperature of the front, middle and back of the rotary kiln, making it easy to monitor the temperature inside the kiln at any time. In addition, the temperature of the heat exchange water, the heat exchange inlet and outlet temperatures can also be monitored at any time. In case of emergency, press the emergency stop button to stop the operation of the equipment.

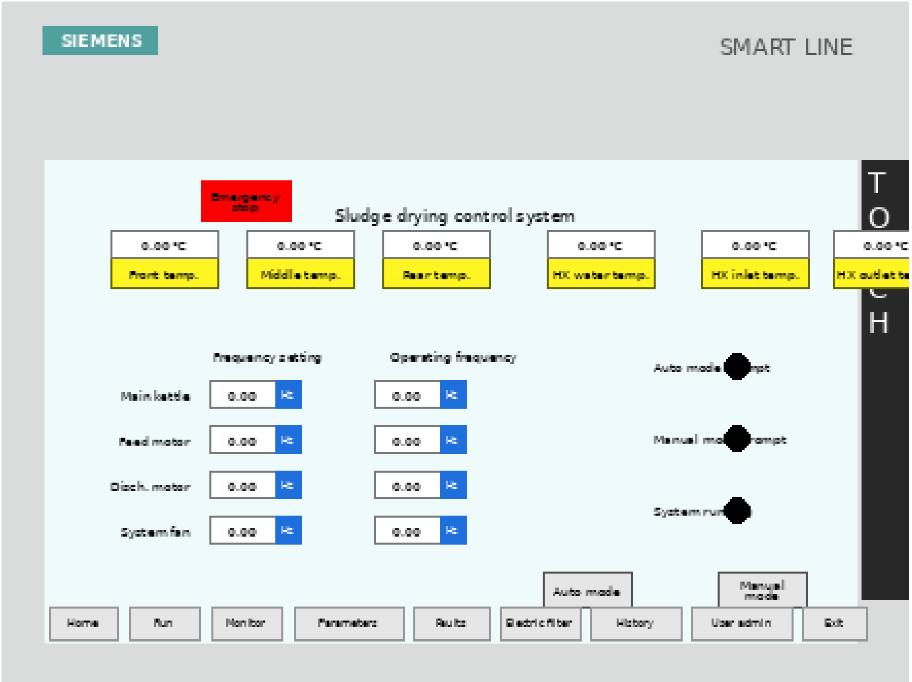


Figure 15: Diagram of the touch screen running page

The manual control interface of the system is shown in Fig 16. After pressing the manual mode of the operation interface, you can jump to the manual mode. In this interface. The operator can manually switch on and off the execution parts on the touch screen.

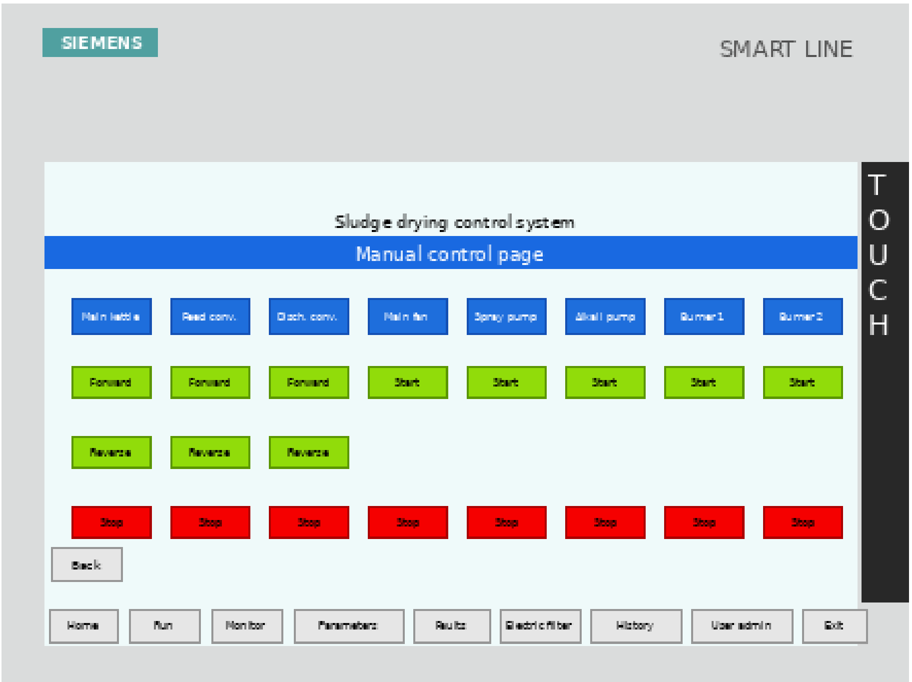


Figure 16: Manual control page diagram

The automatic mode is also turned on in the operation interface, and when it is turned on, the execution parts will be started sequentially according to the logical sequence in the appeal program diagram. As shown in Figure 17, the Motion Status Indication interface of the Monitor button allows you to view the current start and stop of the actuated components. The interface displays the running status of the system components, which is convenient for the operator to monitor the running status of the system in order to understand the current execution steps of the system and ensure stable and reliable system operation. When an error occurs in the operation, the fault indicator will light red to remind the system to suspend the operation; when the error is solved, the system will reset and work again.

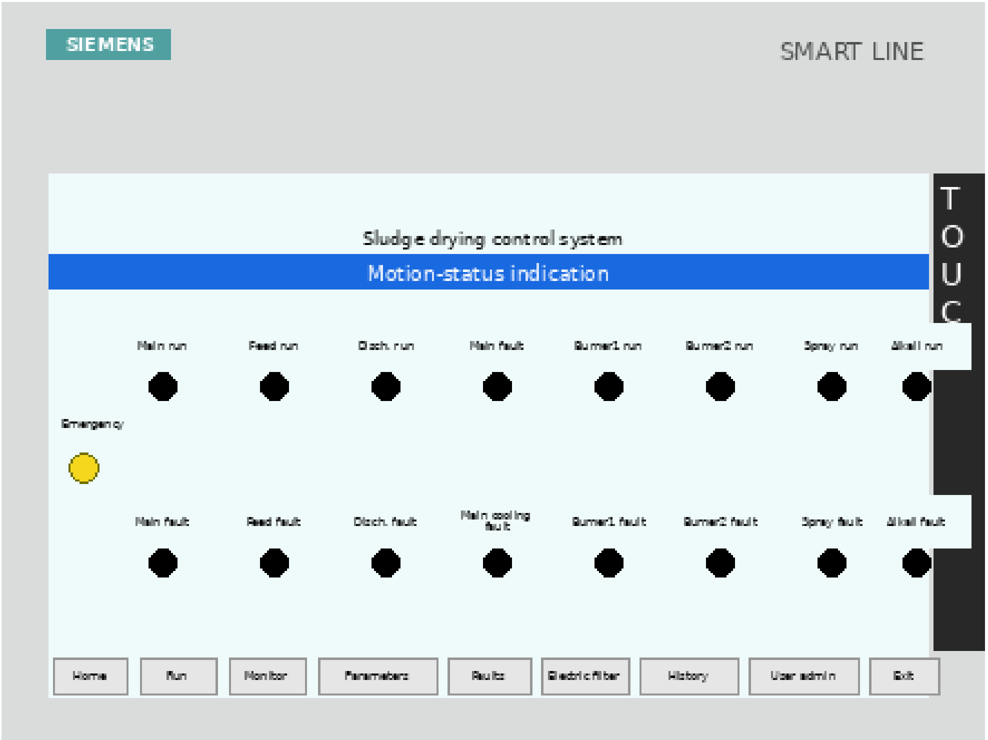


Figure 17: Motion status indication page graph

5 Instance validation

The picture shows the actual rotary kiln main equipment, the site for PLC program download and debugging, rotary kiln sludge drying device to verify each control function (Figure.18~ Figure.21). When the manual program is started, the manual mode indicator light of the electronic control cabinet is on, the equipment starts to run, the induced draft fan, the exhaust gas treatment system works and the exhaust gas treatment, the burner is started, the discharging is started, the preheating is started in the rotary kiln, and then the sludge starts to be fed, and the touch-screen operation status interface can display the information of each executive part in real time. The results show that: in the process of operation, the degree of system automation is improved, the sludge rotary kiln drying equipment is running normally, the touch screen interface function is perfect, the operator can adjust the operating parameters of the equipment through the touch screen to adapt to the requirements of different working conditions.

Figure 18: Diagram of the main equipment of the rotary kiln

Figure 19: Exhaust gas treatment equipment diagram

Figure 20: Touch screen control interface diagram of electric control cabinet

Figure 21: Diagram of sludge with a moisture content of 50% after drying

6 Summary

PLC-based sludge rotary kiln drying device can realize the process of efficient sludge drying to meet the ability to receive wet sludge with less than 85% moisture content, the sludge treated can be adjustable between 1% and 50% moisture content, and the daily sludge treatment capacity of up to 100 tons. The efficiency and adaptability of sludge drying can be improved by dynamically adjusting the feeding and discharging, the rotating speed of the main kettle, and the block position of the burner. The control system takes Siemens 200 Smart series PLC as the control core, which has the advantages of rich instruction set, easy programming and convenient wiring. Through the sensor detection and feedback of temperature, pressure, gas and other key parameters in the drying process, the operator can intuitively monitor on the touch screen. At the same time, the touch screen interface has the functions of automatic adjustment of specific parameters in the process of sludge drying, monitoring of operation status, fault alarm and storage of on-site data. It makes the system operation precision and automation level get a significant improvement, reduces the labor intensity of the operator, and ensures that the exhaust gas meets the emission standards. The whole system runs stably and reliably, and meets the strict requirements of sludge drying industrial production.

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About the Authors

Yuhui Li was born in Yongzhou City, Hunan Province, China in 1999. He obtained a bachelor's degree from Hunan Institute of Technology and is currently studying at the School of Mechanical and Intelligent Manufacturing, Central South University of Forestry and Technology. His main research directions are mechatronics.

Zhongliang Gong was born in Jingmen City, Hubei Province, China in 1965. He obtained a bachelor's degree from Nanjing University of Aeronautics and Astronautics. Currently, he serves as a professor at the School of Mechanical and Intelligent Manufacturing, Central South University of Forestry and Technology. His main research directions are mechatronics.

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