Design of ship exhaust gas desulfurization control system based on S7-1500 PLC

Qi Yin¹*, Majed Shreka¹, Ruifeng Gao¹ and Yunlong Zhu¹

¹College of power and energy engineering, Harbin engineering university, Harbin, Heilongjiang, 150001, China

*Corresponding author’s e-mail: yqiheu@163.com

Abstract. In this paper, an exhaust gas desulfurization control system for the ship was designed based on the sodium-alkali desulfurization system. The control system composed of the process control and the monitoring system. Besides, Siemens S7-1500PLC was used to realize the process control. Moreover, the monitoring system consisted of the machine side touch screen and the remote host computer, which provided the real-time monitoring of the system. Furthermore, the main functions of the system were introduced and the design points were given. Eventually, the system had a good functional performance and achieved the expected control objectives after the control system debugging.

1. Introduction

SOx emissions from the ship exhaust are responsible for some serious environmental and health problems. Recently, it has been confirmed by the International Maritime Organization (IMO) that the sulfur emissions should be limited to 0.5%, which will be implemented from January 1, 2020. Thus, the use of exhaust gas treatment devices is an important measure to reduce the emission of sulfur oxides from the ship's exhaust gas up to the required level and protect the global environment. Therefore, the desulfurization device and its control system play an important role in providing the actual discharge of ship exhaust. While designing a suitable desulfurization unit for ship exhausts, it is also necessary to establish an intelligent and stable automatic control system that can achieve the goal of high-efficiency desulfurization rate. Desulfurization of ship exhaust is a kind of exhaust gas treatment process in which the interlocking of field equipment is a continuous production process, the field data is difficult to obtain, and the functional units are relatively dispersed. Based on these facts, an exhaust gases desulfurization control system for the ship was designed in this paper using Siemens latest PLC controller S7-1500 PLC together with the host computer and touch screen. Section 2 illustrates the system process. Section 3 discusses the system structure, the PLC hardware configuration, the system software design, and the communication design of the control system. Lastly, the conclusions are elucidated in Section 4.

2. System process

The ship exhaust gas desulfurization control system consists of three parts: the host computer, the touch screen, and the PLC. The host computer uses a Siemens industrial personal computer and forms a monitoring system with touch screen next to the machine. The monitoring system provides a good human-computer interaction interface to monitor the operation of the whole system and modify the parameters [2] while the PLC uses Siemens S7-1500 PLC to control I/O equipment and frequency converter to achieve stable operation of the desulfurization system.
The desulfurization control system of ship exhausts adopts the sodium-alkali desulfurization technology, which uses NaOH solution as the desulfurization absorbent. The process flow of ship exhaust gas desulfurization system is shown in figure 1. The system mainly includes the exhaust gas system, the washing tower system, the circulating pump module, the alkali supply module, the seawater cooling system, and the electrical control system.

The technological process of sodium alkali desulphurization system is as follows: 50% concentration of NaOH solution is used as absorbent and seawater as process water. After the ship flue gas enters the scrubbing tower through the exhaust bypass valve, and the washing liquid is sprayed by spiral nozzles evenly arranged in the spraying layer by using circulation pump. The washing liquid uniformly covers the inner space of the tower and reacts with the SO2 of the exhaust gases, which makes SO2 trapped in the exhaust gas entering the liquid phase [3]. The density gradually increases as the washing solution continues to circulate and when the density of the aromatic washing solution reaches the set value, it will be diverted into the waste water treatment unit. Besides, a two-layer mist eliminator is installed at the outlet of the scrubbing tower to reduce gas entrainment and spray escape. The demister is washed with process water regularly. Washed exhaust gas is discharged into the atmosphere through the induced draft fan.

3. System design

3.1. System structure

The structure of the desulfurization control system is shown in figure 2. The control system structure of "monitoring system + industrial Ethernet +PLC" was designed through the analysis of the desulfurization process and the operational requirements and parameters [4]. The structure accords with the characteristics of the complex desulfurization process, the various types of equipment, the multiple I/O points, and the dispersed. The desulfurization control system consists of the host computer PC, the touch screen, the PLC, the external electrical components, the sensors, the actuator, and other components. At the field control layer, the measurement signals such as temperature, pressure, flow, and valve opening are transmitted to the PLC through the isolator. In addition, the PLC controller completes
the logic control function and the analog data collection and processing. The monitoring layer consists of the host computer and the touch screen beside the computer, both of which are connected by Ethernet to control the CPU of the central processing unit of Siemens PLC.

![Diagram of monitoring object, field measurement and control signal section, PLC, and monitoring system.](image)

Figure 2. Desulfurization system control system structure.

### 3.2. PLC hardware configuration

According to the process characteristics of desulfurization system, it can be analyzed that the number of variables that the system needs to control is about 80. Besides, the Siemens compact PLC 1511C-1PN is selected as the control system is based on Industrial Ethernet. Moreover, the CPU is integrated with Ethernet interface and equipped with an LED display screen, which can easily display CPU status and fault information. Based on considering the margin, referring to the S7-1500 selection manual for the selection of modules such as digital input/output modules, analog input/output modules, and high-speed counters [5]. The final PLC hardware configuration is shown in figure 3. PLC provides the smooth operation of the desulfurization process by extending the connection of each function module and controlling the field I/O equipment.

![Diagram of PLC hardware configuration.](image)

Figure 3. PLC hardware configuration.

### 3.3. System software design

The software design of the desulfurization control system mainly includes three parts: PLC control program design, touch screen software design and design editing of the host computer. In the process of
desulfurization control, the real-time control and the monitoring of the parameters for the whole desulfurization system are realized by exchanging data between the controller and the monitoring system. The good monitoring interface design helps the operator to keep abreast and improve the stability of the operating status of the desulfurization. Amongst them, the PLC, the touch screen, and the host computer share data with each other through data transmission. The system software is written by Siemens TIA Portal V15 software. TIA Portal software fully embeds all devices and systems into a complete automation solution that saves equipment and resources. Besides, this software provides automated information transparency for the system. Therefore, the convenience of programming configuration is greatly improved.

3.3.1. PLC control program design. The PLC program is written in step7 professional edition of Siemens TIA Portal V15. The control program is designed, the control conditions of the process are judged, and the programming is completed by using the ladder language to complete the entire control process and according to the desulfurization process flow. PLC control program uses modular programming, which means that the program is divided into different logic blocks according to functions and each logic block performs different functions. In the main loop OB1, different functions can be called according to the conditions, which is characterized by easy division of labor and cooperation and convenient debugging [6]. According to the working principle of the Siemens S7-1500PLC, the function block is first edited according to each control function and then each block is called in the main loop OB1 according to the logical sequence of the system. In addition to the main block, there is also an interrupt control function that puts the PID loop control program into the timed loop interrupt organization block OB35, which can cycle intermittent execution functions. Moreover, the initialization alarm flag bit, the initialization filter flag bit, the initialization fault flag bit, the initialization filter buffer, the alarm upper and lower limit assignment, and the assignment of other systems initial operating parameters are edited in the initialization block OB100. Furthermore, there are 3 PLC program blocks, 14 FC function blocks, and 9 data blocks in the desulfurization control system.

The steps of PLC control procedure are as follows:

1. Adjusting the liquid level of desulfurization tower to the set value by controlling seawater supply pump.
2. Adjust the pH value of washing circulation liquid to reach the set value by controlling the alkali liquor supply pump.
3. During the desulfurization process, the circulating pump is always running so that the washing liquid continuously circulates in the washing tower and in the pipeline and is cooled by the seawater heat exchanger to perform desulfurization reaction with the ship exhaust gas.
4. When the density of the detergent reaches the set value, the high-density detergent is discharged by controlling the diversion valve of the detergent.
5. The pH of the washing solution decreases with the desulfurization reaction, and the pump needs to supply fresh lye to keep the pH of the washing solution within the required range.
6. Regularly open the water supply valve on the upper part of the washing tower to clean the mist eliminator of the washing tower.

The system control mode is divided into four types: emergency stop control mode, switch manual control mode, software manual control mode, and automatic control mode. The transformation of control mode is controlled by the logical combination of corresponding Boolean variables or variables.

3.3.2. Touch screen software design. The touch screen of desulfurization control system uses Siemens TP1500 smart panel. Touch screen software design is compiled by WINCC professional edition of TIA Portal V15 and integrated with PLC. The touch screen is installed on the front panel of the control cabinet, which is mainly used for displaying the real-time status for each device in the system operation, the online modification of relevant parameters of the control system, the alarm information, and the manual control of each device under the manual mode of software. Besides, the operation is simple and
convenient and is suitable for operators to monitor the desulfurization system on site. There are 10 buttons that can be manually controlled on the control cabinet below the touch screen. After the system is powered on, the main control interface of the touch screen is entered as shown in figure 4.

![Figure 4. Main interface of touch screen.](image)

The upper side of the main control interface shows the schematic diagram of the desulfurization system, which displays the operating status of the system and the values of each parameter in real time. On the lower side are five control buttons namely "washing master map", "washing system", "alkali supply", "water treatment", and "operation interface". Click the button to enter the corresponding screen and realize monitoring, parameter setting, and other functions. The alarm display bar will appear on all operation interfaces so that the user can see the alarm information of the system.

### 3.3.3. Software design of upper computer configuration.

In order to facilitate the monitoring of the remote desulfurization system in the ship control room by the operator, the system host computer uses a Siemens industrial computer and is placed in the ship control room. The configuration software also uses the professional version of Portal WinCC because the variables defined in STEP7 can be directly used in WinCC, which can greatly reduce the project time. The main functions of the upper computer configuration software are:

1. Communicate with the field PLC controller.
2. Controlling system parameter setting and modification.
3. Displaying the operation of pumps, valves, and other equipment in the desulfurization system.
4. Displaying the alarm information in the desulfurization system.
5. Trend recording of main parameters.
6. Implement user management, login, security protection, permission setting, and other functions.

Figure 5 shows the functional block diagram of the host system state software. From Figure 5, the system process flow chart is the main screen of monitoring and each screen is managed and switched by buttons [7]. The ship waste gas desulfurization control system has four working modes: automatic control, software manual control, switch manual control, and emergency stop mode. According to the operating conditions of the desulfurization system, the corresponding working mode is selected. In fact, the design and development of touch screen software and upper computer software have great similarity in system process monitoring and operation function but there are limits of permissions in operation control. No matter manual operation or automatic operation, it can be realized on both interfaces but only on one interface at a time, which can ensure the safety and stability of the system.
3.4. Communication design of control system

The communication scheme of desulfurization control system is based on Siemens Ethernet communication. The Industrial Ethernet technology is widely used supported by all programming languages with extensive hardware and software resources, fast communication speed, large space for sustainable development, and other characteristics. The desulfurization control system completes and controls the program debugging download of the CPU and the control of the host computer and the touch screen through Ethernet communication based on the TCP/IP protocol.

The ethernet connection port of desulfurization control system adopts industrial Ethernet switch module model SCALANCE XB004, which has 4 industrial Ethernet ports. It is a plug and play device without any setting during debugging. Through the automatic negotiation mechanism, repeaters and terminal devices can automatically determine the transmission speed and mode of partner ports [8]. The CP1612 communication module is selected in the upper computer to communicate with the touch screen and the PLC. The connection diagram is shown in figure 6.

4. Conclusion

Based on S7-1500 PLC ship exhaust gas desulfurization control system, the performance of the control system that developed in this paper was reliable and its monitoring interface was friendly. In addition, the operation of the system was simple and has been successfully carried out real machine experiments. Moreover, in the debugging application, the PLC signal acquisition was good, the monitoring software regulation was normal, the system communication was smooth, and the indicators basically met the requirements. Finally, the target of desulfurization of more than 95%, energy-saving, and emission reduction has been achieved. Eventually, the control system reduced the cost of desulphurization of the ship exhaust gas and has a broad application prospect.
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