Research and development of ship ballast water treatment system

CHEN Wen-xiang¹, ZHU Fa-xin¹, TENG Xian-bin²*, Yang He-wu², DING Kong-xing¹, WANG Zhao-jian¹

¹ School of Naval architecture and maritime of ZheJiang Ocean University, ZhouShan Zhejiang 316022, China
² School of Marine Engineering, Guangzhou Maritime University, Guangzhou Guangdong 510725, China
*Corresponding author’s e-mail: tengxbin@163.com

Abstract. If the ballast water is discharged without treatment, it will cause serious ecological damage to the local port. This paper takes the ship ballast water treatment system as the research object. The existing ballast water treatment system is investigated. A ship ballast water treatment system with capacity of 150m³/h, filtration accuracy of 40um and UV dose of 350mJ/cm² is designed. This paper introduces the working principle of the main unit of ship ballast water treatment system, and designs an automatic monitoring system based on PLC and LabVIEW. The results show that the device has high practicability and feasibility.

1. Introduction
With the acceleration of world economic integration, the development of world economy and trade is becoming more and more active. Maritime transportation has become the first choice of transnational trade for its advantages of large carrying capacity, low transportation cost, safety and reliability. As the main means of maritime transport, ships undertake more than 95% of the world's trade[1]. To maintain the stability and seaworthiness of the ship, a certain amount of ballast water must be loaded on the ship[2]. The ballast water of ships comes from different sea areas, which contains a lot of aquatic organisms. The untreated ballast water is discharged randomly after the ship arrives at the port, as well as the invasive species will cause serious ecological damage to the local port[3]. To fulfill China's international marine obligations and ensure the sustainability of China's marine economy, it is extremely important to equip ships with fast and effective ballast water treatment devices.

At present, there are mainly three methods for ship ballast water treatment, which are mechanical method, physical method and chemical method. The biological and other impurities with high density can be removed by installing suitable mesh filter and centrifugation[4]. This treatment method is simple to operate, but when dealing with large flow of ballast water, the size of the device may bring big problems. Moreover, this method can not remove the impurities and organisms with the same density as seawater. Physical treatment methods mainly include ultraviolet method, deoxidation method and ultrasonic method. Ultraviolet irradiation is used to irradiate microorganisms in ballast water and destroy their nucleic acid structure, so as to inactivate or lose their reproductive capacity. This method does not need to use any chemical additives, and will not cause any harm to personnel, environment and hull. It is widely used in ballast water treatment process. However, the penetration of UV is affected by the turbidity of ballast water. UV treated microorganisms may have the possibility...
of light resurrection [5]. Chemical treatment methods mainly include disinfectant, electrolysis technology and ozone technology. They use strong oxidants to kill larvae or spores in ballast water. It directly acts on the cell wall of microorganism to enhance its permeability and make cells die due to excessive loss of cytoplasm. It can also be broken down by enzymes in microorganisms [6]. The treatment method has the advantages of fast sterilization, no water quality restriction and wide killing range. However, in the process of treatment, strong oxidants may cause different degrees of corrosion to the treatment cabin, and the products after treatment may cause secondary pollution to the marine environment.

2. Composition of ship ballast water treatment system
The ballast water treatment system designed in this paper is mainly composed of self-cleaning filter, medium pressure ultraviolet sterilizer, control unit and corresponding pipeline and accessories.

2.1. Self-cleaning filter
The filter precision of the self-cleaning filter is 40um. The filter screen is used to intercept the large aquatic organisms and sediments in the ballast water to reduce the turbidity of the ballast water. It uses differential pressure sensor to automatically detect the filtration resistance of the filter screen. Due to the accumulation of impurities intercepted by the filter, the pressure difference of the filter increases continuously. When the set upper limit of pressure difference is reached, PLC will automatically carry out the self-cleaning condition. Through the cleaning suction nozzle inside the filter screen, the impurities attached on the filter surface of the filter screen are cleaned. The cleaning suction nozzle is driven by the motor through the central shaft and moves axially along the surface of the filter screen. Under the effect of negative pressure, the cleaning surface is formed to complete the cleaning of the filter screen [7]. The solid impurities and marine organisms intercepted by the filter will be discharged back to the local sea area along with the backwashing drainage during the automatic cleaning of the filter. It can not only reduce the number of active marine organisms entering the ballast tank, but also effectively reduce the sediment in the ballast tank. The survival rate and growth possibility of marine organisms in ballast tanks should be reduced as much as possible. Its main components are mainly composed of cylinder, filter element, dirt absorption structure, cleaning motor, exhaust valve, etc., as shown in Figure 1.

![Figure 1. Self-cleaning filter.](image)

- Water inlet
- Water outlet
- Cylinder
- Cleaning motor
- Filter element
- Dirt absorption structure
- Exhaust valve

2.2. Medium pressure ultraviolet sterilizer
The structure of the medium pressure ultraviolet sterilizer is closed type, adopting 316L stainless steel metal cylinder. The design pressure of the reaction chamber is 0.8MPa, which is suitable for the ship ballast water condition. The reaction chamber adopts cross flow and pipeline type to install several medium pressure ultraviolet sterilization lamps. Quartz glass lamp is used to protect the outside of the lamp to ensure the normal output of ultraviolet light [8]. When the ballast water flows through the reaction chamber, the internal structure of DNA and RNA of microorganisms will be destroyed by ultraviolet radiation, so as to achieve inactivation. Temperature and ultraviolet light intensity sensors
are also installed inside the medium pressure ultraviolet sterilizer to monitor the UV dose of the ultraviolet lamp in real time. PLC and electronic ballast are used to control the UV dose in the reaction chamber to ensure the reliability of UV sterilization. Its main components are mainly composed of reaction chamber, medium pressure ultraviolet lamp, junction box, exhaust valve, ultraviolet light intensity sensor, temperature sensor, etc., as shown in Figure 2.

2.3. Control unit
The control unit of ship ballast water treatment system developed in this paper takes PLC as the lower computer and LabVIEW as the upper computer. The mechanical and electrical equipment, testing instruments, valves and power system are connected to complete the automatic operation of ship ballast water treatment. The specific functions of the control unit are: automatic opening and closing of the valve; Filter differential pressure monitoring and self-cleaning function; Automatic light intensity adjustment of ultraviolet sterilization unit, self-cleaning of lamp surface and monitoring of light intensity and temperature; Ballast water loading and unloading place and time record; Fault alarm and record, etc.

3. Working principle of the system
The basic principle of the system is to achieve the requirements of ship ballast water treatment through the opening and closing of valves, collaborative self-cleaning filter and medium pressure ultraviolet sterilizer. Ship ballast water treatment system usually has three conditions: ballast condition, discharge condition and emergency bypass condition. Although three different pipeline channels are involved, a set of comprehensive pipeline must be designed from the reality, and the automatic operation of three working conditions can be completed through the automatic switching of valves [9]. The pipeline diagram designed in this paper is shown in Figure 3. The number in the figure is the number of the valve.
Under ballast condition, PLC control program in the system opens valve 1, a, B, valve 3, valve 5 and valve 7 in turn to perform ballast preheating. The ballast water extracted from the sea gate is filtered and sterilized by ultraviolet, and then returns to the suction of the ballast water pump through the return valve. That is to ensure the reliability of UV sterilization module sterilization ability, but also take away the excess heat. The whole ballast preheating process is monitored by the electromagnetic flowmeter to prevent the system failure caused by backflow failure. After ballast preheating, the system will automatically close the return valve, open valve 9 and valve 10. The treated ballast water is controlled by the flow control valve and injected into the ballast tank in cooperation with the ballast water allocation system.

Under deballast condition, the PLC control program in the system opens the valves 2, a, B, 6 and 7 in turn to perform the unloading preheating. Since the impurities in ballast water have been removed in the process of ballast, the filter is not connected in the process of ballast water unloading. Considering the possibility of survival and photorecovery of marine organisms during the storage of ballast water in ballast tank. Therefore, before the discharge of ballast water, the UV sterilization module is needed to inactivate the bacteria and microorganisms in the ballast water for the second time to ensure that the treated ballast water can meet the D-2 discharge standard. In the process of ballast water unloading and preheating, ballast water flows back to the suction of ballast water pump through UV sterilization module. After the unloading preheating is completed, the system will automatically close the return valve, open valve 9 and valve 11. The treated ballast water is controlled by the flow control valve, and the ballast water meeting the D-2 standard is discharged out of the pipe.

In case of emergency, serious danger to the safety of ship and crew, or failure of ballast water treatment system, the bypass operation can be performed immediately. After the ship ballast water treatment simulator receives the stop command, the PLC control program in the system will open valve 1 and valve 10 or valve 2 and valve 11 according to the actual working conditions, and also open valve 12. At this time, the self-cleaning filter module and UV sterilization module are bypassed, and the ballast water can be ballasted and unloaded without treatment.

4. Control system

4.1. Hardware selection

The hardware of ballast water treatment system designed in this paper is Siemens S7-1200 PLC. CPU 1214C DC / DC / DC is selected as CPU module, which has 100kb working memory. It carries 24VDC power supply and PROFINET interface, which can be used for data communication among programming, HMI and PLC. I/O digital output module selection SM1222 DQ16 × 24 VDC, plug-in terminal block. I/O analog input module selects SM1231 AI8, which is plug-in terminal block. The upper computer uses LabVIEW and communicates with PLC by OPC. All the sensors (pressure difference sensor, electromagnetic flowmeter, temperature sensor, ultraviolet light intensity sensor) work at 5 ~ 24 V, and the maximum output current is 10 mA.

4.2. Software selection and design

The control system of the lower computer is programmed with Siemens series programming software TIA Botu. The upper computer remote monitoring system is developed based on LabVIEW software platform.

4.2.1. Software system flow chart.

The backwash control flow chart of self-cleaning filter is shown in Figure 4.
Figure 4. Flow chart of backwash control of self-cleaning filter.

After the system is started, the self-test program is carried out first, when everything is normal. According to the working condition and the data automatically collected by the sensor, the system analyzes it. The signal is transmitted to the relevant parts through PLC to complete the automatic ballast or discharge of ballast water.

4.2.2. Human machine interface.

The man-machine interface of the system is written in LabVIEW and runs on the remote computer interface. The parameters in the system are monitored and alarmed in real time, and the operation data is saved and retrieved. The system consists of main operation interface, parameter setting interface, manual automatic conversion interface and alarm recording interface. LabVIEW keeps communication with PLC through OPC communication technology. It can read corresponding parameters from PLC and transmit commands to PLC at the same time. Limited to space, this paper only introduces the man-machine interface of ship ballast handling system. Figure 5 shows the man-machine interface of ship ballast water treatment system.

Figure 5. Interface of ship ballast water treatment system

When the ship ballast water treatment system is under ballast condition, just click the ballast start button, and the system will automatically open and close the relevant valves. The ballast flow direction inside the system and the opening and closing state of the valve can be distinguished according to the color. When the ballast condition is over, press the system stop button. In order to ensure the safety and reliability of the system, the automatic conversion interface of valve operator is set. To avoid the control system failure, affect the ship ballast water treatment. For routine
maintenance and overhaul, the alarm recording interface is set. It can display real-time alarm contents and inform users of alarm items.

5. Conclusion
1) This paper takes the actual ship ballast water treatment system as the reference object. According to the latest "rules for the classification and construction of steel ships" and "ballast water Convention". Combined with the current ship ballast water treatment technology, the structure, technology, operation, cost and maintenance are considered. A ship ballast water treatment system based on filtration and ultraviolet combined treatment method is designed.

2) This paper introduces the working principle of ship ballast water treatment system and the operation steps of three working conditions. The hardware and software design of the control system is described, and the structure and function of the man-machine interface of the system are emphatically introduced.

3) The ballast water treatment system is designed with modular installation, small floor area, high operation efficiency, and can effectively remove algae, bacteria and other impurities in ballast water.

4) The research in this article belongs to the previous theoretical research. Whether it can be applied to a real ship needs further research. In the course of the follow-up project, further research can be made from bench experiment, numerical simulation, model verification and other aspects.

Acknowledgments
Authors wishing to acknowledge assistance or encouragement from colleagues, In addition, the author would like to thank the Guangzhou teaching achievement cultivation project (2020123206) for supporting this paper.

References
[1] Tang Zhujun, Feng Jing, Zhu Xiaogang. Thermal design and implementation of ballast water sterilization UV lamp power supply[J]. Mechanical Engineer, 2019(06): 43-45.
[2] Long Qirui, Guo Zhiwei, Bai Xiuqin, Yuan Chengqing. Research on Design Technology of Ballast Water System of Large Cruise Ship[J]. Ship Science and Technology, 2020, 42(09): 85-91.
[3] Lan Sihai. A Brief Talk on Ballast Water Management in Australian Ports[J]. Tianjin Navigation, 2020(01): 15-17.
[4] He Detao. Analysis of the status of ship ballast water treatment technology at home and abroad [J]. Science and Technology Innovation, 2019(06): 4-5.
[5] Li Junxia. Simulation study of ship ballast water treatment system based on inert flue gas[D]. Jiangsu University of Science and Technology, 2019.
[6] Liu Minghui, Zhang Xiao, Liu Jiaming, Wang Ni, Liu Tao, Ji Zhiyong. Study on the sterilization performance and mechanism of electrolytic treatment of ship ballast water[J]. Journal of Marine Technology, 2019, 38(01): 61-65.
[7] Song Jjinju, Xu Fengqi, Li Ying, Li Chao. Self-cleaning filter technology applied to ship ballast water treatment system[J]. Ship Engineering, 2018, 40(12): 10-12+23.
[8] Wang Dongsheng, Zhang Li, Fan Chunhua, Dong Lihua. Design of Ship Ballast Water Treatment Device Based on Low Pressure Ultraviolet Technology[J]. Mechanical Engineer, 2012(04): 1-3.
[9] Chen Xiaohui, Tian Wei. Modular layout scheme of ship ballast water treatment system [J]. Ship materials and market, 2020(12): 35-36
[10] Liu Ming, Zou Ning, Zhang Yunyan. Development of automatic control and monitoring alarm system for ballast water of Haidun [J]. China Equipment Enggineering, 2020(21): 156-158