Multi-functional Tugboat for Monitoring and Cleaning Bottom Fouling

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Multi-functional Tugboat for Monitoring and Cleaning Bottom Fouling

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Abstract. Ming at the shortcomings of the current monitoring and cleaning methods of ships, a new type of multi-functional tugboat for monitoring and cleaning bottom fouling of ships is designed. The tugboat integrates multi-color auxiliary light source fouling monitoring system and fouling removal device based on cavitation jet and ultrasonic cavitation technology, which can effectively remove bottom fouling of ships docked in ports and anchorage.
The results show that the multi-function tugboat can effectively, safely and economically remove the bottom fouling of the ship.

1. Introduction

When a ship sails or berths on the sea, marine life attaches itself to the hull. These attachments will have a significant impact on the energy consumption of ships: on the one hand, hull attachments will significantly increase the running resistance of ships. Through the experimental measurement, after six months in the ocean, the sailing resistance of ships will increase by 3 times when the sailing speed of ships is 2~9 kn. On the other hand, attaching organisms that have not been removed for a long time will affect the hull protection paint, accelerate the corrosion of the hull and affect navigation safety [1]. Therefore, it is of great significance to develop multi-functional tugboats for monitoring and cleaning bottom fouling to quickly monitor and clean bottom fouling, so as to reduce energy consumption and discharge of ships, increase navigation safety and prolong service life of ships.

Aiming at the deficiency of monitoring and cleaning bottom fouling and combining with the characteristics of tugboats, a kind of multi-functional tugboat that can quickly monitor and clean bottom fouling near anchorage or wharf is designed. The tugboat can monitor and clean bottom fouling efficiently, safely and economically.

2. General design of multi-functional tugboat for monitoring and cleaning bottom fouling

In order to meet the demand of cleaning bottom fouling of ships, a multi-functional tugboat for monitoring and cleaning bottom fouling of ships is designed. The multi-functional tugboat in this design is composed of the tugboat, the robot operation platform, mechanical arms, the fouling monitoring module, the fouling cleaning module and ship balance module. Among them, the monitoring module consists of underwater camera and distance sensor. The cleaning module consists of high pressure water pump sets and underwater robots. The general design is shown in figure 1.

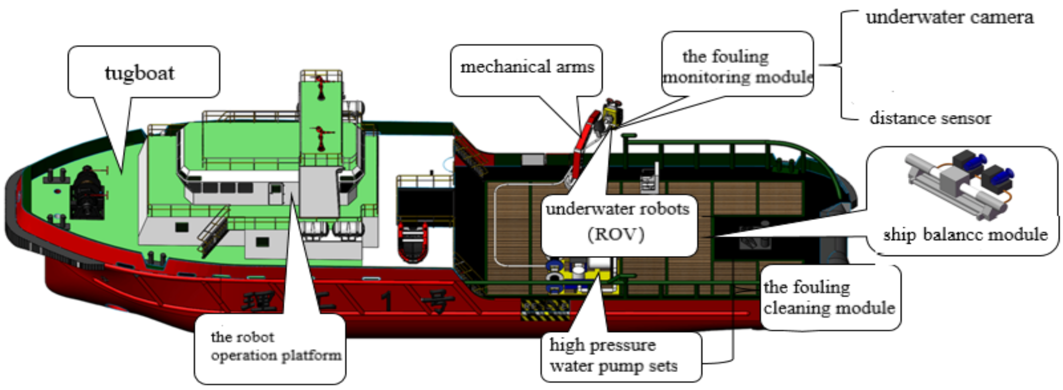


figure 1 Sketch diagram of multi-function tugboat

The functions of each component are as follows: the monitoring module realizes the monitoring of bottom fouling; the cleaning module realizes the cleaning of bottom fouling; the robot operation platform realizes the control and operation of the underwater robot; the robot arm realizes the release and recovery of the underwater robot; the ship balance module reduces the inclination of the tugboat in the working process of the mechanical arm.

According to the requirements of the tugboat platform, and considering that the multi-functional tugboat needs enough load and power to realize the loading of monitoring and cleaning equipment, the full circle swinging harbor tugboat with a displacement of 500t and a main engine power of 3,600kw was selected as the whole layout design of the modified platform.

3. Design of monitoring method of ship fouling bottom

Water has an absorption effect on light. Light has a short propagation path and a small absorption effect under 1~2 m of water, and the color can reflect normally. The absorption of water increases and the color begins to turn blue-green over 2 m. When the water is 6 m deep, the red color disappears. At a depth of 20 m, almost all colors become blue-green and black. And if you go any further, it's going to be blue-green. At this time, the depth sensor mounted at the bottom of the underwater robot monitors the water depth in real time and transmits it to the control system of the underwater robot. According to the different water depths, the control system automatically switches the underwater auxiliary light source. From 6 to 20 m, green light is used as an auxiliary light source to detect bottom fouling. The detection method of bottom fouling is shown in figure 2.

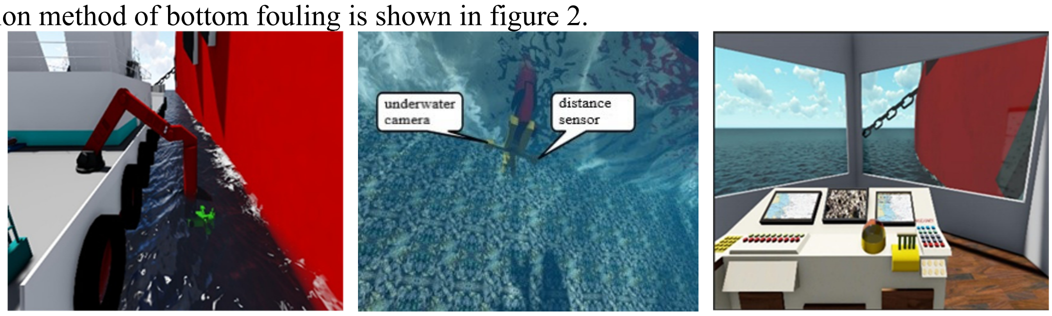


figure 2 Schematic diagram of monitoring method

4. Design and research on working mode of the underwater robot

4.1 Design of the underwater robot

According to the requirements, the design of the underwater robot is carried out. The underwater robot consists of the underwater robot platform, underwater monitoring equipment, cavitation cleaning equipment and external pipelines mounted on the platform of the underwater robot.

The functions of each component of the underwater robot are as follows: the platform of the underwater robot provides a platform for the fixation of each component of the underwater robot, and at the same time realizes the adsorption of the robot on the ship wall surface and the movement of the underwater robot on the surface of the ship shell; the monitoring equipment is used to monitor the bottom fouling of the ship in more detail. Meanwhile, the real-time picture of the underwater robot cleaning work is transmitted back to the operation platform of the multi-functional tugboat for the convenience of the operators to understand its working state; the cavitation cleaning equipment is used to clean the bottom fouling of the ship by layer; the external pipeline is used to supply water and energy to the underwater robot and to maintain its communication with the multi-functional tugboat, while the internal safety rope is installed to ensure its safe recovery by the multi-purpose tugboat in case of emergency. The schematic diagram of the underwater robot based on the above design is shown in figure 3.

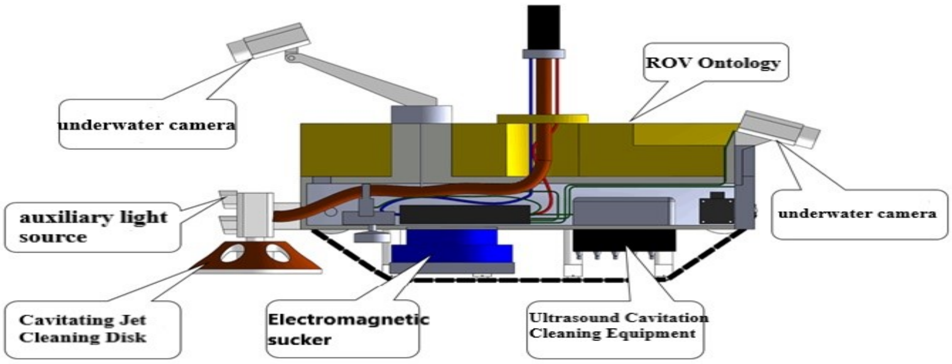


Figure 3 Side view of ROV

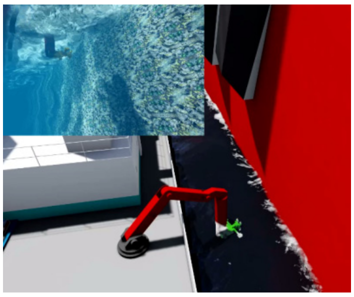
4.2 Research on working mode of the underwater robot

The tugboat shall sail to the target ship after receiving the request for monitoring and cleaning bottom fouling of the target ship at the port or the anchorage near the port. After approaching the ship, the robot arm equipped with the distance sensor and underwater high-definition camera will go deep into the vicinity of the underwater wall of the ship to observe the underwater bottom fouling. If the wall surface of target ship is observed to be relatively clean and does not need to be cleared, the underwater high-definition camera can be recovered through the robot arm. If the bottom fouling of the ship is serious, the robot arm can be used to put a cleaning device on the bottom fouling to remove the bottom fouling of the ship.

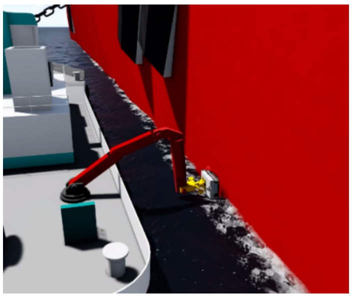
In the process of fouling bottom monitoring, the water depth sensor is installed on the cleaning device to detect the water depth. According to the water depth data detected, the control system of the cleaning device will automatically open the corresponding multi-color auxiliary light source at the front of the cleaning device to provide an appropriate auxiliary light source for the camera in the cleaning device.

In the process of fouling bottom cleaning, the high pressure water pump set of tugboat transports 15 MPa high pressure water through the flexible high-pressure pipe to the cavitation cleaning plate in front of the cleaning device, using cavitation jet to remove shells, coral and other hard attachments and using the ultrasonic cavitation device at the back to produce a large amount of cavitation bubble used to remove soft attachments such as algae. Two kinds of cleaning methods can achieve the purpose of stratified cleaning the bottom fouling of the ship, so that the cleaning effect is better. After cleaning, the rear camera will monitor the cleaning effect. If it is not clean enough, it needs to be cleaned again.

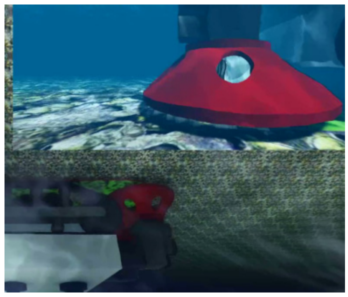
The entire process of fouling monitoring and cleanup, the ship posture monitoring device installed will monitor the ship heeling angle in real-time. When the ship heeling angle is more than 2 °, the hydraulic balance system of the tugboat will automatically start to realize the ship lateral balance.



(a) Initial monitoring of ship fouling bottom

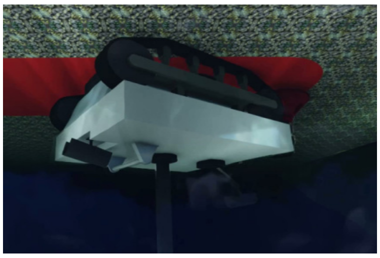


(b) Underwater Vehicle Release

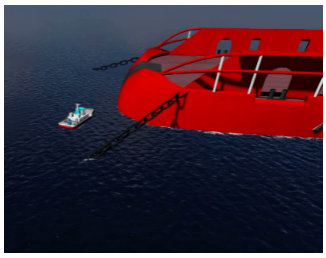


(c) Cavitation Jet Cleaning of Fouling Bottom

(d) Ultrasound Cavitation Cleaning of Fouling Bottom



(e) Differential Transition of Underwater Vehicles



(f) Clear the other wall of the ship

Figure 4 Schematic diagram of ROV woking process

5. Design of ultrasonic cavitation jet cleaning system

5.1 Cavitation jet cleaning technology

5.1.1 Requirements of cavitation cleaning equipment

The functions that cavitation cleaning equipment need to realize are to form micro-jet on the wall surface of the ship shell to generate impact force to remove the attachments on the bottom fouling, including the hard attachments on the top of bottom fouling such as shells and corals and the soft attachments such as barnacles and seaweed.

5.1.2 Design of cavitation cleaning equipment

The relationship between the impact pressure generated by cavitation jet and the impact pressure of continuous jet under isothermal compression is derived as follows [3]:

$$p_f = \frac{p_s}{6.35}\left[\exp\left(\frac{2}{3\partial}\right)\right] \qquad (5\text{-}1)$$

Where, p_f is the impact pressure of continuous jet, p_s is the impact pressure of cavitation jet, and ∂ is the gas content in the liquid.

The ∂ value was obtained by experiments. Assuming that the ∂ value was within the range of 1/6~1/10, different p values could be obtained by changing p_s. The relationship between the impact pressure of cavitation jet and continuous jet was obtained by connecting lines in the coordinate system,. As can be seen from figure 6, when ∂ =1/6~1/10, the relation between them is [4]:

$$p = (8.6\sim124)\, p_s \qquad (5\text{-}2)$$

If the velocity of the jet is constant, that is, if the pump pressure is constant, the impact pressure of the cavitation jet is 8.6~124 times that of the continuous jet with the same flow rate. The continuous jet flow is 0~18 MPa and is ejected from the cavitation cleaning plate. The cavitation jet can generate pressure of hundreds of MPa on the hull surface. Such a high jet impact pressure is enough to clean, cut and destroy hard materials such as rocks and metals.

According to the above requirements, the selection of cavitation jet cleaning equipment was carried out. According to the robot 1000 mm×675 mm×400 mm size of the device and the specific cleaning radius 300~ 500mm of the cleaning plate, the device adopts the cavitation jet cleaning plate with a diameter of 350 mm customized by a company in Qingdao, as shown in figure 5.

According to the theoretical calculation of cavitation jet, when the outlet pressure of the pump reaches 20 MPa, the cavitation pressure can reach hundreds of MPa, which is enough to clean the bottom fouling of ships. However, considering the cleaning efficiency, a JF106/20 high-pressure water pump set of a company in Qingdao is adopted. The outlet pressure of the pump is 2.5 ~20 MPa, and the flow rate is 106 L/min, as shown in figure 6.

figure 5 cleaning disk chart

figure 6 High pressure water pump unit

5.2 Ultrasonic cavitation cleaning system

5.2.1 Requirements of ultrasonic cavitation cleaning equipment

The functional requirements of ultrasonic cavitation cleaning equipment are as the complementary means of cavitation jet cleaning. The ship wall surface that has not been totally cleaned after cavitation jet cleaning will be cleared to achieve the best cleaning effect of bottom fouling.

5.2.2 Design of ultrasonic cavitation cleaning equipment

After the calculation of ultrasonic cavitation and the simulation results under different ultrasonic frequency (see figure 7), only when the natural resonant frequency of the cavitation bubble is equal to the ultrasonic frequency, the ultrasonic and cavitation bubble can achieve the most effective energy coupling. When the ultrasonic power density is larger than 0.35 W/cm^2, cavitation occurs. With the natural resonant frequency of the cavitation bubble in 20 ~ 40 kHz and the ultrasonic frequency in 23 ~ 24 kHz, the maximum pressure on the wall is produced [5].

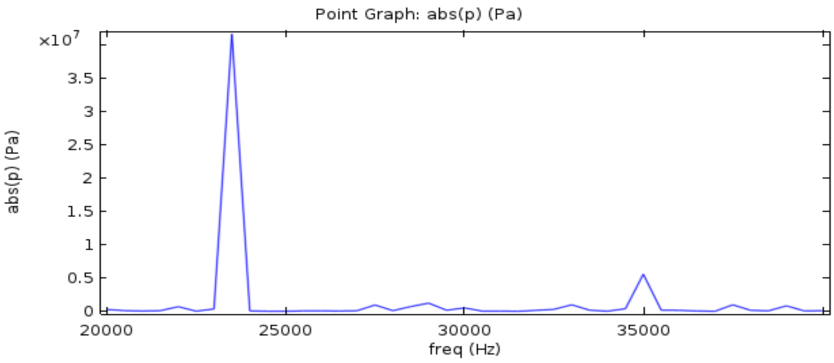


figure 7 Wall Pressure Distribution Curves at Different Frequencies

It can be concluded that in the process of cavitation bubbles collapse, the pressure difference formed on the rigid wall surface gradually increases with the decrease of the initial diameter of cavitation bubbles and the pressure difference gradually increases with the increase of the number of cavitation bubbles. Its power density is 0.8 W/cm^2, and the frequency of occurrence is 20 ~ 40 kHz (see figure 8), which can meet the functional requirements of ultrasonic cavitation. Moreover, the GAWG3 -12 ultrasonic generator is adopted because of its high cost performance compared with other types of equipment at home and abroad.

According to the type of ultrasonic generator, a CH-4PZT-3868Y transducer matching with it is selected (see figure 9), which carries the power density larger than 0.8 W/cm^2. The efficiency can be maximized when the transducer array is arranged in a rectangle. Therefore, the designed transducer is arranged in a 5×5 rectangle array.

figure 8 The ultrasonic generator

figure 9 Ultrasonic transducer

6. Conclusion

It is inevitable for ships producing bottom fouling when sailing at sea, which will increase the energy consumption and reduce the service life of the ship. Therefore, it is of great significance to design a fast monitoring, safe, efficient and economical device for monitoring and cleaning bottom fouling to reduce energy consumption, increase navigation safety and prolong service life of ships.

This paper designs a new type multi-functional tugboat, which retains the original function of the tugboat and endows the tugboat with a new function of monitoring and cleaning bottom fouling. The main research contents of this paper are as follows:

(1) According to the existing technology and theory, combined with the characteristics of the ship, the adsorption mode of combining the permanent magnet and electromagnet and the drive mode of electric are adopted. According to the principle of selective absorption of light by water, white light and green light are selected as auxiliary light sources for the monitoring system of bottom fouling. Better cleaning effect can be achieved by using the cleaning mode of the combination of cavitation jet and ultrasonic cavitation.

(2) Based on the existing technology and theory, the design of multi-functional tugboat for monitoring and cleaning bottom fouling of ships is carried out. Firstly, the demand analysis of the multi-functional tugboat for monitoring and cleaning bottom fouling is carried out, and the overall design of the multi-functional tugboat for monitoring and cleaning bottom fouling is developed according to the design demand. The main design contents of the multi-functional tugboat include the tugboat platform, shipborne robot arm, bottom fouling monitoring equipment, underwater robot, cavitation jet cleaning equipment, ultrasonic cavitation cleaning equipment and other six aspects.

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