International Journal of Multiphysics
Volume 18, No. 2, 2024
ISSN: 1750-9548

Study on a New Type of Offshore Oil Spill Recovery Device Based on Embedded System

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Abstract

With the development of economic globalization, oil exploitation and transportation are becoming increasingly prosperous, especially marine oil. This has led to the frequent occurrence of marine oil spill accidents. However, the research and development of traditional oil spill recovery devices are still not perfect enough, and there are still problems such as low recovery efficiency, low level of automation and intelligence, small application range, and a large degree of influence by sea conditions. The purpose of this paper is to analyze the problems of traditional oil spill recovery methods and devices and to design a new type of marine oil spill recovery device based on an embedded system for these problems. Based on the goal of improving recovery efficiency while meeting the demands of harsh environments, the structural design and material selection of the main components are combined with the described working principle, and an experimental program is developed for simulation numerical modeling. Through the feasibility analysis of structure, technology, and handling, it is concluded that the device has high feasibility and provides a new method for offshore oil spill treatment.

Keywords: Embedded systems, oil spill recovery, oil suction components, offshore oil spill

1. Introduction

With the continuous growth of global energy demand, the importance of marine oil resources is becoming more and more prominent, and oil extraction and transportation also grow, and the marine environment it faces is also characterized by complexity and diversity. At the same time, in recent years, many oil spill accidents have occurred in the ocean, such as the Iranian "ZOORIK" oil spill in 2009 [1], "Sangji" oil spill in 2018 [2], "Ruochao" oil spill in 2020 [3], and so on. According to incomplete statistics, from 1965 to 2017, more than 80 ship oil spill accidents of more than 10,000 tons occurred worldwide. Zhoushan Port, one of the larger ports in China, had nine ship oil spill accidents between 2002 and 2011 [4]. The oil spill spreads rapidly on the sea surface and forms a certain area of oil film, which floats on the sea surface for a long time. The oil film not only reduces the energy transferred from solar radiation to seawater, but also isolates the exchange of oxygen and carbon dioxide in the water, which seriously affects the photosynthesis of marine plants, and causes serious pollution to the sea and mudflats [5-6], as shown in Figure 1. If these oil spills are not treated in time, emulsification or precipitation will occur, and they will undergo a series of long and complex physical and chemical changes in the ocean before they can finally be decomposed and disappear [7], during which the oil spills will constitute irreversible damage to the marine ecosystem. Whether it is due to man-made or other reasons [8], the damage caused by oil spills is extremely serious, and the ecological environment is also damaged and the biodiversity is reduced as a result. Therefore, when an oil spill occurs, how to control and recover the oil spill efficiently and stably has become an urgent problem.

Figure 1 Oil spill contamination

Table 1 Domestic and foreign oil spill recovery equipment

Designation	Working Principle and Function	Oil spill recovery capability
SAE CAT 15/SAE CAT 17	Oil spill containment, recovery, and disposal with global positioning and echo-sounding function	High recycling efficiency
Spain SASEMAR	Floating anti-fouling equipment storage, with water first aid, pollution prevention and control, oil spill recovery and firefighting, etc.	Oil recovery 1730m^3, 95% recovery rate
Spillglop Series Oil Spill Recovery Vessel	In addition to oil spill recovery equipment, there are also firefighting and chemical spill response equipment, which can fulfill several tasks.	High oil spill recovery efficiency, up to 60,000m^3/h for large-scale and 35,000m^3/h for small-scale
Hite 071, 111, 191.	Oil spill recovery, temporary storage, treatment, etc., taking into account oil spill containment, degreasing agent spraying, emergency auxiliary unloading, oil spill monitoring, key pollution source monitoring, etc.	Oil spill recovery efficiency can reach 200m^3/h
Marine oil 252	It can recover oil spills of different viscosities and thicknesses and is equipped with a monitoring radar, which allows it to perform functions such as emergency response and recovery of oil spills.	High efficiency and speed of oil spill recovery, recovery capacity up to 200m^3/h
Victory 503	The bow of the ship is equipped with MS200 oil spill and garbage recovery module, and there are PSB80 spraying arms installed on both sides of the ship, with 5 nozzles on one arm, and both arms can be extended to both sides of the ship at the same time during the operation so that oil pollution can be eliminated in a large area and quickly.	Skimming Capacity up to 200m^3/h

At present, most of the oil spill recovery equipment is used for oil spill recovery at home and abroad, as shown in Table 1, but the research and development of the equipment are not perfect. Mavi Deniz, as the world's most extensive antifouling ship design and production company, designs and produces the SAE CAT model multifunctional antifouling ship, which can better cope with small-scale oil spill accidents, and China's current most advanced Hite 071, 111, 191 oil spill emergency recovery vessel equipped with a large crane, can be lifted directly to the oil containment equipment, to respond to oil spills on the sea surface [9]. However, the existing oil spill recovery equipment in the actual use of the process, by the impact of poor sea conditions, the recovery efficiency is significantly reduced, and consumes a lot of manpower and material resources, the degree of automation is low. This paper combines the development status quo of oil spill recovery equipment at home and abroad, analyzes its problems and shortcomings, designs and develops a new type of marine oil spill recovery device based on embedded system, and formulates an experimental program, first determines the preliminary model and parameters through simulation, then perfects the equipment through physical model test, and finally

analyzes its feasibility by combining the experimental data, and concludes that this device is feasible and effective for the It is concluded that this device is viable and effective, and provides a new idea for oil spill recovery under severe sea conditions.

2. Conventional Oil Spill Recovery Methods and their Problems

When an oil spill occurs, it needs to be effectively controlled in the shortest possible time to prevent it from continuing to spread. There are three main traditional methods for recovering oil spills at sea in the world [10]:

(1) Physical treatment method

The use of clean-up vessels, oil booms, skimmers [11], and other mechanical equipment around the collection of floating oil spills on the sea surface, as shown in Figure 2, this treatment is less polluted, but most of the equipment requires a large number of manual personal operation, the cost is high and has the risk of injury or death, and there are certain limitations, it is usually difficult to remove the oil film on the surface of the seawater, seawater dissolved oil, emulsified oil, etc., and it is easy to be affected by the amount of oil spills and the sea conditions, resulting in the recovery efficiency is not high or the final removal of incomplete. It is easy to be affected by the oil spill volume, sea conditions, and other factors, resulting in poor recovery efficiency or incomplete removal.

Figure 2 Live view of marine oil spill recovery

(2) Chemical treatment method

The burning method [12] is used to clear large quantities of oil spills in a short time, or chemicals such as oil spill dispersants, gelling agents, settling agents, etc. are used to change the physical properties of the oil spills or to trigger a chemical reaction to make it easier to collect and degrade the oil spills. Although the chemical treatment method is more thorough compared to other methods, this method will inevitably lead to secondary pollution, and when dealing with large-scale oil spills, the cost of chemicals is high and ignition of oil spills is likely to cause secondary accidents.

(3)Biological treatment method[13]

The use of some special microorganisms can oxidize the decomposition of oil in the water to remove the oil spill, safe and non-polluting, but the method is easily limited by the number of microorganisms, species, and the degree of contamination, the environment, and the composition of the oil spill and other factors, and has not been widely used.

3. Design of Oil Spill Recovery Device Based on Embedded System

3.1 Overall design requirements

Aiming at the problems of low recovery efficiency, high recovery cost, low degree of automation and intelligence, and a large degree of influence by the environment in the practical application of the traditional oil

spill recovery device or method, we propose a new type of device that utilizes embedded system to realize the recovery of oil spill on the surface of the sea, and the design requirements of this device include several aspects:

(1) To maximize the space-saving on the deck of the vessel and to improve the oil collection efficiency, we designed a dual embedded oil spill recovery system [14], which consists of two sets of boom rollers and suction devices mounted inside the hull of the vessel with front and rear two deflector gates to achieve high-precision and highly-efficient oil collection.

(2) The traditional oil spill recovery device can only be used in calm seas, and will not be able to operate normally or the oil collection efficiency will be reduced when encountering adverse sea conditions, to ensure that the device can still operate normally in unfavorable sea conditions, the front and rear ends of the hull are left with air chambers, and a retractable rotating sweeping arm is installed on each of the left and right sides of the hull, the sweeping arm is controlled by a hydraulic system, and the two form the sweeping arm system. Through the oil sweeping arm in the occurrence of oil spill on the sea surface arrangement of the oil boom, effective containment of oil spill on the sea surface, to avoid the oil spill in the wind and waves under the influence of further spread.

(3)To prevent the absorbed oil spill from flowing out again, the pressure plate is combined with the oil-absorbing parts to form an oil absorber located inside the device. The oil spill is channeled into the interior of the vessel through the boom, and then the oil and water are separated through the absorber so that the oil spill can be handled promptly within a certain space.

(4) When a major oil spill accident occurs, the oil spill is difficult to be dealt with in time, and under the influence of wind and waves and other sea factors, the oil spill will undergo different degrees of weathering phenomenon [15], and the viscosity of the oil will increase. To make the device able to absorb oil spills with different viscosities, we designed the suction part and the self-heating pipeline, using special materials and increasing the temperature inside the pipeline, so that even high-viscosity oil spills can be absorbed quickly by the device.

3.2 Principle of operation

The oil spill recovery device based on the embedded system mainly includes the impeller drive at the tail, the main body of the device, the oil sweeping arms on the left and right sides, the air chambers at the front and rear ends of the hull, the power station and infrared sensors on the upper surface of the deck, as well as the oil suction device inside the hull. The specific model structure of the device is shown in Figure 3.

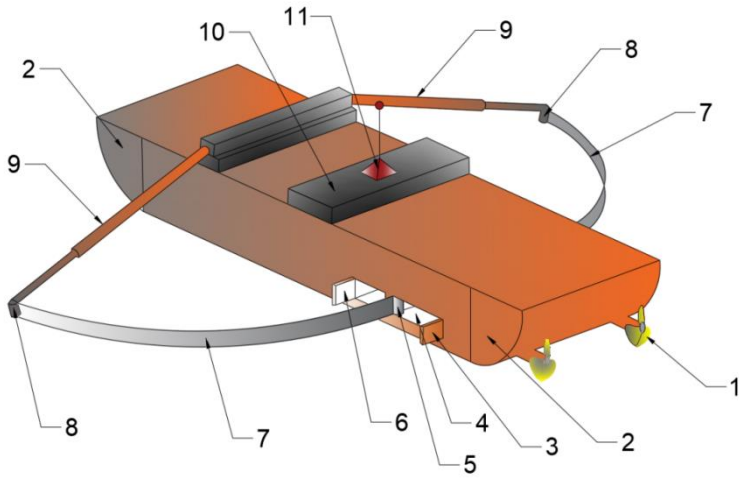

Figure 3 Schematic diagram of oil spill recovery device based on embedded system

Notes: 1-Impeller 2-Air chamber 3-Rear deflector door 4-Oil absorber body 5-Boil roller 6-Front deflector door 7-Barrier 8-Barrier float 9-Sweeping arm 10-Power station 11-Infrared sensor.

When an oil spill occurs, the operator can send a signal command through a remote control device on the shore or the ship, the infrared sensor on the top of the device receives the signal, the impeller starts, and the device quickly and accurately arrives at the oil spill area, the oil sweeping arm slowly unfolds through the hydraulic system, and the boom float at the top of the sweeping arm synchronously drags the booms to spread out from the boom drum, and the length and angle of rotation of the sweeping arm are adjusted to change the size of the water area swept by the boom, according to the total amount of oil spilled and the size of the spreading area. According to the total amount of oil spill and the size of the spreading area, adjust the telescopic length and rotation angle of the oil sweeping arm, to change the size of the area of water swept by the boom. The oil-water mixture under the enclosure of the boom flows into the body through the front guide door and then enters the body of the oil absorber through the through hole under pressure. After a series of oil-water separation treatments inside the oil absorber, the separated oil spill will eventually flow into the oil storage body through the self-heating pipeline under the action of the pump, while the excess seawater will be discharged through the rear deflector door. After the oil spill treatment is completed, the oil sweeping arm will be reset, the boom will be re-coiled on the drum, and the front and rear deflector doors will be closed.

3.3 Design Content

3.3.1 Embedded system design

The oil absorber and oil containment drum are installed inside the device, and a set of embedded oil spill recovery devices is installed on the left and right sides of the device body, forming a double-embedded oil spill recovery system. Under the guide flow of the boom, the device realizes the absorption of the oil-water mixture and the discharge of seawater by opening the front and rear guide gates sequentially. After the oil collection work is completed, the boom is retracted into the unit by the oil sweeping arm, so that the oil spill recovery work can be carried out again. This saves space on the deck of the unit. The overall design of the device is long and wide, and there is an air cavity at both ends of the device to ensure that the device is not easy to roll over under wind and wave conditions, which improves the stability of the device and is conducive to its normal work in poor sea conditions, greatly improving the efficiency of oil spill recovery.

3.3.2 Device body on both sides of the two-way oil sweeping arm system with the design of the oil fence

An oil containment drum installed in the device on both sides of the interior, with the oil sweeping arms and floats to ensure that the oil containment [16] from the drum stretches out, can be surrounded by two curved sweeping cross-sections on the sea surface. This design is in response to the severe sea conditions, where high winds and waves can easily lead to the rapid spread of oil spills, making oil spill recovery operations difficult. When the equipment is in normal operation, the length and angle of the sweeping arm can be adjusted to control the sweeping area and enclose the oil spill [17].

3.3.3 Oil absorber design based on the combination of the pressure plate and suction components

The oil-water mixture flows into the oil absorber through the front deflector gate. When the motor-driven chain pulls up the pressure plate, the 26 circulars through holes of the same size design on the side of the oil absorber are just below the pressure plate, and the oil-water mixture is sucked into the oil absorber under the effect of pressure difference; when the chain drives the pressure plate to drop to just in contact with the absorbing parts, all the circular through holes are blocked again to prevent excessive oil-water mixture from flowing in at one time, and to form a top-to-bottom pressure on the pressure plate to prevent the absorbed oil spill from overflowing. The oil spill adhering to the oil absorbing part is finally transported to the oil storage body under the dual action of the pressure plate and the suction pump. As shown in Figure 4 and 5.

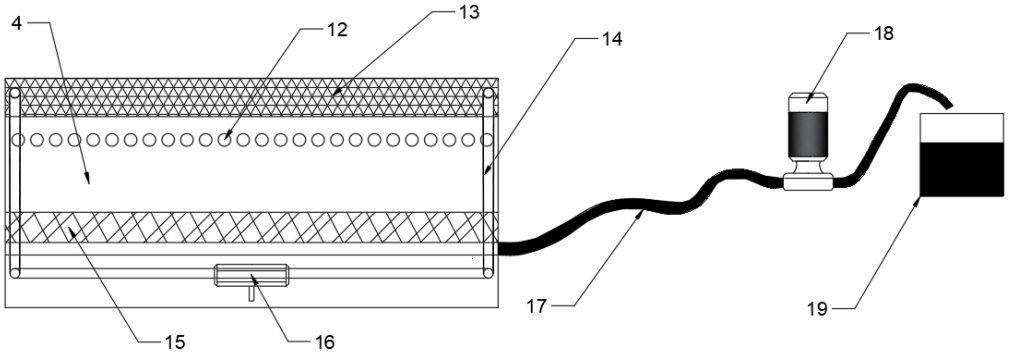

Figure 4 Oil absorber based on the combination of a pressure plate and an oil-absorbing component

Notes: 4-Oil suction body 12-Through hole 13-Pressure plate 14-Chain 15-Oil suction parts 16-Motor 17-Self-heating pipeline 18-Suction pump 19-Oil storage body.

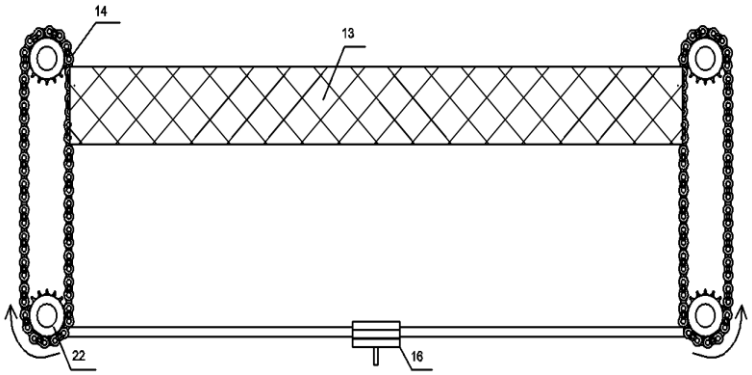

Figure 5 Schematic diagram of the working of the fixed pressure plate on the chain

Notes: 13-Pressure plate 14-Chain 16-Motor 22-Rotating gears.

3.3.4 Interfacing suction part and self-heating piping design

Below the oil suction component, we designed a self-heating oil delivery pipe and connected it to the oil suction component. There are 14 heating columns above this channel, which transfer heat to the oil suction part by electric heating. The oil-absorbing component is made of a high-resilience sponge [18] with an outer layer coated with octadecyl trichlorosilane (OTS) [19]. The heat-generating column converts electrical energy into thermal energy, and the oil-absorbing component absorbs the heat, the temperature increases, the rate of oil spill absorption is accelerated, and it can absorb oil spills with higher viscosity, which improves the oil spill absorption efficiency. As shown in Figure 6 and 7.

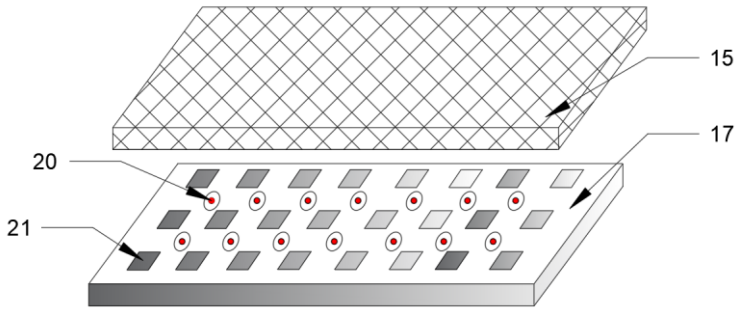

Figure 6 Arrangement of self-heating oil delivery pipe and oil suction parts

Notes: 15-Oil suction part 17- Self-heating oil delivery tube 20- Heat generating column 21- Square through hole.

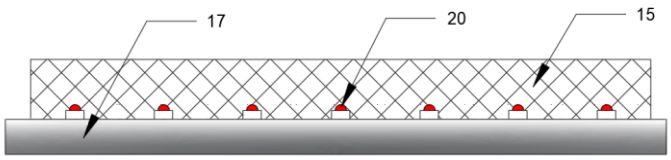

Figure 7 Schematic diagram of the surface of heat-generating oil conduit and the side of oil suction port

Notes: 15-Oil suction part 17-Self-heating oil conduit 20-Heating column.

4. Research Program of Oil Spill Recovery Device Based on Embedded System

4.1 Research Route

First of all, study the working mode and structural characteristics of the existing oil spill recovery device, according to the design characteristics and design concept of the device designed in this paper, combined with the basic theoretical knowledge of mechanical design, fluid mechanics, and other basic theories, to determine the basic shape and performance of the new offshore oil spill recovery device, and use CAD software to carry out preliminary modeling of the device. Then, under the premise of meeting the functional requirements of the design, strong stability, and high recovery efficiency, materials are selected for each component and the basic model of the device is determined [20]. After that, simulation software was used to simulate and test the established model and analyze the test results to optimize the device structure [21-22]. Then, field tests were carried out in the laboratory or reservoir, different concentrations of oil-water mixtures were selected for experiments and experimental data were recorded to compare the simulation and simulation calculation results, and numerical experiments were carried out several times. Finally, through repeated experiments and simulation data for comparison and analysis, summarize the parameter relationship, so that the device model works to achieve the best results.

4.2 Simulation test values and optimize the model structure

Use STAR to carry out water surface simulation sailing experiments on the established device model, the relationship between the Xingbo resistance and buoyancy size, and the length and angle of the oil sweeping arm. At the same time, the influence of the change of the drag coefficient on the oil-feeding effect of the circular through-hole is investigated to determine the relationship between the oil-sweeping arm, the size of the booms, and the number and size of the circular through-holes. The magnitude of the pressure exerted by the pressure plate on the oil-absorbing parts was adjusted to achieve efficient oil skimming. The power of the oil sweeping arm during the operation was debugged using STAR software to calculate the most stable oil sweeping performance [23]. Then, the model is established by 3D software, and the force analysis of the whole device is carried out by using professional finite element software such as Patran, placing the water surface wave monitor during the simulated operation to generate the animation of wave change in the water area, and at the same time, analyzing the oil spill recovery efficiency of the oil spill recovery equipment in the sea surface under the different parameter models and structures, combining with the actual values measured by the site experiments, selecting the best parameter models and structure, determine the strength of each component and optimize the structure again [24]. Finally, validation experiments are conducted to continuously optimize the device to achieve the best results.

5. Feasibility Analysis of Oil Spill Recovery Device Based on Embedded System

5.1 Structure feasibility analysis

Based on the principle of mechanical design, we designed an oil spill recovery device based on an embedded system. The work of the device is affected by the environment to a low degree, and under the coordination of the oil sweeping arm and the oil absorber, it can realize the synchronization of oil collection and oil absorption, and ultimately complete the oil spill recovery work efficiently. The overall structure of the device is simple and reliable, and the coordination between the systems is seamless, so it can give full play to its advantages and respond to oil spill incidents quickly and effectively.

5.2 Technical feasibility analysis

We used CAD software to build the model and used STAR simulation software to perform optimization simulation, structural optimization, and simulation testing to establish the model and final parameters. The device can be operated remotely, and the operator can be operated on the shore or on the ship, which is suitable for all kinds of complex waters or harsh marine environments, and can significantly reduce the time of oil spill recovery, save a lot of manpower and material resources, and has a fairly high degree of technical and feasibility.

5.3 Control feasibility analysis

The use of the equipment is very simple, only a small amount of human input, can quickly and effectively respond to the occurrence of oil spill events. In the event of an oil spill, staff can use remote control equipment to control the equipment, and quickly move to the oil spill area for cleanup. Without the sweeping arm system, the oil spill can also be collected by flowing through the circular through-hole into the suction unit, thus reducing the risk of accidents when operators are close to the spill area and improving recovery efficiency.

6. Conclusion

Nature gives mankind many available resources, in the development and utilization of natural resources at the same time, we should also pay attention to the protection of the ecological environment. The ocean is the cradle of life, and frequent oil spill accidents have caused irreversible damage to the marine ecology, to protect the ocean, the new offshore oil spill recovery device designed in this paper is more efficient in oil spill recovery, more stable, capable of adapting to harsh environments, and smarter in operation compared with the traditional oil spill recovery methods and devices. The feasibility is analyzed through simulation and field experiments, and the device is realizable and can respond to marine oil spill events more effectively.

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