Mooring Chain Working State Detection Device

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Abstract. In order to change the current situation that the mooring chain magnetic particle detection is completely completed manually by workers, and improve the detection coverage accuracy, an automatic mooring chain full-ring magnetic particle detection device has been developed to fill the domestic gap. The device is mainly composed of 4 parts: a vertical scanning mechanism, a circular rotation mechanism, a probe linear motion mechanism and a probe adaptive mechanism, which have a total of 6 degrees of freedom. At the same time, ABAQUS finite element analysis software was used to check the static strength, stiffness and dynamic characteristics of the large-span vertical scanning mechanism in the device. The calculation results show that the static strength and stiffness of the vertical scanning mechanism are reliable; the driving pulsation frequency is far from the main excitation frequency, and the structure has good dynamic characteristics.

1. Project Background and Research Significance

In today's world, there is an urgent need for marine resource exploration and mining, and the development of marine engineering equipment has made rapid progress. Floating oil, gas and natural gas production systems around the world have grown exponentially. As of November 2013, a total of 277 floating production units (FPU, Floating Point Unit) were recorded, of which 62% were classified as floating production storage and offload (FPSO, Floating Production Storage and Offloading).

A mooring chain is a device that connects and fixes between the surface facilities and the sea floor. It is a device used to ensure that the hull or floating platform stays at the required water level. Offshore platforms need to be serviced in the harsh deep-sea environment for a long time. This puts forward higher performance requirements for marine structures such as mooring chains, such as high strength, high toughness, and corrosion resistance.

China has also included deep-water mooring chains and their energy-saving assessment projects in the “13th Five-Year Plan” key plan. With the increasing demand of offshore engineering, marine facilities such as offshore oil extraction, marine exploration, and national defines construction require a large number of marine mooring chains, and the demand has increased year by year. The diameter and material strength of service anchor chains have gradually upgraded.

Although the diameter of the anchor chain has reached more than 100mm at this stage, accidents caused by the damage of the mooring chain still occur from time to time. The design life of a floating production system is generally 20-50 years, and according to the data reported by Beihai (1980-2001), it will experience a mooring fault every 4.7 years. Although magnetic particle and ultrasonic flaw detection are performed on each mooring chain when it leaves the factory, because it serves in the
harsh environment of the deep sea, the most common underwater inspection method is a trained diver diving into the bottom of the water for manual non-destructive testing. For safety reasons, divers are not allowed to check the chain in the splash area. Visually-assisted ROV (Remote Operated Vehicle) inspection is commonly used in industry, but according to the history of mooring chain accidents and fractures, conventional ROV inspection cannot be considered a reliable method. Therefore, research on mooring chain detection is imperative.

2. Innovation of the project

1) Structural innovation: The L-shaped semi-enclosed structure is combined with orthogonal track and suspension structure design, which can better adapt to the complex geometric characteristics of mooring chains under different working conditions.

2) Functional innovation: The integrated ultrasonic cleaning device based on high-pressure jet and ultrasonic pulse reflection improves the reliability of detection.

3) Application innovation: The detection device can be used in both offshore platforms and mooring chain detection in water conservancy projects such as floating bridges.

3. Implementation plan of the project research and proposed research methods and technical routes

3.1. Mechanical part

3.1.1. Track wheel drive module. When working in the air or underwater, the working environment is relatively harsh, and because the chain links are rough, curved, uneven, and amphibious, the environment in which the device travels is more complicated. Track drive has the advantages of high payload capacity and relatively small control complexity. Driving with tracks enables the device to adapt to various complex situations and overcome different shapes on the chain links. At the same time, the use of tracks also greatly improves the device's adsorption the friction generated on the chain link guarantees the stability and reliability of the device.

The choice of the driving module's adsorption method is permanent magnetic adsorption. This adsorption method has the advantages of simple structure, no external energy, reliable adsorption, and strong wall adaptability. Due to the orthogonal placement of the track units (tracked wheels), each track unit is driven by an external motor and gearbox, as shown in Figure 1.

Due to the more complicated terrain on the mooring chain and the twisting between the mooring chain links, which results in extremely high requirements for the adaptability of the track during the operation of the device, a suspension system with two degrees of freedom is designed. The main body of the system is a four-bar structure, and a spring shock absorber is connected at the opposite corner to provide resistance, which ensures that the track and the mooring chain are in close contact, and at the same time, it can reduce the impact and vibration caused by the operation. The suspension system can make the crawler running module move up and down at the front and back ends, and it can also realize smaller rotation along the connecting axis to adapt to the complex and varied mooring chain environment.
3.1.2. Introduction to Frame Structure Design. In order to make the device continuously move continuously on each chain link distributed orthogonally, the movement mode of the device is designed to use two sets of crawler units, which are placed orthogonally to match the orthogonal links of the mooring chain. One track wheel unit moves on one chain link and the other track unit moves on an adjacent orthogonal chain link. Thus, the robot moves continuously along the chain by two sets of orthogonal track wheel unit groups.

Units A and D (see FIG. 2) represent parallel wheels moving on parallel tracks of a link on one side, and units B and C represent parallel wheels moving on parallel tracks of an orthogonal link. During the climbing process, the A-D and B-C track units engage with the relevant chain surfaces to support movement. During the climbing process, three crawler units can be guaranteed to contact the chain links at any time, which ensures the stability of the device's movement between the chain links and the accuracy of positioning during detection.

3.1.3. Cleaning the module. As a lot of animals and plants are attached to the marine mooring chain, it will affect the operation of the device on the mooring chain, and at the same time, it will cause certain damage to the mooring chain itself. A cleaning module is set at the front of the device. The module is provided with multiple high-pressure nozzles and six impeller pumps driven by a motor in different directions. During operation, the module sprays high-pressure water to remove the attachments on the mooring chain.

3.2. Control module

3.2.1. Ultrasonic testing module. The ultrasonic detection module of this project is composed of single-chip microcomputer control, ultrasonic flaw detector and probe, A / D sampling card, etc. With the support of software, it completes the echo signal collection, defect wave feature extraction and processing, and uploads it to the data centre to control the system block diagram is shown in Figure 3.
3.2.2. **Overall workflow.** The device of this project is a semi-enclosed structure. The device is correctly placed on the mooring chain, and the device is opened. The device attracts the mooring chain by magnetic force, the stepper motor starts, and the device starts to move by driving the wheel. After the device enters the bottom of the water, the water gun spray module starts to work, and the surface of the mooring chain is subjected to high-pressure water shock cleaning. The ultrasonic detection module performs flaw detection on the mooring chain, and records and uploads the result data to the data centre.

![Device working flowchart](image)

**Figure 3.** Device working flowchart.

4. **Project feasibility analysis**

4.1. **Background analysis**

The importance of mooring chains for offshore engineering is self-evident. It is mainly used in offshore development facilities such as offshore oil drilling platforms and single-point mooring structures. Once some parts of it cannot withstand seawater corrosion, particle abrasion and ocean waves Failure to detect and replace cracks due to impact will result in serious consequences. From Table 1, we can see that drilling platforms around the world have suffered severe weather such as strong typhoons and hurricanes, and about 26% of these accidents were caused by broken mooring chains.

According to records, from 1973 to 2007, there were 2,742 oil spills of various types in the surrounding waters of China, with an average of once every 4 to 5 days. There was a total of five times in 2009, with a total oil spill of up to 40,000 tons. The development of a robot capable of real-time detection and feedback of data for monitoring through this project can greatly reduce the probability of such accidents, reduce the risk of collapse of large offshore facilities such as drilling platforms, and reduce seawater pollution. The probability of this type of accident is calculated as 26%, which is substituted into the formula:

\[
P = \frac{S}{a_2 - a_1} \times p_1
\]  

(1)
In the formula, P is the area of marine pollution reduced each year, S is the estimated value of total polluted marine area from 1973 to 2007, a2-a1 is the difference between years, and p1 is the probability of an accident due to damage to the mooring chain.

The area of marine pollution that can be reduced every year is about 58.12 square kilometres. The direct consequence of a large amount of crude oil leakage is the straight rise in hydrocarbon emissions, because the final product will become no matter whether it is recycled or biodegraded. Carbon dioxide is emitted into the atmosphere, and this part of the emitted carbon dioxide does not provide humans with a proper energy source. It is an unnecessary emission, which has further exacerbated the global greenhouse effect. If the amount of carbon dioxide emitted is calculated by material conservation (the proportion of carbon in crude oil is 83% - 87%), we can get the following formula:

$$m_{CO_2} = \left( M_{oil} \times 85\% \times p_1 \right) \times \frac{M_{CO_2}}{M_C}$$

Where $m_{CO_2}$ is the carbon dioxide emissions, $M_{oil}$ is the total oil spilled in 2009 without major accidents in China, and $M_C$ and $M_{CO_2}$ are the molar mass of carbon and carbon dioxide, respectively.

Calculating the data, it can be obtained that in 2009, the total amount of carbon dioxide emitted by China in the absence of a major oil spill accident due to a mooring chain failure could reach $3.24 \times 10^3$Kg.

4.2. Benefit Analysis

After the spill of crude oil, it will not only cause serious marine ecological pollution, but its subsequent treatment will also be very cumbersome. The existing methods are mainly: (1) first circling the leaked crude oil, then gathering it, pumping it to the transport ship with water, and finally going ashore (2) another method is a microbial treatment method, which uses an lyophilic bacteria to "eat" the environment's alkanes, aromatic hydrocarbons and other substances, and converts them into bacterial cells, water, and carbon dioxide. Bacteria in the environment containing oil stains will rapidly multiply and continuously eat the surrounding oil stains until the oil stains completely disappear; at the same time, the bacteria will produce a surfactant, which is essentially an enzyme that will accelerate the decomposition of the oil. The above-mentioned first treatment method inevitably misses a part of the crude oil and cannot be completely collected. The current treatment efficiency is generally about 68.2%, and there are still 31.8% crude oil residues. The second method has a higher processing efficiency than the first method. It can reach 99.3%, but again, using this method will waste all the energy contained in crude oil, exacerbate the greenhouse effect, and even cause a certain degree of damage to the ozone layer. It can be seen that neither method can completely deal with the leaked crude oil, and the residual crude oil also contains a lot of energy. The quality of crude oil leaked from around the world every year can be roughly estimated from the data from 1973 to 2007, and its value is about 3.28 million. Tons, according to the formula:

$$Q = M_{oil} \times p_1 \times \Delta p_2 \times q_{oil}$$

In the formula, Q is the total energy loss value, $M_{oil}$ is the mass of crude oil, $\Delta p_2$ is the average value of the residual crude oil in the above two methods, and $q_{oil}$ crude oil is the calorific value of crude oil combustion.

By substituting the numerical calculation, it can be obtained that the energy loss caused by the damage and breakage of the mooring chain can reach $2.47 \times 10^{12}$J.

5. Application Prospect Analysis

This work responds to the national "Thirteenth Five-Year Plan" and carries out structural and functional innovation. It can be widely used in offshore oil production floating production systems,
semi-submersible drilling platforms, single-point mooring structures, and floating production tankers other marine development facilities have broad application prospects.

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