Study on the Safety Guarantee of Ship Mooring from Frequent Cable Accidents

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Abstract. According to the review of the frequent mooring broken cable accidents around the world, this paper analyzes the current situation of port ship mooring operation, and analyzes the innovative research, development and application of mooring technology at home and abroad. In this paper, on the basis of the motion compensation principle of active anti-rolling, and relying on the parallel platform, an intelligent mooring system which can act as both cable and fender function is developed. The system can autonomously adapt to the ship's six-degree-of-freedom movement, monitor the ship's load data, and realize the active control of the ship through follow-up and damping, so as to achieve the purpose of autonomously controlling the ship-shore mooring process intellectualization.

1. Introduction

On June 3, 2019, a shipping agent at the Port of Ancona Anchorage, Italy, died after accidentally breaking a cable while checking the loading and unloading of container ships. On October 8, a cargo ship in the Spanish port of Sagunto broke its cable suddenly while berthing, resulting in one death and one injury. On June 28, 2018, a dry bulk cargo ship in Longview Port, Columbia River, Washington, THE United States, suffered a rebound of its mooring line, resulting in one death and three injuries. On May 7 that year, a large container ship was leaving a Saudi port when its cable jumped out of its bollard, killing two sailors. On February 23, 2017, two ships collided in Taichung, Taiwan province, causing the death of the deck crew after a cable broke. On April 15 of the same year, a tugboat operating at GCT Bayonne pier in New York Harbor, United States, was assisting a large ship to leave the harbor when the crew's whole arm got stuck between the cables and tore off. On May 4 of the same year, a bulk cargo ship broke cables while berthing in Trois-Riveres, Quebec, Canada, killing one person. On March 2, 2015, the world's largest LNG ship was berthing at South Hook LNG Terminal in the UK. One person was seriously injured when the ship's bow cable was broken. On August 13 of the same year, the crew of Panamanian bulk carrier broke the mooring rope of the ship in the Caucasus port of Russia, resulting in the death of one person and the serious injury of two [1]. According to U. S. Coast Guard data (see Figure 1 below), cables accounted for the second largest number of fatal accidents, with a total of 51 crew members involved in a nine-year period from 2006
to 2014. Thus it can be seen in the mooring accident frequent fatality rate is relatively high, the faith of maritime network had similar incidents have been reported for many times, although the industry has repeatedly stressed that the owners, ship and port management company also attaches great importance to this, such as cable breaking rebound, the cable force from the rope jump out and hit the crew and dock workers of accidents have occurred from time to time. At the same time, China has studied and summarized 18 possible factors for ship cable break [2]. Among them, many factors can be mutually implicated, intensified or offset. All factors influence each other. The lower the low tide, the less the rich water depth under the keel, the faster the overcurrent velocity of the ship, leading to the sinking of the ship, namely the increase of draft, and the higher the draft, the less rich water depth. Such a vicious cycle, almost every cable breaking accident is caused by a combination of multiple adverse factors. The most important factors affecting mooring safety include poor technical condition of the cable, defects in the mooring device, and ineffective care of the mooring [3]. The cable and mooring device have defects or uneven forces. Even if the cable and brake are adjusted, there is a high probability that the loose cable will cause the ship's initial drift and it is difficult to adjust and control, and the cable is likely to break, thus leading to greater risks.

2. Status quo of ship mooring

2.1. Operation status

After ship enter the port, after pushing the auxiliary tugboat, the ship line on the wharf bollard, again by the boat winch taut, and to complete assignments on mooring, including hawser, warping, the course of the line, fixed, spring, and a series of movements, in the end by the cable/fender of synergy will ship together on one side of the "post" in the dock, the dock ship have the ability to resist a certain wind flow conditions, the traditional ship mooring, has continued in one thousand, the way and not change with the development of the shipbuilding technology, port facilities and [4], as shown in Figure 2.

![Figure 2 Traditional wharf requires tugboat berthing and mariner mooring](image)
In the traditional dock mooring and unloading operation, the ship can adjust the tightness of the mooring rope by the brake pad of the winch. When the ship completes the mooring operation, the winch brake is always maintained to balance the external forces received by the ship in the case that the external conditions do not change. After the ship unloading due to reduce draft reducing load degree, float on the water after the hull, ship and mooring pile spacing variable length, Angle also produces change, at this time the cable on tension changes limited to fill the space, namely the tension of the cable co., LTD. Alone to regulate external force, obviously this will lead to the paranormal, overloaded stress, cable tight, beyond the limit of breaking force, leading to accident broken line. Also, due to the draft when loading, shipping and bollard relative distance will be shortened, the Angle change, the cable will often lax lead to ship without stress are more likely to drift wharf, ship and port clearance, stress inconsistent cases Angle and the effect of loading operation, ship and the wharf even in have frequently under wave hit dock fender. The frequent relaxation and tensioning of the mooring rope will affect the safety of the ship. At the same time, passing ships in the same port area will generate ship traveling waves under high speed, which will cause changes in the mooring status of ships in the adjacent dock, directly affecting the mooring ships in the adjacent dock. Ship wave surge in the ship berthing, heaving line force suddenly changed ups and downs, under this kind of instant changes even if equipped with automatic winch cable can't be in a very short time rapid response, ship bow movement range is opposite bigger, because of the influence of ship keel asymmetry, motion response time also have differences, damage of hull and wharf; the largest, in turn, due to the uneven, original balance of mooring state will easily appear uneven, will be the first one of the most fast rope tense than breaking force limit, then the fault line. Since then, the uneven stress of the mooring system between the ship and the shore has become worse, leading to the consequence of cable breaking one after another [5]. Under the mooring condition, the length and Angle of the cable between the shore should be adjusted frequently to ensure the uniform force to overcome the motion response of the mooring ship, including timely adjustment of the cable, preparation of fender, and reduction of damage to the dock and the hull. This kind of work intensity and risk is great. Therefore, after berthing, port ships must pay enough attention to the changes of loading and unloading operations, mooring conditions and external natural conditions, and make adjustment preparations at any time.

2.2. Security measures
According to the IMO guidance document and relevant rules and regulations [7], the force of each mooring rope of the ship must be kept balanced to prevent the ship from breaking when it is subjected to strong external forces. However, it is quite difficult to achieve the balanced force of all the mooring ropes of the ship in actual mooring operation. At present, the measures that can be taken in the industry mainly include the following: (1) To improve the balanced force of the mooring rope during berthing, and adjust its tightness appropriately according to the old and new conditions of the cable, for example, the new cable should be tighter while the old cable should be looser; (2) Use cables of the same material and diameter whenever possible; (3) If the mooring rope is made by the automatic mooring winch, the mooring rope should be pulled by the brake instead of being kept in the automatic position during strong winds or rapids; (4) Each root cable can be twisted more tightly, but each bollard should not be pulled too tightly in the cable. In case of strong winds or rapids, the bollard should be stretched first and then slipped out, and then several bollards should be added to prevent them from slipping out again, so as to relieve the uneven tension of the cable; (5) Reduce the difference of elongation of each root cable under the action of strong force [8]. In addition, by increasing the number of cable and arrange tug technique in some cases is a better solution, for example, in order to overcome some of the open type wharf of lateral flow force from the ship and shore increase cable shall be reinforced at the same time, or when the number of cable can not meet the requirements in order to increase the safety stock, tug pusher methods if necessary to reduce the lateral force component [9].
3. Innovative development of mooring system

In addition to the traditional way of mooring, people have never stopped to explore more advanced and safe ways. Foreign countries began to study mooring system as early as in the 1970s. In the 1980s, strain measurement method was adopted to directly measure bollard load data. However, at that time, computer, sensor, electronic and communication technologies were not developed, and the conditions for developing mooring safety guarantee system were not yet available. Mid 80 s, Finland's rauma - present deck machinery factory has developed a device equipped with electronic control automatic hoist, which means that the application of electronic technology of automatic device began to replace the traditional mechanical system, to become the world's first automatic hoist system, from now on for the wharf berthing of automation control of the first step. At present, a number of international companies are engaged in the research, development and manufacturing of automated mooring safety assistance systems, such as Australia's MarineHarbour, Denmark's Marimatech, America's OceanTech and Mampacy, etc. Nowadays, the mooring quick-release cable hook system used in LNG and crude oil terminals is quite common, and some domestic companies also carry out imitation and peripheral products research and development.

At present, the application of automatic mooring system has been realized, especially the combination of intelligent automatic control technology. With the rapid development of computer, electronic control, robot and artificial intelligence technology, great breakthroughs have been made in foreign countries. Moor Master200 of Cavotec, Switzerland, for example, has a suction force of 20T and a suction force of 10t/m2 on the hull plate, which has a strong adsorption control capability \[^{10}\]. At the same time, the adsorption method adopts magnetic chuck, which has been widely used in metallurgy, lifting, mechanical processing and other industries. The technology is quite mature and can produce a suction force of 600 ~ 1200 kN/m², and the magnetic force line is short (only about 10 cm), which will not affect the ship's electronic instruments and equipment while ensuring the safety of the ship. At present, foreign intelligence department berthing equipment research and development is very fast, in addition to Cavotec companies mentioned above, the Dutch Mampaey Dock - Locking system of the company, as well as emperor, mandy nima ShoreTension cable force monitoring system and AutoMoor systems in Sweden TRELLEBORG companies are successively developed can realize automatic mooring homework solutions, and similar systems on the ship on the sea lightering operation implementation process achieved good using effect, at the same time, foreign also accumulated a large number of field test results,This kind of intelligent equipment has been used in foreign countries gradually from ship lock, ferry terminal to Marine container terminal and then to bulk cargo terminal is gradually expanding, the number of ports installed this equipment is also gradually increasing. The ports of Geraldon in Australia, Rotterdam in the Netherlands, Bell Island in Canada and The Bay of Portugal, Sinish in Portugal, Portsmouth and Fishburne in the United Kingdom, Cotonou in Benin, Helsinki in Finland and Andar in Norway are examples of ports that have been put into use in recent years.

Figure 3 Example of automated mooring system that has been developed by European company
4. Research and development of intelligent mooring system
At present, intelligent ship, unmanned port tally work has become a reality, solved by the ocean to the port, wharf to yard to the rear of the intelligent technology, then in the trend of using intelligent automatic control technology to ensure safety of vessel berthing in lieu of years of traditional way with cable has become possible, by boat to the dock this last period of realizing unmanned is inevitable trend. Day science college technical team in fully absorb and draw lessons from active damping on the basis of the principle of motion compensation technology and relying on the parallel platform mechanism of smart plan implementation and ACTS as the function of the cable and fender, able to adapt to the ship six degree of freedom movement, and monitoring of ship motion and force load data, based on the judgment to identify follow-up with damping adjustment, realize the active control of mooring ship mooring operation so as to realize independent control.

4.1. Research on intelligent mooring system scheme

4.1.1 Mechanism scheme design
Therefore, the classic Stewart derived configuration of the parallel mechanism, the 6-drive, 12-power double parallel (2-3UPS/6UPS), is selected to meet the requirements of the vessel's 6-DOF motion and good impact resistance and high stiffness characteristics. Six auxiliary branches are evenly distributed on the outside of the mechanism, each of which is composed of a spring branch and a pull rod sensor. Three drive branches are distributed inside the mechanism, and the drive branches are arranged in a cross way to provide enough movement space as far as possible, and to ensure that no singularity occurs in the initial position of the double parallel mechanism. The main function of the system is to replace the mooring rope and FDH to realize the stable mooring of the ship, and to detect the load of the ship during the mooring. When the hydrological conditions are good, that is, the vessel's velocity conforms to the safety operation standard, and the mooring mechanism follows the ship's model, and the damping effect is used to reduce the ship's motion. When the hydrological conditions become complicated, the vessel's physical activity is beyond the recommended safe range, and the mooring mechanism needs to be adjusted actively to resume its movement within the required range.

4.1.2 Prototype development and system construction
In the research and development demonstration stage, in order to adapt to the laboratory test and verification, the functional prototype of the intelligent mooring mechanism system is a electromechanical and gas integration system based on the dual parallel 6-DOF mechanism configuration. The whole system is mainly composed of mechanical body, sensor detection part, pneumatic system and electronic control system. The double parallel mechanism is numbered #1 and #2 respectively. In the overall arrangement, it can be adjusted along the track according to the spacing requirement of mooring points along the horizontal direction, and it can be adjusted along the track according to the water level, ship type depth and draft along the vertical direction.

4.1.3 Test verification
According to the scale of the intelligent mooring system prototype, the test matches the appropriate test ship model. Considering that enough freeboard is left to meet the adsorption of the device, the loading state of the ship model only considers one state of ballast. The geometric scale of the model ship is 1:60.
The results show that: (1) In the case of regular waves, the mooring effect under different wave conditions is better, especially in the translational motion, with good repeatability. (2) In case of irregular wave effect, the effect of different wave conditions combined is different. Due to the randomness of wave action, especially when the action time is shortened and rapid response is required, the motion control feedback of the mechanism still lags behind and has some stability, so the adjustment control strategy is improved. (3) From the overall results at present, the established mechanism control strategy is feasible. As long as the locking system is sufficient, satisfactory results can be achieved after further improvement and optimization. The test results are shown in Figure 4.

5. Conclusion and prospect

Therefore, the main advantage of intelligence department docking system characterized by the following several aspects: (1) to improve security: cable, unmanned operation is realized, can reduce human cable release and ship berthing operation error caused by the accident in the process of offshore, especially for dangerous goods ship dock, away from hazards, sharply reduce the destruction of property loss; (2) Reduce the foundation investment: Further optimize the length of the wharf, which can reduce or even omit the layout of bollards of head and tail cables and save engineering investment; (3) Controlling operating cost and saving energy and increasing efficiency: The number of operation and maintenance personnel of the automatic mooring device is generally low, which can be used for traditional mooring, shortening manual operation time, realizing whole-process automatic operation, increasing effective operating time of the wharf, improving operation efficiency and reducing carbon emission; (4) Flexible layout and strong adaptability: it can be used for auxiliary strengthening of existing wharfs or equipment innovation of new wharfs; (5) Promote the realization of the whole process of port operation without humanization, including the whole process of port logistics and transportation, loading and unloading of goods, and docking and leaving of ships at the dock.

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