Study on modern ship stabilizer technology

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Abstract. When the ship is traveling on the sea, the unstability caused by waves may lead to accident. Most ships are equipped with stabilizers to ensure stability, seaworthiness and safety. With the development modern ships, stabilizers play increasingly critical roles. This article mainly discusses the stabilizers' history, principles, function, advantages, and disadvantages. The characters of traditional stabilizers like bilge keel, fin stabilizer, anti-rolling tank, and rudder roll stabilization are analyzed. The new technology of stabilizers like integrated roll reduction devices, Magnus stabilizers, and gyroscopic roll stabilizers are also introduced. Through the study of the current research status of integrated anti-rolling devices and technologies, it has been found that the integrated anti-rolling device has a much superior anti-rolling effect compared to a single stabilizer. The vigorous development of integrated anti-rolling technology is the main development direction of the future ship rolling reduction technology. This article may offer a reference for the development of stabilizers.

Keywords: Stabilizer, Fin stabilizer, Bilge keel.

1. Introduction

Maintaining stability is critical to ensuring the safety of a ship. Various devices have been proposed and used to reduce ship roll motion[1]. The stabilizer becomes the most important factor of the ship. The stabilizer can provide stability to the ship, enhancing the seaworthiness and safety of the ship. Nowadays, people are still searching for better ways to raise ships' stability.

Stabilizers have always been a hotspot for marine research, and different kinds of stabilizers have been invented, each with a different structure and principle. Bilge keel, Fin stabilizer, Anti-rolling tank, and rudder roll stabilization are the most popular stabilizers. With the development of stabilizers, new kinds of stabilizers come up, such as integrated roll reduction devices, Magnus stabilizer, and gyroscopic roll stabilizers. With the mature of single anti-rolling, integrated anti-rolling technologies are studied to meet the needs better. The comprehensive anti-rolling technology researched at present mainly has the following forms: fin-controlled passive anti-roll tanks, Controlled passive anti-roll tanks-pneumatic anti-heeling tank, fin-rudder roll stabilization[2].

This article focuses on different types of stabilizers, summarizes the history and principles of traditional stabilizers, and compares the improvement of ship stability. On the base of the analysis of traditional stabilizers, the new technologies of stabilizers are analyzed. Through the study of the current research status of integrated anti-rolling devices and technologies, it has been found that the integrated anti-rolling device has a much superior anti-rolling effect compared to a single stabilizer. In addition, the prospect of stabilizers is made.

2. History and Principle of Traditional Stabilizers

2.1. Bilge Keel

To increase the damping of the ship, Froude proposes to install long strips of plates perpendicular to the outer bilge plates on both sides of the bilge in the midship direction of the ship's length. The working principle of the bilge keel is that the flow field around the ship will be disturbed when the boat swings in a transverse direction, producing an additional transverse swing-damping moment. This concept has existed for many years and has become more commonly used since the 1870s.

2.2. Fin Stabilizer

The fin stabilizer is first made in 1889 by John Sonnenickelov. In 1923, Mitsubishi Heavy Industries invents the first set of sway-reducing fins that can change the angle of the fins and can be successfully installed on ships. Danny Brown fin stabilizers have been actively installed on boats since the late 1930s, and then fin stabilizers become increasingly popular.

Nowadays, anti-roll fins are among the most effective roll-damping devices for ships, achieving roll reduction rates of 80% to 90%. This is because these fins are often designed like aircraft wings. As the ship moves through the water, the flow induces lift on the fins, which counteracts the rolling motion.

2.3. Anti-Rolling Tank

Rolling-reducing water tanks may date from the 19th century. People add a certain amount of water to the bottom of the ship to help reduce rolling. In 1911, Frahm from Germany proposes a U-shaped anti-roll tank, turning anti-roll tanks into a practical roll reduction device. The principle is based on the energy generated by the ship's rolling motion to make the water inside the tank move, creating a torque that reduces the ship's rolling motion. People have considered the advantages and disadvantages of both passive and active anti-rolling tanks and proposed a method to control the tank using minimal energy, allowing the anti-rolling tank to reduce rolling across a broader range of wave frequencies effectively. This leads to the development of the controlled passive anti-rolling tank.

2.4. Rudder Roll Stabilization

Rudder rocking reduction technology is a comparatively recent innovation when measured against rocking reduction fins and tanks. It was initially proposed by Dutch academics Cowley and Lambert in 1972 and has been validated on genuine vessels, garnering considerable interest. Using the rudder for roll stabilization requires understanding the interplay between yaw (turning) and roll[3]. When the rudder is deflected, it turns the ship and introduces a heeling moment, which can be harnessed for roll stabilization. This concept leads to the development of rudder roll stabilization systems in the latter half of the 20th century.

The roll period of a ship is typically 7-15 seconds, and the bow-to-bow cycle is 20-40 seconds. The purpose of reducing roll is achieved by adjusting the rudder angle according to the different responses of the rudder to lateral and longitudinal motion. Test results indicate that the roll reduction rate of this method is approximately 60%.

3. Advantages and Disadvantages of Traditional Stabilizers

3.1. Bilge keel

The main advantage of the bilge keel is the low cost. The bilge keel has a simple structure. As a result, the bilge keel is installed on the majority of ships today. Moreover, the bilge keel does not take up internal space or add weight to the hull.

However, the bilge keel t does not provide as strong a roll-dampening effect as other stabilizers. Therefore, the bilge keel is usually used in conjunction with other stabilizers. Although the bilge keel can gives some stabilization at all speeds, the effect diminishes at higher rates. In addition, the bilge keel disrupts the flow around the boat, reducing the ship's speed. The bilge keel is not suitable for some types of ships. For fishing ships, the bilge keel may interfere with the catch.

3.2. Fin stabilizer

The anti-roll fin systems can be categorized into non-retractable, retractable, and telescopic types. Non-retractable fins remain fixed and always in operation after installation; retractable fins can be deployed or stowed as needed; telescopic fins can be extended, accommodating different water depths and sailing conditions.

Based on their application, fins can be classified into traditional anti-roll fins and zero-speed anti-roll fins. Traditional anti-roll fins can't support stability when driving at low speeds or stays. Traditional stabilizer fins offer sufficient stabilization only when the ship travels at high speeds. In contrast, zero-speed stabilizer fins can provide stability at any speed[4]. MARIN Pools of the Netherlands, KoopNautic, and Quantum Controls have jointly investigated the lift generation mechanism of the wake reduction fins for small vessels at zero speed. The lift generation mechanism of the wake reduction fins has been investigated and the wake reduction effect has been verified using a model test method[5,6]. However, zero-speed stabilizer fins consume more power than traditional fins, and the frequency of their movement is much higher than that of conventional stabilizer fins. As a result, the fin shaft is more prone to wear and tear, and the noise level is also higher. Therefore, the current trend for ships is to use stabilizer fins and bilge keels together.

3.3. Anti-Rolling Tank

There are three types of anti-roll tanks: passive anti-roll tanks, controlled passive anti-roll tanks, and active anti-roll tanks. The passive anti-rolling tank has a simple structure, low maintenance cost, and no need for an external power supply, but design parameters and the specific wave frequency range limit its effectiveness. The passive anti-rolling tank may not be effective at particular frequencies. Compared to passive anti-roll Tanks, the principle of controlled passive anti-roll tanks is almost the same, but the anti-roll tank can control the water flow and improve the performance over different wave frequencies. The active anti-roll tank detects the rolling motion of the ship and the power equipment such as the pump, actively controls the flow of water inside the tank and creates the necessary counteracting force to offset the ship's roll. The controlled passive anti-roll tank is relatively complex in structure and control, with higher energy consumption and costs. Active anti-roll tanks take up much space on the ship and are expensive to build, but have the advantage of slowing the ship at low speeds. The recently developed water tanks, which can be passively controlled and stabilized, are now more commonly used. This type of tank has proven to be particularly fitting for ro-ro ships, car and passenger ferries, container ships, and drilling ships. It not only diminishes shaking and tilting but also boosts loading and unloading efficacy and lowers transportation costs[7].

3.4. Rudder Roll Stabilization

As this method requires no unique stabilizer, it has received much attention. However, the steering motion of the rudder roll reduction can easily cause additional wear on the steering gear, and the power of the rudder motor needs to be increased. The movement of the rudder can also increase drag and other adverse factors.

4. New Technology of Stabilizers

With the development of stabilizers, many new technologies come out. Stabilizers are not only able to provide safety to the ship but also provide comfort and economic benefits.

4.1. Integrated Roll Reduction Device

Although traditional stabilizer technologies are mature, no stabilizer can deal with all situations. The fin is not able to produce sufficient anti-sway moments when the ship is at low speed, and the bilge keel has a lousy performance at high speed. The combination of these two devices can provide a ship with sufficient anti-sway moment. This combination is one of the most popular integrated roll reduction devices.

4.1.1. Fin-Controlled Passive Anti-Roll Tanks

This method suits boats that need to reduce rolling at all speeds. It is necessary to rely on the fin at high speeds to achieve stability. At low rates or anchors, the effect of the sway reduction is mainly dependent on the anti-sway tanks.

4.1.2. Controlled Passive Anti-Roll Tanks-Pneumatic Anti-Heeling Tank

Anti-roll and anti-heel tanks can use the same compartment to fulfill their functions, but the functionality of the same room can only be used for one of these purposes. In other words, while the damping effect can be achieved, the anti-heeling impact cannot be applied. Therefore, when this combination structure is used, there are usually one or more independent anti-heeling water tanks.

4.1.3. Fin- Rudder Roll Stabilization

As early as 1981, Kallstrom used multivariable linear-quadratic control theory to control the rudder fins in an integrated manner, achieving excellent performance in both heading control and sway reduction[8]. For strong wind and wave conditions, using rudders to control stabilizers can effectively reduce the design volume of the fins. This approach can also reduce roll and ensure course stability. The combined roll reduction device of the ship's rudders integrates the benefits of stabilizer fins and rudder roll stabilization. This method is usually used on large displacement ships and become the most essential research in reducing ship rolling in the last few years.

4.2. Magnus Stabilizer

Based on the Magnus effect, the cylindrical rotary roll stabilizer has recently emerged as a low-speed stabilizer. Design Ideas for Marine Rocking Reduction Devices Based on Magnus Effect The idea of designing a marine rocking reduction device based on the Magnus effect appeared in the work of Pangalila and Kollenberger [9,10].The Magnus stabilizer differs from conventional stabilizer fins. It employs a rapidly rotating cylinder to generate upward or downward lift forces, depending on the magnitude and direction of its rotational speed [11]. These lift forces create a stabilizing torque that counters lateral rolling, achieving roll reduction. The Magnus stabilizer offers distinct advantages for low-speed maritime operations, such as cruising, anchoring, and slow-speed maneuvers. Its compact design and potential for energy efficiency make it a promising choice, contributing to reduced fuel consumption and improved environmental impact. However, its applicability is limited to lower speeds, and the complex nature of its high-speed rotating components may necessitate more intricate maintenance procedures. Additionally, susceptibility to wind direction may affect its effectiveness, particularly in crosswind scenarios. While offering unique benefits in specific conditions, it is essential to consider the limitations carefully.

4.3. Gyroscopic Roll Stabilizers

Due to the capability for roll reduction at full speed, gyroscopic stabilizers achieve impressive roll reduction rates of 50% to 80%. This technology primarily competes with zero-speed stabilizer fins within the yacht market. Unlike zero-speed stabilizer fins, gyroscopic stabilizers do not necessitate protrusion from the ship's hull, simplifying the installation process. Additionally, the gyroscopic stabilizers exhibit enhanced stability at lower speeds. However, the gyroscopic stabilizers is not suitable for larger ships due to significant space requirements and higher energy consumption.

5. Conclusion

This paper mainly describes the characteristics of different stabilizer types and discusses their working principle, advantages, and disadvantages. At present, the function of a single stabilizer can not meet the complex conditions of the ship when sailing on the sea, and the combination of multiple rolling reductions can better solve the needs of various loading conditions. The traditional fins and controllable passive rolling reduction tanks still hold the dominant positions of the central part of the ship's rolling reduction device. It is anticipated that the future direction of ship stabilizer will be toward integrated rolling reduction.

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