Controlled methods for roll stabilization on ship

Bo Han [1], Hao Zhang [2]

[1]Merchant Marine College, Shanghai Maritime University, Shanghai 201306, China;

[2]Merchant Marine College, Shanghai Maritime University, Shanghai 201306, China

Abstract

This paper reviews several control methods for ship roll reduction. The application of several main control methods such as adaptive control, intelligent control, robust control and variable structure control in the fin stabilizer, rudder roll and rudder fin joint control are discussed respectively. The technical problems still exist and the prospects are pointed out. A valuable research was directed.

Keywords

Ship; roll stabilization; controlled methods.

1. Introduction

When ships are sailing and working at sea, they are inevitably swaying due to the disturbance of the sea environment such as waves, sea breeze and currents. If the ship is studied as a rigid body, the movement generally has six degrees of freedom, called roll, pitch, sway, sway, sway, and heave (or heave). Since ships often need to sail on rough waters, violent shaking will have a great impact on the ship's seaworthiness, safety, and the normal operation of the equipment, the fixing of the cargo and the comfort of the occupants. For military ships, the violent sway will affect the normal take-off and landing of the aircraft, delay the aircraft; it will also make the artillery unable to accurately hit the target, so that it is in a passive position in the war. Therefore, for the safety of navigation of ships and the improvement of comfort during navigation, ship rolling has been the goal of unremitting efforts.

Since ship motion is a nonlinear and complex system, it is one of the hot issues in ship motion control research to seek effective methods to improve the navigation performance of ships to reduce the amplitude, velocity and acceleration of the sway motion.

At present, there are three commonly used methods for ship anti-rolling control: fin roll reduction, rudder roll reduction, and rudder fin joint control roll reduction.

2. Ship fin rolling control system

Due to the small damping of the ship's roll motion, the ship will experience severe roll in the wind and waves. Excessive roll motion not only affects the navigation of the ship, but also adversely affects the equipment on the ship, and brings unsafe factors to the cargo and personnel on board. In order to reduce the ship's roll, the ship designers have made a lot of efforts to successfully design a variety of anti-rolling devices[1].

Ship fin stabilizers have developed rapidly at home and abroad and have been widely used in various ships. The earliest patent for fin stabilizers was obtained by John Sannickcroft in 1889. In 1935, the "Dennis-Brown Fin" designed by Brown Brothers of the United Kingdom was successfully applied to a 2,200-ton strait ferry "Shaq Island". Since then, fin stabilizers have been widely used. Since the beginning of the 1960s, China has been working on the development of ship fin stabilizers. In recent years, China has installed fin stabilizers on large-scale customs vessels, public security boats, transportation boats, passenger rolling boats and large-scale fishery vessels.

After the fin capacity and fin type and the corresponding follower system are determined, the effect of fin stabilizer is closely related to the control strategy adopted. Therefore, as people's requirements for ship navigation stability continue to increase, various fin stabilizer control algorithms have emerged. The principle of the fin stabilizer control system is shown in Figure 1.

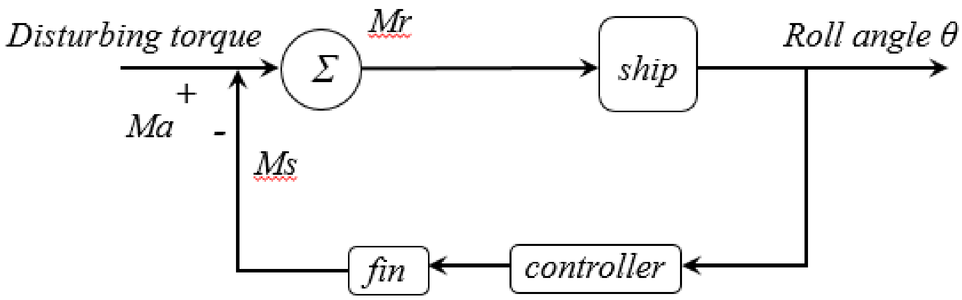

Fig. 1 Fin stabilizer control system block diagram

Cui Chunzhong and Wang Mingxing[2] studied the application of the PID control principle in the ship fin stabilizer system. They linearize the roll model of the ship after being disturbed by the waves, and use PID control to reduce the roll, which is easier to achieve, but it is difficult to obtain the parameters required for the best anti-rolling effect of the ship at various roll-crossing frequencies. Or the optimal parameters under a certain wave angle, PID is difficult to achieve the best anti-shake effect once the ship's heading changes or the wind direction changes, so PID control is essentially a trial and error method.

Liu Sheng and Yao Bo[3] proposed the application of minimum variance control in the ship fin stabilizer system. Compared with the PID-controlled fin stabilizer system, the results show that the quasi-minimum variance control and the minimum variance of the fin stabilizer system motion control can obtain better control effects. However, the above method is based on the assumption that the ship's roll motion equation is linearized when the ship's roll motion is small, and the control effect is not obvious when the roll motion is large.

Due to the incompatibility of PID control in ship anti-rolling applications, intelligent control has begun to be utilized in ship fin stabilizer control. Xu Pei, Wang Kejun and Jin Hongzhang[4] proposed the application of fuzzy control in the ship fin stabilizer system. The fuzzy controller is designed to control the characteristics of the fins without relying on the specific mathematical model and according to the rules of human experience. The controller has strong adaptability, and compared with the PID control, it has a good anti-rolling effect for the non-set sea conditions.

With the development of control strategies, robust control and variable structure control began to be applied to ship fin stabilizer control. Liu Weiting, Zhang Bing and Jiang Jianguo proposed the application of robust control in ship fin stabilizer control in the literature, and achieved good control effects under different sea conditions. Yang Yansheng and Jia Xinle et al. proposed a robust controller for the fin stabilizer structure for the nonlinearity and parameter uncertainty of the ship fin stabilizer system, and the control results were good.

3. Ship rudder control system

Compared with the fin stabilizer, the rudder anti-rolling device that uses the rolling moment generated by the rudder during steering is low in cost, has less space in the ship, and is convenient to use and maintain. Therefore, the rudder anti-rolling technology has attracted widespread attention. In 1972, Cowley and Lambert explored the possibility of using the rudder as a stabilizer, and successfully tested it on a merchant ship, which attracted people's attention. In the early 1980s, the China Ship Science and Technology Research Center carried out theoretical and experimental research on rudder reduction, and discussed the feasibility and optimal control rules and anti-rolling effects of installing the rudder anti-rolling device. Since the 1990s, the study of rudder reduction has become more profound.

Since the steering can cause the ship to generate a heeling moment, the rudder rolling is used to counteract the wave-induced rolling disturbance torque, that is, the steering generated by the steering is used to counteract the wave-induced roll.

Shen Jianqing and Chen Jian[5] studied the application of adaptive control in the rudder reduction roll system. By neglecting the coincidence relationship between heading and roll in the rudder anti-rolling system model, it is simplified into two sub-models for adaptive control. The simulation results show that it can play the role of anti-rolling. With the rapid development of computer technology, the rudder reduction roll adaptive control system can achieve the adaptive effect, making real-time swaying possible. Because the adaptive control algorithm is complex, the amount of calculation is large, and its robust performance problem is not very It is a good solution, so its application is limited.

Zheng Minghui, Yang Songlin[6] and other Sichuan applied the fuzzy control theory to the ship maneuvering roll motion control, which can achieve the purpose of maintaining the original heading and better control effect on the roll motion. Since the fuzzy control effect directly depends on the selection of the control rules, it is difficult to optimize the control effect.

Since the rudder anti-rolling controller is highly sensitive to ship parameters and it is easy to make the anti-rolling control failed, Yang Chengen[7] et al. will control the rudder and shake the system with robust control. To improve the robustness of the anti-rolling controller, and to improve the robustness by simplifying the complex nonlinear ship model into a relatively simple linear model, and to suppress the influence of the uncertainty of the ship model on the anti-rolling effect.

Since the ship motion model is a complex nonlinear model, Lauvdal [8]et al. use the sliding mode variable structure to control the strong robustness to external disturbances, and apply the sliding control to the control of the rudder anti-rolling system. However, the application of sliding mode control for rudder reduction can only achieve the desired control effect under certain sea conditions, which is its limitation. Wang Xianzhou et al. introduced the genetic algorithm into the rudder anti-rolling system, and used genetic algorithm to optimize the parameters of the selected rudder roll control to automatically obtain a better optimal solution. Xu Yanmin[9] further synthesized fuzzy genetic algorithm by fuzzy logic, neural network and genetic algorithm, and fully utilized their respective advantages to make up for their respective shortcomings, which could improve the ship's rudder anti-rolling effect.

Rudder reduction is a relatively new anti-rolling technology and is still evolving. Due to its outstanding advantages such as low cost, it is still widely studied by researchers in the shipbuilding industry. The main disadvantage of rudder roll reduction is the need for high speed manipulators and poor rudder efficiency at low ship speeds.

4. Rudder fin joint control system

Since the steering has an influence on the roll and the yaw, and the movement of the fins also affects the first roll and the sway, the joint control device of the rudder fin has practical significance.

For horizontal motion control, the traditional approach is to use one or two pairs of fins to reduce the roll amplitude, while overcoming the wheel shake uses one or more rudders. It is well known that the action of the rudder will produce a roll, and the effect of the fins will also cause a sway. If the anti-roll and heading retention system is designed independently, the required fin capacity will be large, when sailing in lower sea conditions. It will inevitably result in waste of fin capacity. From the idea of rudder swaying, in high sea conditions, the use of rudders to assist in swaying can reduce the design capacity of the fins, while also reducing sway and maintaining heading[16].

For ship motion, we built a three-degree-of-freedom model of roll, sway, and sway as follows:

$$m(\dot{v}+ur) = -m_v\dot{v} - m_x ur + Y_v v + Y_r r + Y_\varphi \varphi + Y_{v|v|}v|v| + Y_{vvr}v^2 r + Y_{r|r|}r|r| + Y_{v|\varphi|}v|\varphi| + Y_{vrr}r^2 v + Y_{r|\varphi|}r|\varphi| - (1+\alpha_H)F_N cos\delta + Y_\omega$$

$$J_{xG}\dot{p} = -J_{xx}\ddot{\varphi} - 2N_u\dot{\varphi} - Dh\varphi - z_H\big(-m_y\dot{v} - m_x ur + Y_v v + Y_r r + Y_{v|v|}v|v| + Y_{vvr}v^2 r + Y_{r|r|}r|r| + Y_{v|\varphi|}v|\varphi| + Y_{r|\varphi|}r|\varphi| + Y_\varphi \varphi\big) + (1 + \alpha_H) z_k F_N cos\delta - 2Ll_f cos\varepsilon_f + K_\omega$$

$$J_{zG}\dot{v} = -J_{zz}\dot{r} + N_v v + N_r r + N_{v|v|}v|v| + N_{r|r|}r|r| + N_{vvr}v^2 r + N_{vrr}r^2 v + N_\varphi \varphi + N_{v|\varphi|}v|\varphi| + N_{r|\varphi|}r|\varphi| - (x_R + \alpha_H x_H)\, F_N cos\delta + N_\omega$$

It can be seen from the model established above that the ship's motion is essentially a nonlinear, strongly coupled system. Taking into account the scourge between horizontal movements, a uniform stabilization system can achieve better results. Kallstrom first proposed in 1981 that the multi-variable linear quadratic control theory is applied to the integrated control of the rudder fins, which can achieve excellent performance in both the control of the heading and the anti-rolling[12]. The French "Gao Lele" aircraft carrier and the US Coast Guard 901 class ship are equipped with rudder fin joint anti-rolling equipment. Experiments have shown that it is entirely possible to stabilize the sway, roll and sway motion in the sea state of 5-6 at a speed of 24 kn and a wave of 90-270°. In general, a block diagram of a simulation model considering the ship's rudder fin joint anti-rolling control for ship roll and side roll control[17] is shown in Fig. 2.

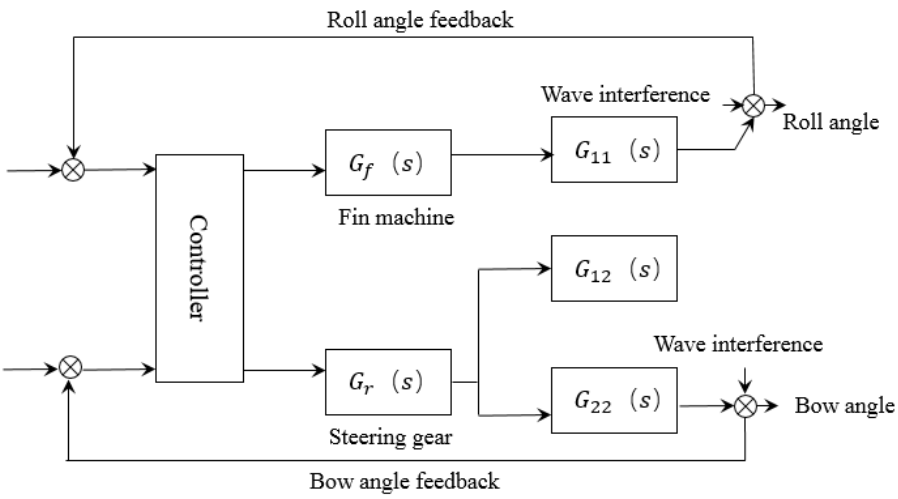

Fig.2 Simulation Model of Ship Rudder Fin Joint Anti-Shake Control

As we all know, the ship's anti-rolling effect is closely related to the control strategy adopted. Zhao Guoliang[10] and others introduced the LQG control into the combined control of the ship's rudder fins, and used the inherent kneading characteristics of the ship's motion to manipulate the rudder fins. In the literature, Zhao Guoliang believes that the ship is actually a six-degree-of-freedom moving body. Due to the mutual compatibility of its various degrees of freedom, it is necessary to use the idea of multi-input and multi-output control system to consider the whole, and to roll the ship. The sway and the sway are used as the output of the control system, and the rudder angle of the fin angle is used as the available control amount. While controlling the heading of the rudder and the anti-rolling effect of the fin, the control of the swaying motion is swayed by means of the rudder fin. The misfortunes are used to reduce them.

Liu Weiting[11] et al. used the optimal control theory to realize the lateral motion of the rudder fin joint control ship, and required the ship motion control model and the wave interference model. In view of the fact that the nature of ship motion is a non-linear and large disturbance process, Yu Ping and Liu Sheng[14] proposed the application of control theory to the control system design of ship nonlinear motion model, and the nonlinear term and sway velocity related term as the system. Disturbance, transforming the nonlinear motion problem of a ship into a linear system design problem of interference suppression.

The joint control system of the ship's rudder fin combines the advantages of the fin stabilizer and the automatic rudder to achieve stable control of sway, roll and sway. It is one of the hotspots of current ship motion research.

5. Conclusion

The development of control theory has prompted the ship's anti-rolling control strategy to be constantly updated. Based on the current research status of ship anti-rolling control, the author suggests that deep research can be carried out in the following aspects:

(1) Due to the nonlinear nature of ship motion, it is meaningful to introduce nonlinear control algorithms into ship anti-rolling control;

(2) Since the research on automatic rudder reduction is still in the pre-research stage, the existing theoretical problems have not been solved well. However, its advantages are obvious, and it is of practical value to carry out in-depth research on the rudder anti-rolling control system;

(3) Due to the advantages and disadvantages of using the automatic rudder and the fin stabilizer for the anti-rolling, it is promising to conduct a deep research on the rudder fin joint anti-rolling control.

References

[1] Liu Weiting, Zhang Bing, Jiang Jianguo, Application Research of Control Theory in Ship Fin Stabilizer Control. Working condition automation. Vol. 4, No. 3, 2000. 6.

[2] Cui Xizhong, Wang Mingxing, Fin stabilizer control system analysis, Electrical Equipment, Vo l. 10, 1995.

[3] Liu Sheng, Yao Bo, Ship fin stabilizer minimum variance control, Information and control. Vol. 4, No. 4, 1997. 6.

[4] Xu Pei, Wang Kejun, Jin Hongzhang, Application of Fuzzy Control in Ship Rolling Technology, Automation technology and application. Vo l. 10, 2001.

[5] Shen Jianqing, Chen Jiahe, Lai Yanhui, Research on adaptive control system of rudder reduction roll, Marine power technology. Vo l. 5, 1994.

[6] Zheng Minghui, Yang Songlin, Simulation Technology of a Rudder Anti-rolling System Using Fuzzy Control, Marine power technology, Vol. 6, No. 4, 1994.

[7] Yang Chengen, Jia Xinle, Multivariable automatic rudder controller for anti-rolling, Ship engineering, Vo 2. 5, 1998.

[8] Lauvdal，T. and T. I. Fossen. Rudder roll damping system for a nonlinear ship model using sliding mode control. Proceedings of European Control Conference (ECC'97) 1997

[9] Xu Yanmin, Wang Pengsa, Rudder Flicker Fuzzy Control System Based on Hybrid Genetic Algorithm Optimization, Journal of Wuhan University of Technology.2003

[10] Zhao Guoliang, Li Jide, Meng Hao, Research on Joint Control System of Rudder Fins, Heilongjiang Automation Technology and Application. Vo 1. 6, 1999

[11] Kallstrom C G. Control of yaws and roll by a rudder/fin system stability . Proceedings 6ship control symposium. 1981

[12] Liu Weiting, Zhang Bing, Ma Jixian, Design of Optimal Navigation Controller for Ships, Journal of East China Shipbuilding Institute, , Vo 1. 3, 1999.

[13] Grimble , M. J. , Zhang , Y. , and Katebi，M. R. H-inf based ship fin-rudder roll stabilization design. Proceedings for the 10 Ship Control Systems Symposlum. Vo1.2:51-66

[14] Yansheng Yang, Changjiu Zhou，Xinle Jia. Robust adaptive fuzzy control and its application to ship roll stabilization. INFORMATION SCIENCE . 2002: 177-194

[15] Wang Xianzhou, Xu Hanzhen, Application of Genetic Algorithm in Optimization of Rudder Rolling Control Parameters, Journal of Huazhong University of Science and Technology. Vo 2. 5, 1997.

[16] Yu Ping, Liu Sheng, Simulation Research on Nonlinear Rudder and Fin Joint Control System Based on H Design Method, Journal of System Simulation.2002

[17] Zhang Boshi, Wang Kejun, Design and Simulation of Ship Rudder Fin Joint Anti-Shake Intelligent Control System by Using MATLAB, Computer Simulation. Vo 2. 5, 1998
[18] Yang Yansheng, Jia Xinle, Uncertain nonlinear nonlinear variable structure robust control of ship fins, Chinese shipbuilding. 1998.