Research on Control of Ship Joint Anti-Shake

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Abstract

The ship's anti-rolling control system can not only greatly improve the stability of the ship, but also facilitate the smooth operation of all the ships. The ship rolling motion model is analyzed from the moment of the moment, and the mathematical model of the ship's fin stabilizer and the anti-rolling tank joint control system is established. The traditional anti-rolling method uses the single sensor and the single anti-rolling device to have the disadvantage of poor anti-rolling effect. A robust fusion Kalman filter technique based on multi-sensor data fusion and uncertain systems is proposed. The simulation results show that the robust fusion Kalman filter technology improves the accuracy of the control system to a certain extent and enhances the anti-rolling control performance of the anti-rolling system.

Keywords

Kaman filter; multi-sensor; robust; joint anti-rolling.

1. Introduction

During the course of maritime navigation, due to external conditions such as wind and waves on the ocean and undercurrent under the sea, a series of complicated rocking movements will occur [1]. This rocking motion is a typical nonlinear motion [2]. The torque generated by it will cause the deformation of the hull to a certain extent, and will also reduce the smooth performance of the ship [3]. Among them, the rolling motion is the most influential on the ship. Therefore, it is important to study the ship anti-rolling control system and design the anti-shake device with good performance to improve the stability of the ship itself [4].

The fin stabilizer can be effectively and effectively reduced when the ship's speed is high, but the anti-rolling effect at low speed or zero speed is poor or even without the anti-rolling effect; the anti-rolling tank has the anti-rolling effect at any speed. However, its anti-rolling efficiency is relatively low, and it is easy to shake under low frequency disturbance [5-6]. Although the anti-rolling gyroscope has the advantages of small volume, convenient installation, good anti-rolling effect, and can be shaken at any speed. However, due to the high cost, there are currently less domestic vessels.

For the ship anti-rolling device, the research at home and abroad mainly focuses on the research of the anti-rolling effect of the single anti-rolling device, and the traditional anti-rolling method is to input the measured value of the angle sensor into the control system to adjust the attitude of the ship, although there is a certain effect. However, the period of action is long. There is little research on the combined control methods of two or more anti-rolling devices, especially the joint control technology of fin stabilizers and anti-rolling tanks. In the literature [6], Jin Hongzhang and Zhao Weiping performed a theoretical analysis on the combined anti-rolling of the fin-chamber, and proved the feasibility of its anti-rolling. In the literature [7], the CSIC Research Institute developed the “Fin Stabilizer-Shake back Water Tank Joint Controller” in 2015, which can be selected by the user to select “joint” and “independent” modes. Switching control mode, but the actual use adopts the user manual switching mode, and does not give the time when the switching control can achieve the optimal control effect.

The research on joint control technology was carried out with the "coal fin/water tank joint control system" as the object [8]。

At present, in the research on joint control of cabin fins at home and abroad, the control method adopted is to control the fins separately, and does not exert any control on the anti-rolling tank. This does not enable the "fence joint control" to reach the maximum. Excellent control effect [9-14]. Aiming at the shortcomings of single sensor's poor rolling performance and the large influence of single anti-rolling equipment on the speed of the ship, the ship rolling motion model is built. The Kalman filtering method is combined with the robust control and combined with multi-sensor information fusion technology to design the fin stabilizer. - Anti-rolling tank double anti-rolling system, and using Matlab software for simulation analysis.

2. Model establishment

In the six-degree-of-freedom movement of the ship, the roll motion has the greatest influence on the inclination angle of the hull. Therefore, the ship's roll model is mainly studied [15], and the ship's motion on the sea wave is assumed to be a linear motion system, and its input is wave. Inclination, the output is the roll angle of the ship, and the transfer function [15] is:

$$G(t) = \frac{Y(s)}{X(s)} = \frac{a_m s^m + a_{m-1} s^{m-1} + \cdots + a_0}{b_n s^n + a_{n-1} s^{n-1} + \cdots + b_0} \tag{1}$$

According to Connolly’s theory, the transfer function of ship rolling motion is:

$$G(t) = \frac{\theta(s)}{\alpha_\theta(s)} = \frac{\omega^2{}_\theta}{s^2 + 2\xi_\theta \omega_\theta s + \omega^2{}_\theta} \tag{2}$$

For the study of joint control of ship fins/water tanks, the main considerations are ship heading retention and roll reduction [16]. When the specific ship is equipped with fin stabilizers and anti-rolling tanks at the same time, the mathematical model of the joint system can be specifically referred to [16]. Here we directly study the model based on the mathematical model given in the literature. The model is as follows:

$$\begin{cases} (I_1 + J_t)\ddot{\varphi} + N_\varphi \dot{\varphi} + Dh\varphi - \rho_t S_0 \lambda t \ddot{z} - \\ 2\gamma S_0 cz = K_w - K_c \\ 2\rho_t S_0 \lambda t \ddot{z} + 2N_t \dot{z} + 2\gamma S_0 - \\ \rho_t S_0 b^2 \ddot{\varphi} - 2\gamma S_0 c\varphi = 0 \end{cases} \tag{3}$$

where, K_w is interference torque for the waves; K_c is stable torque for fin stabilizer; I_1 indicates the moment of inertia of the ship's mass and additional mass to the roll axis, not counting the mass of the liquid in the tank; J_t is the mass moment of inertia of the liquid to the roll axis in the cabin; $\lambda_t = \frac{1}{2}\int_l \frac{S_0}{S} dl$ is the length of the water column in the cabin; $b^2 = \int_l r \sin(r, dl) dl$ is the dimension of the area, which is the static moment of the axis of the water tank to the roll axis, which characterizes the integral of the inertial coupling between the subsystems.; S_0 is the free surface area of the side tank; γ is the angle between r and d ; ρ_t is the liquid density in the tank; c is the horizontal distance from the center of the side tank to the longitudinal section of the ship; D is ship displacement; h is the horizontal stability of the ship after the equipment is equipped with the anti-rolling tank; N_φ is the ship rolling damping torque proportional coefficient; N_t is the water tank rolling damping torque proportional coefficient.

According to the dynamic mechanism of fin control, there is:

$$K_c = \lambda_m Dh\alpha_c(t)$$

If $\lambda_m \alpha_c(t) = \dot{\alpha}_c(t)$, there is:

$$K_c = Dh\dot{\alpha}_c(t),\ K_w = Dh\alpha_w(t)$$

where, α_w is the wave angle of the wave, α_c is the fin angle.

Substituting equation (2) into equation (1), and performing dimensionless processing on the substituted equation, it yields:

$$\begin{cases} \ddot{\varphi} + 2v_\varphi \dot{\varphi} + \omega_\varphi^2 \varphi - \beta \ddot{z} - \alpha z = \omega_\varphi^2 (\alpha_w(t) - \dot{\alpha}_c(t)) \\ \ddot{z} + 2v_t \dot{z} + \omega_t^2 z - b_t \ddot{\varphi} - c\omega_t^2 \varphi = 0 \end{cases} \quad (4)$$

where:

$$\frac{2\gamma S_0 c}{I_1 + J_t} = \alpha, \frac{S_0 \rho_t \lambda_t}{I_1 + J_t} = \beta, \frac{2N_\varphi}{I_1 + J_t} = 2v_\varphi,$$

$$\frac{N_t}{\rho_t S_0 \lambda_t} = v_t, \frac{\gamma}{\rho_t \lambda_t} = \omega_t^2, \frac{Dh}{I_1 + J_t} = \omega_\varphi^2$$

3. Control system design

The joint control system mainly consists of a total system (fin stabilizer / anti-rolling tank) and two subsystems (folder fin system, anti-rolling tank system). In order to achieve intelligent control of the joint control system, it is necessary to design a reasonable control method for the total system and subsystem. The system diagram of the joint control system is shown in Figure 1.

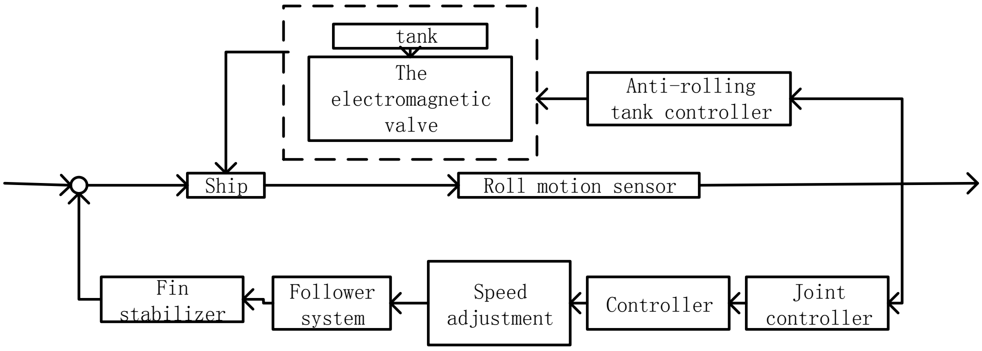

Fig.1 System diagram of the joint control system

3.1 Anti-rolling tank control design

The controllable passive water tank system was adopted as the research object. The working principle is: when the ship is swaying, the ship generates various signals related to roll, such as roll angle, roll angular velocity, roll angular acceleration, and water tank level. After sensing the signals, the sensor converts them into electrical signals and sends them to the controller. The controller generates a control signal for controlling the opening and closing of the water tank valve to realize the flow of water inside the water tank, and generates a torque against the rolling motion by the gravity difference of the water tank to achieve the purpose of the rocking.

The control methods of the anti-rolling water tank mainly include the water level in the cabin, the roll angle of the ship, the roll angular velocity and the liquid flow direction in the cabin. But they all need to accurately determine when the valve is added to the control and control time, and if an error occurs, it will cause a shake. Therefore, the best control method is adopted [17]。

The expression of the valve control signal given by Dalzell et al. to achieve the optimal control method is $L_g = \ddot{\varphi} + a_1 \omega_\varphi \dot{\varphi}$, where, L_g is valve control signal, a_1 is the constant.

Due to the assumption of regular waves, there is $\varphi = \varphi_a \sin \omega t$, so:

$$L_g = \ddot{\varphi} + a_1 \omega_\varphi \dot{\varphi} = \varphi_a \omega \sqrt{\omega 2 + \left(a_1 \omega_\varphi\right)^2} \sin\left(\omega t + \varepsilon_{\lg}\right) \tag{5}$$

Where $\varepsilon_{\lg}$ is the phase relationship between the control signal switching time and the ship's roll motion, and the expression is: $\varepsilon_{\lg} = \arctan \frac{-a_1 \omega_\varphi}{\omega}, \frac{\pi}{2} < \varepsilon_{\lg} < \pi$

If the motion in the controllable passive water tank is reduced to a simple resonance motion, the motion of the water in the cabin can be expressed as: $z = z_a \sin(\omega t + \varepsilon_{\lg} - 3\pi / 2)$

Comparing the phase difference between the water tank motion and the ship rolling motion required by the optimal control principle of the water tank and the lag phase angle in equation L_g , there is $\varepsilon_{t\varphi} = 3\pi / 2 - \varepsilon_{\lg} \to \pi$. For ships with a fixed constant pressure period, according to different sea wave interference frequency ε , changing the control constant a_1 in equation (5), the optimal control requirements can be achieved, and the optimal control of the water tank can be realized.

3.2 Fin control design

The main components of the fin stabilizer control system are fins, hydraulic systems, and controllers. The working principle is: when the ship is panning, the gyroscope collects the signal and sends out the control signal, and generates a command to turn the fin after being processed by the controller. In general, the driving effect of the fin is generated by the electro-hydraulic control system, so that the rotation direction of the fin is opposite, forming the "lifting force" of one of the fins upward, and the "lifting force" of the other fin to the downward force balance state, thereby stabilizing The torque acts on the ship. This torque can resist the disturbance torque from the external environment, which makes the roll angle of the ship smaller and achieves the roll reduction [17]. The system diagram is shown in Figure 2.

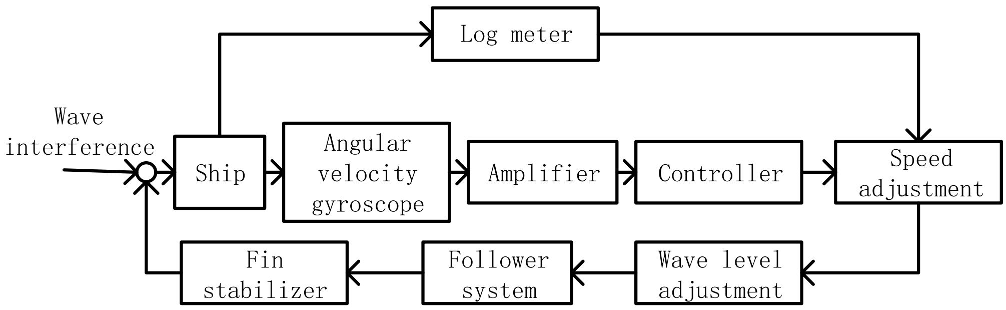

Fig.2 Schematic diagram of the fin stabilizer controller

3.3 Simulation analysis

In order to verify the anti-rolling performance of the system, a ship is used as a model. The parameters are: normal displacement D is 1323; transverse stability h is 0.94; roll natural angular frequency ω is 0.84; total ship length L is 56.5; ship width B is 10.4; the water depth d is 3.1; the square factor of the structure C_b is 0.08. The system was simulated using Matlab software. The simulation results are as follows.

Figure 3 to Figure 5 show the ship's roll condition with a sense wave height of 4 m, a speed of 9 m/s, and an encounter angle of sea.

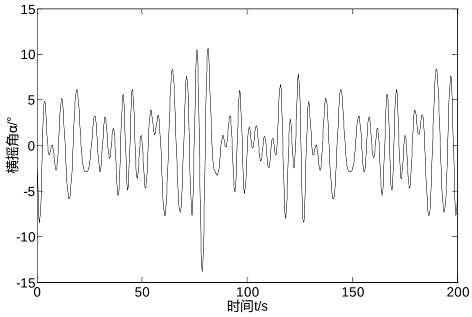

Fig.3 Fin stabilizer alone

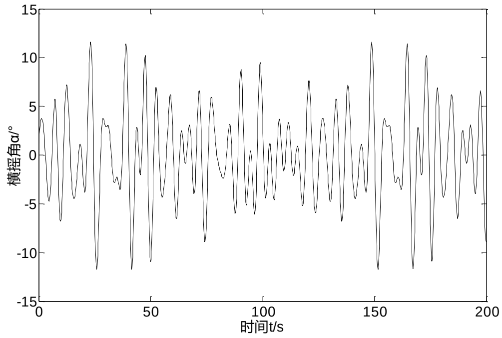

Fig.4 Anti-rolling tank alone

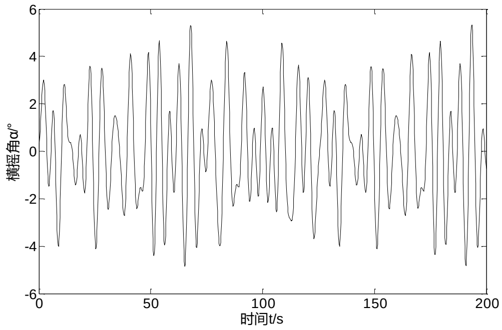

Fig.5 Joint control system

Figure 6 to Figure 8 show the ship's roll condition with a sense wave height of 4 m, a speed of 3 m/s, and an encounter angle of sea.

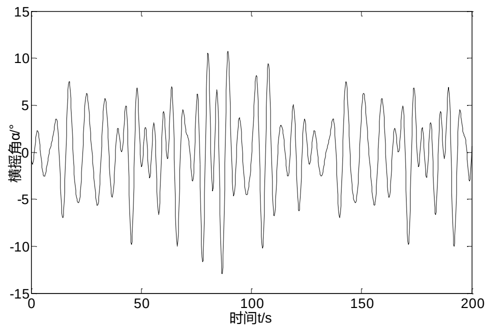

Fig.6 Fin stabilizer alone

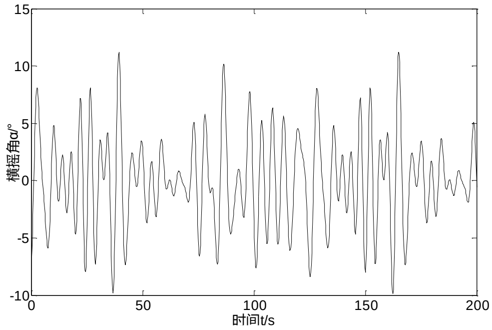

Fig.7 Anti-rolling tank alone

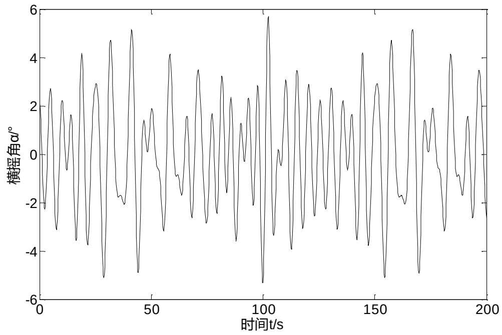

Fig.8 Joint control system

4. Conclusion

The main reason for the ship's roll is the influence of the waves, sea breeze and other forces. The ship's anti-rolling system is conducive to improving the stability and safety of the ship's navigation. Through the scheme design and simulation analysis of the ship fin/water tank joint control system, the following conclusions can be drawn: the combined deceleration control technology not only has good anti-rolling performance for ship anti-rolling control, but also provides ship anti-rolling control technology. A new idea, while providing a theoretical basis for its practical application.

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