A New Insulate Method of Ship-Swaying Interference

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Abstract. When Ship-borne radar tracking target need to solve the problem of ship shaking disturbance at first. This article analyzed the deficiency of the current methods for the isolation ship-swaying, proposed a new insulate method based on gyro swinging loop. Which used inertial space velocity of the gyro sensor signals instead of speed measuring machine speed to complete the closed-loop system, and used a kalman filter to reduce the toll of gyro output noise. The theoretical analysis and simulation results show that the method can greatly improve the degree of isolating ship rocking.

1. Introduction
The ship's roll isolation reflects the ship's radar servo system's ability to offset the ship's roll and stabilize the antenna beam's ground pointing. It is also an important design indicator of the ship's radar servo system. At present, the shipboard radar servo system has designed measures such as self-tracking, ship roll forward, and gyro stabilizing loop to achieve the isolation of the ship roll. The anti-shipping capability of the self-tracking loop is the capability of the servo system and has no effect on the tracking performance of the servo system. Therefore, it is the most stable and reliable anti-shipping solution. Due to the influence of factors such as system nonlinearity and inaccurate mathematical model, the degree of isolation of ship rolls that can be achieved is low. When the sea conditions are poor, the system's requirements for ship roll isolation cannot be met, and the target cannot be tracked normally. In order to improve the shortcomings of the gyro stabilizing ring scheme, this paper proposes a new method of isolating the ship rocking to meet the needs of the system.

2. Basic structure of shipborne radar servo drive
The shipboard antenna drive unit is divided into azimuth and pitch driving branches. The pitch branch adopts DC motor double-chain drive, and the azimuth branch adopts DC motor dual / quad-chain drive. The motor is controlled by electric anti-backlash method. Three-loop control is adopted in the design. At the same time, in order to achieve electrical clearance, it is equipped with a bias torque ring and a differential speed suppression ring to ensure the uniform force of multiple motors. Take the pitch branch as an example to briefly introduce the basic structure of the servo drive. The pitch branch is a dual motor drive system. In order to ensure high measurement accuracy and high dynamic performance, the typical three loop is used as the conventional servo system design. The current loop is the innermost loop, which is realized by modifying the current control loop of the motor controller; speed loop It is an intermediate loop and a loop designed independently. It synthesizes speed control information, bias torque information, differential suppression information, etc. to the current loop; the position loop is the outermost loop, which is a closed loop. Design control algorithms to achieve precise antenna control. Due to the characteristics of the working environment of shipboard measurement and control equipment, a gyro ring to suppress ship sway was added. Two gyros were fixed at specific positions of the antenna
to sense the rotation speed of the antenna relative to the reference, and the induced electrical signal was processed and fed into the speed loop so as to achieve the purpose of overcoming ship sway. The block diagram of the system is shown in Figure 1.

**Figure 1. Block Diagram of Shipborne Radar Servo Control**

3. **Gyro feedback method to isolate the ship's rocking principle**

The gyro feedback method is one of the most commonly used ship rock stabilization schemes, and can achieve a certain degree of ship rock isolation. The dual-axis rate gyroscope is installed on the reference plane of the pitch fork arm of the antenna base, and can sense the velocity information of the inertial space of the azimuth axis and the pitch axis. The velocity information is used for feedback closed-loop control to realize the design of the gyro stability loop. The principle is shown in Figure 2.

**Figure 2. Functional block diagram of gyro feedback method**

Supposing the disturbance isolation degree of the gyro stabilizing loop scheme is $L = L_p + L_i$, there are:

$$L = 20\log \frac{\theta_i}{\Delta \theta} = 20\log(1 + K_g W_p) + 20\log(1 + K \omega_i) = L_p + L_i$$

(1)

After adding the gyro stabilization loop, although the overall ship roll isolation is improved, the frequency band of the original tracking loop is narrowed, the characteristics of the controlled object are deteriorated, and the tracking performance is reduced. Therefore, in practical applications, there is a "no
gyro-tracking” working mode, that is, when the ship’s roll is not very serious, the gyro ring is disconnected and the ship’s roll is isolated by the self-tracking ring to ensure tracking performance.

4. The principle of gyro speed ring isolation ship rocking
The basic idea of the gyro speed loop is to replace the speed signal of the tachometer with the inertial space velocity signal induced by the gyro to complete the speed loop closed-loop work. The inner and outer loops of the servo system are: current loop, gyro speed loop and position loop. In this way, the ship’s turbulence is inside the gyro speed loop, which becomes its internal disturbance. According to the principle of automatic control, the loop has a strong suppression effect on the internal low-frequency disturbance during closed-loop control. The bandwidth of the gyro speed loop is designed at 20 Hz, and the disturbance frequency of the ship’s roll is about 0.08 Hz. Therefore, the gyro speed loop has a strong suppression effect on the ship’s roll. At the same time, the turbulence of the ship is also inside the position ring, which is also suppressed by the position ring. The block diagram of its loop is shown in Figure 3.

\[ E(s) = \frac{\Delta \theta}{\theta_f} = \frac{\Delta \theta}{\dot{\theta}_f} = \frac{N}{(Ns + K_d W_4 \beta s - K_s W_5 K_d W_4) \frac{1}{s}} = \frac{1}{1 + \frac{K_d W_4 \beta}{N} - \frac{K_s W_5 K_d W_4}{Ns}} \]  

At this time, the error transfer function of the ship sway disturbance is:

\[ W(s) = K_d W_4 \frac{1}{N} \beta = NK_s W_5 \frac{1}{N} \beta_s = K_s W_5 \beta_s \]  

\[ \phi(s) = \frac{K_d W_4 \frac{1}{N} \beta}{1 + K_d W_4 \frac{1}{N} \beta} = \frac{K_s W_5}{1 + K_s W_5 \beta_s} \]
After the parameter design, the open loop and closed loop transfer functions of the gyro speed loop are consistent with the original speed loop. $K_3W_3$ is the position loop regulator of this scheme. Designing $K_3W_3 = \frac{1}{N}K_1W_1$ can ensure that the open loop transfer function of the system position loop is also unchanged, so it will not affect the tracking performance of the system.

According to the mathematical model of the shipborne radar, the ship's roll isolation can be calculated as:

$$L_1 = 20\log(1 + \frac{1764(0.048s + 1)}{s^2(0.0016 + 1)} - \frac{29615.5(0.008s + 1)(0.5s + 1)}{s^2(0.0016 + 1)} \times \frac{(0.048s + 1)}{s^2(0.0016 + 1)})$$

(5)

It can be seen that the gyro speed loop scheme obtained through theoretical analysis has a very high degree of rocking isolation, which fully meets the index requirements. However, in the actual use of the gyro, the influence of the vibration of the hull, the thermal noise generated by the internal signal processing of the gyro and the transmission process will cause unnecessary noise interference in the output data. These noises are amplified in the open-loop control may reduce the system tracking accuracy and stability. Therefore, the measurement data of the gyro must be filtered before it can be added to the system loop.

5. Kalman filter algorithm

5.1. Fundamental
Kalman filtering is a linear minimum variance estimation method. The basic idea is to establish a state space model that uses signals and noise, use the previous value of the previous time and the observation value of the current time to update the estimate of the state variable, and calculate the estimated value of the current time. This filtering algorithm is suitable for real-time processing and computer operations.

Let the state equation and measurement equation of the stochastic linear discrete system be:

$$X_k = \phi_{k|k-1}X_{k-1} + \Gamma_{k|k-1}W_k$$
$$Y_k = H_kX_k + V_k$$

(6)

Suppose $W_k$ and $V_k$ are uncorrelated zero-mean Gaussian white noise, ie:

$$E[W_k] = 0$$
$$E[V_k] = 0$$
$$E[W_k \cdot V_k^T] = 0$$
$$E[W_k \cdot W_k^T] = Q_k, Q_k \geq 0$$
$$E[V_k \cdot V_k^T] = R_k, R_k > 0$$

(7)

The iteration process of the Kalman filter algorithm using state equations and measurement equations is as follows:
5.2. Filter

Because the output rate gyroscope is the rate of change in the angle of the antenna, the observation errors of the filter measurement equations are coupled to each other, resulting in the coupling of the filter measurement equations. Although the state equations of the filter are assumed to be independent of each other, in order to ensure the filtering effect, the filter still needs to be designed as a six-state filter, resulting in a very complicated filter calculation process. Since we use a rectangular coordinate system, based on relevant data and engineering experience, it can be approximated that the measurement errors are not related to each other, so the filters can be designed as two three-state filters, which will greatly simplify the filter calculation process. It has no obvious effect on the filtering performance. Therefore, this paper uses this linearized decoupling filtering algorithm.

5.3. Filter effect

Taking the output voltage of the pitch gyro as an example, Kalman filtering is used to process the gyro output data. The filtering result is shown in Figure 4. The blue line in the figure is the output value of the gyro before filtering, the red line is the output value of the gyro after filtering, and the right figure is a partially enlarged view of the left figure. It can be seen from the figure that after Kalman filtering can effectively reduce the gyro noise.

![Figure 4. Output curve before and after pitch gyro filtering](image)

6. Simulation analysis

The MATLAB / Simulink simulation environment is used to realize the simulation of the gyro speed loop scheme. In the gyro speed loop, the output of the rate gyro is the measurement of the angular
velocity of the azimuth and pitch axis in the inertial coordinate system. The Kalman filter algorithm is implemented in MATLAB with m language, and the function is called in MATLAB function module in Simulink. The speed output of the Kalman filter is added as feedback information to the speed loop simulation block diagram shown in Figure 5. The simulation data is output to the MATLAB workspace for processing, and the total ship roll isolation at this time is 67dB.

Figure 5. Gyro speed loop simulation block diagram

7. Conclusion
This paper analyzes the limitations of several current ship-shake isolation schemes, and proposes a new method of ship-shake compensation that uses the inertial space velocity signal induced by the gyro to replace the speed signal of the tachometer to complete the construction of the closed-loop gyro speed loop. Processing the noise in the output data of the gyro, and analyzing this method through simulation can greatly improve the system isolation without changing the tracking performance of the system.

References
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