Design and Implementation of method to increase the isolation of boat rocking for ship-borne radar

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Abstract. The influence of ship rocking is needed to conquer, while capturing and tracking the targets on servo system of ship-borne radar. Aimed at solving the problem that the target can’t be captured through the isolation on the position loop, A new method was proposed that increase the feedback gyro and feedforward gyro in the manual model of the earth coordinate system. The ability of isolating ship shake has significantly improved. These greatly reduced the difficulty of narrow beam ship-borne radar capturing target.

1. Introduction
In order to effectively overcome the effects of ship sway, the shipboard radar servo control system usually uses the following three methods to isolate the ship sway during the test task at sea: the servo itself closed-loop control, gyro stability loop and feedforward compensation method.

The self-tracking position loop is the outer loop of the servo loop. The influence of ship roll can change the relative deviation angle between the electric axis and the target, which is reflected to the system as the error voltage. Movement in the reduced direction aligns the antenna's electrical axis with the target. Therefore, to a certain extent, it plays the role of isolating the ship's rocking.

The gyro stabilizing loop uses two orthogonal rate gyros installed on the pitch fork of the antenna to respectively sense the rotation speed of the antenna pointing in the inertial space. The speed information is used to feedback the closed loop, thereby suppressing the antenna axis in the self-tracking loop. Disturb. Because it is sensitive to inertial space angular velocity, it can sense the ship's rocking angular velocity and isolate the ship's rocking by negative feedback.

There are two types of feedforward compensation methods, namely gyro feedforward compensation and ship roll feedforward compensation. The gyro feedforward compensation uses a feedforward gyro installed in the antenna base, which only senses the ship's rocking angular velocity, and adds the sensitive ship's rocking information to the input of the speed loop, so that the antenna axis rotates at the opposite speed to the ship's rocking. Ship roll feedforward compensation is to use the inertial navigation system to measure the ship roll angle and angular velocity in the corresponding direction, converted to the ship roll angular velocity corresponding to the antenna through coordinate transformation, and also add the input of the speed loop of the corresponding branch to isolate the ship roll. The beam swing caused by the disturbance reduces the additional angle error caused by the boat roll.
2. **Gyro feedforward compensation principle**

After the position loop is closed, a feedback gyro is added to adjust the gyro loop. The principle diagram is as follows:

![Diagram](image)

**Figure 1.** Schematic diagram of position loop plus gyro feedforward compensation principle

Feedback the gyro's sensitive azimuth and pitch movement rate. The output value is the sum of the antenna movement speed in azimuth and pitch direction and the ship's shaking disturbance speed. Due to the addition of the gyro ring, the isolation is higher than the traditional position ring. However, when the rate feedback is closed-loop, the gyro is installed on the antenna axis. It not only senses the rotation speed of the antenna axis in the inertial space when the ship rolls, but also the rotation speed of the antenna axis during active movement. The closed loop with this information is the gyro feedback stability. This stable loop has a disadvantage. When there is no boat roll or the boat roll is not large, and the antenna axis is actively moving, it also performs a dynamic suppression, which reduces the response speed of the antenna axis. At the same time, it also directly affects the bandwidth of the self-tracking loop. To reduce tracking performance. In view of the shortcomings of the feedback gyro, the installation position of the gyro is changed to make it only sensitive to the ship's yaw rate and insensitive to the rotation of the antenna axis relative to the antenna base. Secondly, no special gyro feedback loop is needed, that is, the structure and parameters of the self-tracking loop shown in FIG. 2 are not changed, and only the gyro-sensing ship roll information is added to the input of the speed loop, so that the antenna axis can turning at the opposite speed will compensate. The schematic diagram after adding the feedforward gyro is shown below.

![Diagram](image)

**Figure 2.** Gyro feedforward compensation schematic
Feedback gyro belongs to negative feedback, its essence is to suppress the disturbance of ship sway and improve the pointing accuracy of the antenna position loop; feedforward gyro belongs to positive feedback, its essence is to compensate, add the gyro sensitive ship sway information to the input end of the speed loop To rotate the antenna axis at the opposite speed to the ship's roll. The feedback gyro is processed in the ACU software after the digital loop, and the feedforward gyro is to compensate the voltage signals of the three feedforward gyros to the speed command through operation to achieve the suppression of ship sway.

3. Gyro use strategy analysis

Ship roll isolation is a measure of the ability of a servo control system to resist ship roll disturbances under different gyroscope usage strategies. It is characterized by the decibel number of the ratio of a certain ship roll angle to the antenna pointing error angle.

Table 1 lists the test results of the tracking ring ship rocking isolation of a shipborne radar servo control system under different gyroscope usage strategies.

Table 1. Ship rock isolation test results

| Way of working                          | Isolation / dB |
|----------------------------------------|----------------|
| Self-tracking ring + feedback gyro      | 43             |
| Self-tracking loop + gyro feedforward   | 51             |
| Self-tracking ring + ship roll forward  | 50             |
| Self-tracking loop + feedback gyro + gyro feedforward | 53 |
| Self-tracking loop + feedback gyro + ship roll forward | 53 |

Table 2 lists the effects of ship roll on tracking accuracy under different ship rolls and different ship roll isolation indexes.

Table 2. Ship rock isolation test results

| Total isolation | Boat shake ±6° | Boat shake ±5° | Boat shake ±4° | Boat shake ±3° | Boat shake ±2° | Boat shake ±1° |
|-----------------|----------------|----------------|----------------|----------------|----------------|----------------|
| 50              | 0.019          | 0.016          | 0.013          | 0.010          | 0.0056         | 0.0028         |
| 45              | 0.034          | 0.028          | 0.022          | 0.017          | 0.011          | 0.0056         |
| 40              | 0.06           | 0.05           | 0.04           | 0.03           | 0.02           | 0.01           |
| 35              | 0.107          | 0.089          | 0.071          | 0.053          | 0.036          | 0.018          |

The data in Table 2 indicates that when the ship roll is ± 6°, if the total isolation is 50 dB, the residual angle of the ship roll isolation is ± 0.019°, and so on.

In view of the high requirements on the tracking accuracy of shipboard measurement and control equipment (such as the total error of the angle measurement of the shipboard S-band microwave unified measurement and control system is 0.02°), when the ship is less than ± 3°, the total isolation of 45dB can meet the tracking accuracy The requirement, that is, the gyro feedforward compensation tracking method can meet the corresponding index requirements.

At the same time, considering that the gyro feedback stabilization loop contains the closed-loop resonance frequency of the rate gyro itself in addition to the antenna base mechanical resonance frequency, the gyro feedback loop has a greater influence on the stabilization loop, which limits the gyro's stable loop frequency band expansion. Design and debugging are also more difficult. The gyro feedforward compensation reduces the gyro resonance link in the stabilization loop, so that the frequency band of the stabilization loop can be made higher, and the design and debugging are relatively easy.

Based on the above reasons, this article gives the following strategies for the use of shipborne radar servo control system to capture and track target gyros:
(A). When the ship's roll is not more than \( \pm 3^\circ \), the gyro feedforward compensation capture and tracking method is adopted;

(B). When the ship's roll is greater than \( \pm 3^\circ \), a combination of gyro feedforward and feedback gyro ring is used to capture and track.

4. Gyro feedforward data optimization design

There is a big step at the moment when the feedforward gyro is added and de-energized. If the gyro voltage supply suddenly breaks during the tracking of the antenna or the feedforward gyro is suddenly added after taking the feedforward gyro tracking, a large step disturbance before the servo system is added. The channel will cause the antenna to oscillate, and in severe cases, it may cause the antenna to fly.

Therefore, this article uses an inertial filter function, the expression of the inertial filter function is as follows:

\[
D_0 := 2 \times K_t + T_t;
\]
\[
D_1 := 2 \times K_t - T_t;
\]
\[
\text{CurrAy} := \frac{T_t}{D_0} \times (\text{CurrAx} + \text{LastAx}) + \frac{D_1}{D_0} \times \text{LastAy}
\]

\( K_t \): filter time constant, \( T_t \): sampling period \( \text{CurrAx} \): current input, \( \text{LastAx} \): last input \( \text{CurrAy} \): current output, \( \text{LastAy} \): last output

The gyro power-on output curve before and after the inertial filter function is used is as shown in Figure 4 above, which filters out the step value, which ensures the damage to the equipment caused by voltage shock at the moment of power-on.

During a certain feed-forward gyro power-on process, when the feed-forward gyro is powered on, the output is abnormal, and the recording data is analyzed.

a). The output voltage of the pitch feed forward gyro varies between \( \pm 0.1V \) and is inconsistent with the change of the ship's roll, and the gyro output is obviously abnormal;

b). There is a clear correspondence between the pitch error voltage and the roll angle, indicating that the pitch feed-forward gyro did not play a role in isolating the ship's roll. At that time, the actual working mode was gyro tracking.

After re-energizing the feed-forward gyro, the data of the recording is analyzed.

It can be seen from the changes in pitch error voltage, roll angle, pitch feed forward gyro and ship pitch angle speed:

a). The pitch error voltage is near zero, and the maximum value is around 0.1V near Hangjie, and the tracking is stable;

b). There is a certain correspondence between the pitch feedforward gyro and the ship's pitch angle velocity, which verifies the sensitive ship roll angular velocity of the pitch feedforward gyro;

c). There is a certain correspondence between the pitch feed forward gyro and the roll angle. The change of the pitch feed forward gyro lags behind the change of the roll angle first, and then gradually leads.

The relationship between the angular velocity of azimuth pitch caused by ship roll and the angular velocity of the boat pitch and azimuth pitch angles A and E is as follows:

\[
\omega_A = \dot{\phi} + (\kappa \cos A + \varphi \sin A) \tan E
\]
\[
\omega_E = \kappa \sin A + \varphi \cos A
\]

In order to facilitate the identification of abnormal conditions by post personnel, a curve chart of the difference between the feedforward gyro output and the ship roll is added to the monitoring interface of the servo monitoring software. Through the gyro power-on test, the gyro output and the ship roll angular velocity information calculated by the ship roll information are in good agreement.
5. Conclusion
This article describes the basic method of ship-rocking isolation of the shipborne radar servo control system. Combining the isolation test results and accuracy requirements, the gyro use strategy in the tracking mode of the servo control system is given. At the same time, given that there is no backup of the feedforward gyro, the gyro output is abnormal. In this case, this paper optimizes the design of the state monitoring of the feedforward gyro output. By comparing the ship’s roll angular velocity data calculated by the ship’s roll feedforward data and the inertial navigation information, the feedforward output data is correct and the gyro feedforward is greatly improved. Reliability of compensation.

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