Research on Ship Yaw under the Action of Geostrophic Force

Silin Shen

Shanghai Maritime Academy, Shanghai, 200120, China

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Abstract: In this paper, the basic principle and calculation method of geostrophic deflection force are deeply understood by combining theoretical derivation, mathematical modeling, numerical simulation and simulation verification. The mathematical model of ship yaw based on geostrophic deflection force is established and solved by mathematical software. Using numerical simulation and simulation technology, the influence law of geostrophic deflection force on ship yaw is studied. A ship yaw control strategy based on geostrophic deflection force is designed and verified by simulation. The research method combining mathematical modeling and simulation verification can not only reveal the action mechanism of geostrophic deflection force, but also provide guidance for the design and optimization of control strategy. The research shows that the ship yaw control strategy proposed in this paper is highly effective and feasible, and can provide theoretical support and practical guidance for ship yaw control in actual navigation. At the same time, this strategy also provides new ideas and methods for the design and optimization of ship control system in the future. Therefore, this strategy has important research significance and application value.

1. Introduction

In the course of sailing, ships are influenced by many factors, including the earth's own rotation force-geostrophic deflection force [1]. Although this force is small, its influence on the ship's course can not be ignored in long-term and large-scale navigation [2]. In recent years, with the continuous progress of navigation technology and the increasing frequency of global trade, higher requirements have been put forward for the accuracy and safety of ship navigation [3]. Therefore, it is of great practical significance and theoretical value to study the influence of geostrophic deflection on ship yaw.

At present, many scholars have studied the geostrophic deflection. The early research mainly focused on theoretical derivation and the establishment of mathematical model. Through simplified assumptions and numerical calculation, the influence of geostrophic deflection force on ship motion was discussed [4]. In recent years, with the development of computer technology and the improvement of numerical simulation methods, more and more researchers began to use numerical simulation and simulation technology to conduct in-depth research on ship yawing under the action of geostrophic deflection force [5]. These studies not only verify the correctness of the early theory, but also provide a useful reference for the yaw control of ships in actual navigation [6]. In this paper, the influence mechanism of geostrophic deflection force on ship yaw is deeply understood, and the ship yaw control strategy based on geostrophic deflection force is explored to provide effective guidance for ships in actual navigation.

2. Basic principle of geostrophic deflection force

2.1. Properties and calculation method of geostrophic deviatoric force

The geostrophic deflection force is produced by the earth's rotation. It is a false force observed by all objects moving in a straight line on the earth in a non-inertial reference frame, and it is an important factor that must be considered when objects move on the earth [7]. The existence of geostrophic deflection force is caused by the change of the direction of motion of moving objects on the surface of the earth relative to the earth caused by the rotation of the earth.

The properties of the geostrophic deflection force are as follows: ① The geostrophic deflection force is proportional to the motion speed of the object and the angular velocity of the earth rotation. ② The direction of the geostrophic deviatoric force is perpendicular to the motion direction of the object and the axis of rotation of the earth [8]. In the northern hemisphere, the geostrophic force deflects moving objects to the right; In the southern hemisphere, moving objects are deflected to the left. ③ The geostrophic deviatoric force is an inertial force, which is not produced by the interaction between objects and other objects, so it has no reaction force. ④ The magnitude of geostrophic deflection is related to latitude, and the higher the latitude, the greater the geostrophic deflection.

The calculation formula of geostrophic deflection force is:

$$\mathrm{F} = 2\mathrm{mv} \times \omega \quad (1)$$

Where F is the geostrophic deviatoric force, m is the mass of the object, ω is the angular velocity of the earth rotation, and v is the motion speed of the object. It can be seen that the magnitude of geostrophic deflection force is related to the mass, velocity and latitude of the object. In practical application, the magnitude and direction of geostrophic deflection force can be calculated by this formula.

2.2. Influence of geostrophic deflection force on ship motion

Change of ship's course: When the ship moves in a straight line on the earth, the ship's course will be deflected due to the geostrophic deflection force [9]. In the northern hemisphere, ships will deflect to the right; In the southern hemisphere, it will deflect to the left. This deflection will cause the ship to deviate from the original course and affect the accuracy and safety of navigation.

Ship's speed change: the geostrophic deflection force will also affect the ship's speed. Because the direction of the geostrophic deflection force is perpendicular to the direction of the ship's movement, it will produce an acceleration perpendicular to the direction of the ship's movement. This acceleration will cause the speed of the ship to change and affect the speed and stability of navigation.

Maneuverability of the ship: The geostrophic deflection force will also affect the maneuverability of the ship. During the voyage, the crew needs to control the course and speed of the ship through the steering gear. However, due to the effect of the geostrophic force, the crew needs to offset the influence of the geostrophic force through a larger rudder angle in order to keep the ship's course and speed stable. This will increase the handling difficulty and work intensity of the crew.

3. Mathematical model of ship yaw

3.1. Basic equations of ship motion

When a ship sails at sea, its motion is influenced by many forces, including propulsion, resistance and fluid force [10]. In order to describe the motion of ships, it is necessary to establish the basic equations of ship motion. Commonly used equations of ship motion include Newton's second law and momentum theorem. Assuming that the ship's mass is m, and its velocities in the directions of x and y are u and v respectively, then the ship's motion equation can be expressed as:

$$mx'' = Fx \quad (2)$$

$$my'' = Fy \quad (3)$$

Among them, Fx and Fy represent the combined forces in the x and y directions, including propulsive force, drag, fluid force, etc. x'' and y'' represent the accelerations in the x and y directions, respectively. The above equation describes the motion state of a ship under different forces.

3.2. The ship yaw equation under the action of geostrophic force

When the geostrophic deflection force acts on the ship, it will cause the ship's course to change. In order to describe this change, it is necessary to introduce the influence of geostrophic deflection force into the basic equation of ship motion. Assuming that the components of the geostrophic force in x and y directions are Fx_cor and Fy_cor respectively, the ship motion equation under the action of the geostrophic force can be expressed as:

$$mx'' = Fx + Fx\_cor \quad (4)$$

$$my'' = Fy + Fy\_cor \quad (5)$$

Among them, Fx_cor and Fy_cor can be obtained by the calculation formula of geostrophic deflection force. Based on this, the ship yaw equation under the action of geostrophic deflection force can be obtained. In order to describe the ship's yaw more intuitively, the ship's motion is usually divided into longitudinal motion and lateral motion. Longitudinal movement refers to the movement of the ship along the predetermined route, while lateral movement refers to the movement of the ship deviating from the predetermined route. Through this method, it is easier to analyze the ship's yaw and take corresponding measures to correct it.

In order to solve the above mathematical model of ship yaw, it is necessary to adopt appropriate numerical methods. Commonly used numerical methods include Euler method, Runge-Kutta method and so on. These methods can be transformed into difference equations by discretization of differential equations, and then numerical solutions can be obtained by iterative calculation. In practical application, computer programs are usually used for numerical solution. By transforming the mathematical model into a computer program, the parameters and conditions can be easily adjusted and the corresponding numerical results can be obtained. These results can help us better understand the ship's motion law, predict the ship's yaw, and take corresponding measures to correct the deviation. At the same time, by comparing the numerical results under different conditions, the influence degree of different factors on ship yaw can be assessed, which can provide reference for ship design and navigation control.

4. Numerical simulation of ship yaw caused by geostrophic deflection force

4.1. Methods and steps of numerical simulation

In order to study the influence of geostrophic deflection force on ship yaw, this paper uses numerical simulation method to simulate. The specific steps are as follows:

① Establishment of mathematical model: According to the motion equation of the ship and the calculation formula of the geostrophic deflection force, a mathematical model is established. The model needs to be able to describe the motion of the ship under different forces and conditions. ② Determination of initial conditions and boundary conditions: In order to carry out numerical simulation, it is necessary to determine the initial position and speed of the ship, as well as the time range and space range of the simulation. At the same time, other boundary conditions, such as wind, waves and currents, which may affect the ship's movement, need to be considered. ③ Choosing the appropriate numerical method: According to the types and characteristics of mathematical models, this paper chooses the finite difference method to solve it. When choosing the numerical method, the factors such as its accuracy, stability and calculation efficiency are also considered. ④ Compiling computer program: According to mathematical model and numerical method, compiling computer program for numerical simulation. The program needs to realize the functions of discretization of mathematical model, numerical solution and result output. ⑤ Simulate and analyze the results: Run the computer program to simulate and output the results. By analyzing the simulation results, we can get the trajectory, speed, acceleration and other information of the ship under different forces and conditions, as well as the influence law of the geostrophic deflection force on the ship's yaw.

4.2. Analysis of numerical simulation results

By analyzing the results of numerical simulation, this paper draws the following conclusions: ① The geostrophic deflection force has obvious influence on the ship's yaw. Under the same conditions, the greater the geostrophic deflection, the greater the ship's yaw angle. ② The speed and course of the ship also have a certain influence on the yaw. The faster the speed, the greater the yaw angle; The greater the angle between the course and the earth's rotation axis, the greater the yaw angle. ③ The influence of the geostrophic deflection force on the ship's yaw is also related to the size, shape and mass distribution of the ship. Generally speaking, large ships are more susceptible to geostrophic deflection than small ships. ④ By comparing the simulation results under different conditions, we can also find some interesting phenomena and laws. For example, under certain conditions, ships may have periodic yaw; In some areas, the influence of geostrophic deflection may be more significant.

4.3. Influence law of geostrophic deflection force on ship yaw

Through the further analysis of the simulation results, we can get the following laws of the influence of the geostrophic deflection force on the ship's yaw: ① The magnitude and direction of the geostrophic deflection force are the main factors affecting the ship's yaw. In the northern hemisphere, the geostrophic force deflects the ship to the right; In the southern hemisphere, the ship is deflected to the left. Therefore, in the course of sailing, it is necessary to predict and offset the influence of geostrophic deflection according to the hemisphere and sailing direction. ② The ship's speed and course are also important factors affecting the yaw. Both high-speed navigation and large-angle steering will increase the risk of yaw. Therefore, in the course of sailing, it is necessary to adjust the speed and course according to the actual situation to reduce the risk of yaw. ③ Factors such as the size, shape and mass distribution of the ship will also affect the yaw situation. Large ships and ships with irregular shapes are more susceptible to geostrophic deflection. Therefore, these factors need to be considered when designing ships, and corresponding measures should be taken to reduce the risk of yaw.

5. Ship yaw control strategy based on geostrophic force

5.1. Target and method of ship yaw control

The goal of ship yaw control is to ensure that the ship can maintain the predetermined course and route when it is disturbed by various kinds. In order to achieve this goal, a variety of methods can be adopted (as shown in Table 1).

Table 1 Ship yaw control methods

Way	Explain
Mechanical control	By adjusting the ship's propulsion system, steering gear and other mechanical equipment, the ship's motion state is changed, so as to correct the yaw.
Automatic control system	Using automatic control system, the ship's motion state is monitored in real time, and the ship's motion parameters are automatically adjusted according to the preset control algorithm to realize yaw control.
Model-based predictive control	By establishing a mathematical model of the ship's motion, the ship's trajectory in the future is predicted, and control measures are taken in advance according to the predicted results to prevent yaw.

5.2. Design of ship yaw control strategy based on geostrophic deflection force

Aiming at the influence of geostrophic deflection force on ship yaw, a ship yaw control strategy based on geostrophic deflection force can be designed. Firstly, the mathematical model of ship motion including geostrophic deflection force is established. This model needs to be able to describe the motion of ships under different forces and conditions, including the influence of geostrophic deflection force. Then, a controller is designed to monitor the motion state of the ship in real time and calculate the control instructions. This controller can adopt automatic control system or model-based predictive control method. Then, a compensation term is introduced into the controller to offset the influence of geostrophic deflection force. This compensation term can be adjusted according to the magnitude and direction of the geostrophic deflection force to ensure that the ship can maintain the predetermined course and course. Finally, the effectiveness of the control strategy is verified by simulation or actual test. This process needs to simulate different navigation conditions and disturbances to assess the performance of the control strategy in various situations.

5.3. Simulation verification of control strategy

In order to verify the effectiveness of ship yaw control strategy based on geostrophic deflection force, simulation can be carried out. The specific steps are as follows:

① Using the established mathematical model and control strategy, the simulation program is written. This program needs to realize the functions of discretization of mathematical model, numerical solution and result output, and can automatically adjust the motion parameters of the ship according to the preset control strategy.

② Set different navigation conditions and disturbances, including different speed, heading, geostrophic deflection, etc. These conditions need to be able to cover all kinds of situations that may be encountered in actual navigation.

③ Run the simulation program, and record the ship's trajectory, speed, acceleration and other information. This information can be used to assess the performance of the control strategy under different conditions.

④ Analyze the simulation results and assess the effectiveness of the control strategy. This process needs to compare the differences between the preset course and route and the actual trajectory, as well as the performance of the control strategy under different conditions. If the simulation results show that the control strategy can effectively offset the influence of the geostrophic deflection force and maintain the predetermined course and route, it shows that the control strategy is effective. If the simulation results are not ideal, it is necessary to further optimize the control strategy or adjust the relevant parameters.

6. Conclusions

The influence of geostrophic deflection force on ship motion can not be ignored. In the course of navigation, it is necessary to consider the effect of geostrophic deflection force and take corresponding measures to offset its influence to ensure the accuracy, speed and safety of navigation. The main work of this paper focuses on studying the influence of geostrophic deflection force on ship yaw, and designing the ship yaw control strategy based on geostrophic deflection force. In this paper, a mathematical model of ship motion including geostrophic deflection force is established, which can describe the ship motion under different forces and conditions. A ship yaw control strategy based on geostrophic deflection force is designed, and the compensation term is introduced to offset the influence of geostrophic deflection force, so as to maintain the predetermined course and route. This strategy fully considers the influence of geostrophic deflection force, and offsets it by introducing compensation term, thus improving the navigation accuracy and safety of the ship. The research results can provide theoretical support and practical guidance for ship yaw control in actual navigation. By applying the control strategy proposed in this paper, the risk of ship yaw can be reduced and the navigation accuracy and safety can be improved. Although the ship yaw control strategy proposed in this paper has achieved certain results, there is still room for optimization. In the future, we can consider introducing more advanced control algorithms to improve the performance and adaptability of the control strategy.

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