Ship Maneuvering Performance Prediction Based on MMG Model

Yu Xia, Shutao Zheng, Yu Yang and Zhiyong Qu
Department of Mechatronics Engineering, Harbin Institute of Technology, Harbin 150001, China

*Corresponding author e-mail: Zhengst77@hit.edu.cn, *xiayuyui@163.com, yangyu@fทย2010.com, quzhiyong@fทย2010.com

Abstract. This paper expounds mathematical model and computer simulation of ship maneuvering, and use MMG's manipulation of motion mathematic model and related series of experimental results as the foundation, establish the basic model of ship maneuvering movement. Building a simulation model in MATLAB, and carry out simulation experiments on ship maneuvering motion. The simulation results are basically in line with the actual situation.

1. Introduction
As a tool for water transportation, the ship's safety and economy are the most important and most interesting features as other transportation vehicles [1]. Ship maneuverability is an important performance of safe navigation of ships, and it has a very important impact on shipping safety [2]. The main aspect of ship maneuverability research is the ship's ability to maintain and change its speed, heading and position, which is closely related to the safety and economy of navigation.

The ship's maneuverability forecast is based on the ship's maneuverability parameters calculated from the ship's (including propeller and rudder) parameters at the initial design stage of the ship, enabling the designer to have a quantitative indicator of ship maneuverability [3]. To judge the ship's handling performance, this is also one of the main purposes of ship maneuverability research.

2. Mathematical model of ship maneuvering motion
The MMG model only considers the horizontal maneuvering motion of the ship on the hydrostatic surface, assuming that the ship is sailing in infinitely deep waters [4]. The ship motion coordinate system is based on the ship's center of gravity as the coordinate origin, with the bow direction as the x-axis positive axis, the ship starboard as the y-axis positive axis, the vertical axis perpendicular to the center of gravity as the z-axis, and the z-axis forward pointing to the ship's keel [5], As shown in Fig. 1.
The mathematical model of ship motion is mainly based on the second law of Newtonian motion and the conservation of momentum. The separation model represented by Japan MMG is used to model the ship, propeller and rudder as separate research objects, establish a basic mathematical model of ship motion as in Eq. 1.

\[
\begin{align*}
\text{m}(\dot{u} - vr + wq) &= X \\
\text{m}(\dot{v} - wp + ur) &= Y \\
l_x \ddot{\phi} + (l_z - l_y)qr &= K \\
l_z \ddot{\psi} + (l_y - l_x)pq &= N
\end{align*}
\]

(1)

In Eq. 1, X and Y represent the sum of the external forces received by the ship on the x-axis and the y-axis. Jx, Jy and Jz represent the inertia tensor of the ship, and K and N represent the sum of external torques.

3. Calculation of forces and torques

According to the MMG method, the forces and torques the ship receives in still water mainly include: hull force and torque, propeller force and torque, rudder force and rudder torque. According to the previous studies, scholars have obtained empirical expressions of the force exerted by the ship in still water through a large number of actual ship experiments, as shown in the following Eq. 2, Eq. 3, and Eq. 4.

\[
\begin{align*}
X_H &= X_{uu}u^2 + X_{uv}v^2 + X_{uv}vr + X_{rr}r^2 \\
Y_H &= Y_v v + Y_r r + Y_{vr}vr + Y_{rr}r^2 \\
K_H &= -2K_{\phi} \ddot{\phi} - \Delta \cdot GM \cdot \phi - Y_H \cdot z_H \\
N_H &= N_v v + N_r r + N_{vr}vr + N_{rr}r^2 + N_{vr}vr + N_{rr}r^2 \\
X_p &= (1 - t_p) \rho n^2 D_p^4 K_T (f_p) \\
X_P &= (1 - t_p) \rho n^2 D_p^4 K_Q (f_p) \\
X_R &= (1 - t_r) F_N \sin \delta \\
Y_R &= (1 + a_H) F_N \cos \delta \\
K_R &= -(1 + a_H) z_R F_N \cos \delta \\
N_R &= (x_R + a_H x_H) z_R F_N \cos \delta
\end{align*}
\]

(2)

(3)

(4)

Eq. 2 is the force and torque on the hull, Xuu…,Yu…,Kϕ, Nu… is the hydrodynamic derivative, Δ is the displacement, GM is the ship’s stable height, and zH is the z coordinate of the action point of YH.
Eq. 3 is the propeller force and torque on the hull, $t_p$ is the thrust derating coefficient, $n$ is the propeller speed, $D_p$ is the propeller diameter, $K_T$ is the thrust coefficient, $K_Q$ is the torque coefficient, and $f_p$ is the speed coefficient.

Eq. 4 is the rudder force and torque on the hull, $F_N$ is the positive pressure, $\delta$ is the rudder angle, $\epsilon_R$ is the derating factor, $\alpha_H$ is the correction factor, and $z_R$ is the vertical distance from the center of the rudder positive pressure to the center of gravity of the ship. $x_R$ is the longitudinal distance from the center of the rudder to the center of gravity of the ship, and $x_H$ is the longitudinal distance from the center of the steering force induced lateral force of the hull to the center of gravity of the ship.

4. Simulation of ship maneuvering motion in still water

According to the mathematical model, taking the displacement of 6000t cargo ship as an example, the total length of the ship is 11.7 m, the ship width is 20.5 m, the ship draught is 6.7 m, and the square coefficient of the ship is 0.694, and the displacement is 6860t.

4.1. Cycle test

The left and right cycles were tested at an initial speed of 15.9 knots and a rudder angle of 35° and -35°. The trajectory is shown in Fig. 2 and Fig. 4. The heel angle during the left and right turn is shown in Fig. 3 and Fig. 5.

According to the requirements of the maneuverability of the ship in the resolution of the Maritime Safety Committee MSC.137 (76). When the rotary ring is operated, the longitudinal distance shall not exceed 4.5 times the length of the ship, and the diameter of the rotating ring shall not exceed 5 times the length of the ship. According to Fig. 2 and Fig. 4, the simulation results show that the longitudinal
The distance is less than 3.5 times the length of the ship, and the diameter of the rotating circle is less than 4 times the length of the ship, which satisfies the requirements of the turning capacity.

4.2. Z-type manipulation test Cycle test

Fig. 6 is the simulation result of the left 10°/10°Z type maneuver test of the ship, and Fig. 7 is the simulation result of the right 10°/10°Z type maneuver test of the ship.

![Figure 6. Left Z-type manipulation test.](image1)

![Figure 7. Right Z-type manipulation test.](image2)

According to the yaw correction and heading stability requirements of the Maritime Safety Committee Resolution MSC.137(76), in the 10°/10°Z type maneuver test, the first overshoot angle should not exceed 10°, the second overshoot angle The value should not exceed 25°. From Fig. 6, it can be seen that in the simulation test, the first Z angle test has a first overshoot angle of less than 10° and a second overshoot angle of less than 10°. From Fig. 7, it can be seen that in the simulation test, the first Z angle test has a first overshoot angle of less than 10° and a second overshoot angle of less than 10°. Both can meet the required capabilities.

5. Conclusion

In this paper, the MMG separation modelling method is used to calculate the force of the hull, paddle and rudder, the model has clear physical meaning. A four-degree-of-freedom ship motion simulation model is established to calculate the motion state of the ship. Using the model for operational prediction experiments, it is proved that the slewing ability and yaw correction and heading stability ability meet the requirements, and the rationality of the mathematical model is verified.

Acknowledgments

This work was financially supported by Science and Technology Project of Heilongjiang (No. GC13A415).

References

[1] Shin D, Hong J H, Park C W, et al. Ship motion simulation using stewart platform [J]. 한국정밀공학회 학술 발표대회 논문집, 2017.

[2] Zhang R. The study of 6-DOF motion simulation platform for passenger ship [C]// International Conference on Mechatronics, Materials, Chemistry and Computer Engineering. 2017.

[3] Zhang X K, Yuan-Kui L I. Prediction of Ship Maneuverability Indices [J]. Navigation of China, 2009, 32 (1): 96-101.

[4] Guo H P, Zou Z J. System-based investigation on 4-DOF ship maneuvering with hydrodynamic derivatives determined by RANS simulation of captive model tests [J]. Applied Ocean Research, 2017, 68: 11-25.

[5] Wang C, Li X, Wang Q. Study on Positioning Method of Submarine Control Point Based on Ship-fixed Coordinate System [J]. Site Investigation Science & Technology, 2014.