Research on Viscous Hydrodynamic Calculation and Motion Prediction of Hybrid-monohull

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Abstract—Hybrid-monohull is a kind of high performance ship which has perfect seakeeping performance and equivalent resistance in calm water of round bilge ships, and its most feature is the built-up longitudinal-stabilizing appendage fixed on the bottom of bow. In this paper the hydro-coefficients of bow where built-up appendage is fixed will be calculated using 2-D and 3-D viscous numerical methods. RANS method is used and the influence of free surface is calculated using VOF method. And RANS method is also used for calculating the lifting damp of built-up appendage. The hydro-coefficients calculated by potential method will be modified by viscous results, and then is put into the motion equations of ship. The calculated results indicate that the method used in this paper can reflect the reducing effect obviously, and the precision of prediction is much more improved.

Keywords- hybrid-monohull; hydrodynamics; seakeeping performance; viscous damp; motion prediction

I. INTRODUCTION

Hybrid monohull means to set a leading-edge linear semi-submersible body at the bottom of the ship, to install a pair of delta wings on both sides of the semi-submersible body and to move longitudinally with viscous damping generated by combination of appendage and dynamic lift damping that restrain the ship body. It is confirmed by the theory research, the model test and the ship experiment research that the environmental suitability of hybrid monohull is outstanding, which can sail quickly and smoothly in gale and rough sea ^{[1][2]}

Research result indicates that microtomy that adopts potential flow theory is unable to reflect anti-rolling effect of motion prediction of hybrid monohull, since potential flow theory ignores viscosity, viscous damping has nonlinear characteristics and viscous damping plays an important role in anti-rolling effect of appendage combination, thus viscosity must be corrected in the process of motion prediction ^{[3][4]}. This article adopts RANS to calculate hydrodynamic coefficient of two dimensional ship section and three dimensional ship bow with combination of appendage whilst also adopting

RANS to calculate combination possessed dynamic lift damping. Correct the result of potential water power coefficient with viscous flow calculation result and plug it into motion equation for obtaining the answer. The result shows that prediction method based on plastic flow power could perfectly reflect the anti-rolling effect of hybrid monohull, which greatly increases the prediction accuracy.

II. ADOPT RANS TO CALCULATE THE HYDRODYNAMIC COEFFICIENTS OF TWO-DIMENSIONAL OBJECTS

Based on two-dimension RANS equation, calculate when two-dimension section is seen as the radiation power of simple harmonic heaving oscillation. Use the finite volume method to disperse fluid area, which is divided into two parts: water and air. The free surface applies VOF means to dispose, the turbulence model uses RNG-K- ϵ model and the grid employs unstructured grid. The drainage area approximately takes 10 times of beam $\times$ 10 times of draught. Infill the grid around the free surface, combining dynamic mesh technique. The prelude section of hybrid monohull is shown as Graph 1 and division of watershed refers to Graph 2.

Figure 1. Sections of hybrid monohull bow

Figure 2. Grids of calculation field for bow sections

Calculate and get vertical special anchoring force F . Get added mass and damping coefficient after separation. The calculation equation is as follows:

$$\mu_{33} = \frac{\rho g B A - F_a \sin \theta_0}{A \omega^2}, \quad \lambda_{33} = -\frac{F_a \cos \theta_0}{A \omega} \quad (1)$$

In Equation (1) ρ , g , B , A , and ω are all known, so just by segregating F_a and the sum θ_0 from the vertical special anchoring force F calculated, we can get heaving added mass μ_{33} and damping coefficient λ_{33} .

This paper calculates some 425-ton-weighted hybrid monohull's HYDRODYNAMIC coefficient when its prelude section is forced to slightly vibrate, and the ship body's principal dimension refers to Table 1. Compound ship type's first part is divided into 10 sections, among which there are two kinds of sections: one with semi-submersible body and the other with semi-submersible body and fin, as shown in Table 3, you can see the calculation results of third stop section with semi-submersible body considering vertical force when $\omega_e = 2.6$.

TABLE1 PARAMETERS OF THE BOAT

signed displacement	425t	designed waterline length	60m
designwaterline breadth	6.92m	Designed Draft	2.25m

Figure 3. Vertical force of the bow section

Get all sections' HYDRODYNAMIC coefficient by separation of calculation's vertical force based on Equation (1), compare it with potential flow's calculation findings, and the potential flow's calculation uses source-sink distribution method [5]. As shown in Graph4-5, there

are the heaving added mass coefficient μ_{33} and heaving damping coefficient λ_{33} . B is the width of every ship body's section and D refers to draught. It is proved necessary to make amendment of viscosity on built-up stabilizing appendage given the calculation results.

III. THE CALCULATION OF THREE-DIMENSIONAL STEM SWAYING HYDRODYNAMIC COEFFICIENT

Currently, there is certain difficulty to calculate the swaying HYDRODYNAMIC coefficient when the entire ship has free surfaces by applying the three-dimensional RANS method. First of all, there has to be big enough watershed for the entire ship to make the mesh faces become enormous, and apply the VOF method infilling meshes around the free surfaces so as to make mesh faces further increase; In addition, the dynamic mesh technique applied in swaying has high requests on the mesh division around ship body. Therefore, direct calculation of the whole ship's HYDRODYNAMIC coefficient requires a huge amount of calculation times, and the calculation process can be easily diffused.

(a) Added mass

(b) Damping coefficient

Figure 4. Added mass and damping coefficient of section 4/3

(a) Added mass

Figure 5. Added mass and damping coefficient of section 2

This paper tries to calculate the hydrodynamic coefficient when hybrid monohull's part under the waterline of the prelude is put in unbounded flow and slightly sways. At the same time, it calculates the hydrodynamic coefficient when bare hull's corresponding part under the waterline is put in unbounded flow and slightly vibrates, then by subtracting the HYDRODYNAMIC coefficients we get above, we can have correction of hybrid monohull compared to bare hull's hydrodynamic coefficient. Following is the calculated result of hydrodynamic coefficient of the bow of compound ship type of naked hull and additionally installed combination appendage.

Figure 6. Vertical force of heaving section

Figure 7. Moment around gravity center of heaving section

Set amplitude of pitching and heaving A , initial phase θ_0 , amplitude of vertical unsteady force caused by slight heaving F_{a33} , amplitude of vertical unsteady force caused by slight pitching F_{a53} , amplitude of torque of

steering around gravity caused by slight heaving M_{a35} , amplitude of torque of steering around gravity caused by slight pitching M_{a55} . Corresponding hydrodynamic coefficient can be gained when force and torque are obtained by calculation:

$$\begin{aligned} a_{33} &= \frac{-F_{a33} \sin \theta_0}{A\omega^2}, & b_{33} &= -\frac{F_{a33} \cos \theta_0}{A\omega} \\ a_{53} &= \frac{-F_{a53} \sin \theta_0}{A\omega^2}, & b_{53} &= -\frac{F_{a53} \cos \theta_0}{A\omega} \\ a_{35} &= \frac{-M_{a35} \sin \theta_0}{A\omega^2}, & b_{35} &= -\frac{M_{a35} \cos \theta_0}{A\omega} \\ a_{55} &= \frac{-M_{a55} \sin \theta_0}{A\omega^2}, & b_{55} &= -\frac{M_{a55} \cos \theta_0}{A\omega} \end{aligned} \quad (2)$$

According to the calculation of the above formula, the bow of hybrid monohull doesn't conform to the hydrodynamic coefficient when the section of monomer ship bow makes slight heaving and slight pitching.

Figure 8. Coefficients of the hull and hybrid monohull bows

From above calculated result, we can know that the added weight and damping coefficient both have big changes after the anti-pitching combination appendage is additionally installed on regular monomer ship bow. After the combination appendage is added, added mass of heaving and damping coefficient both increase, and added mass of heaving and pitching coupling and damping coefficient both decrease; added mass of pitching and damping coefficient both increase, and added mass of pitching while heaving coupling and damping coefficient both decrease. We can get the hydrodynamic correction coefficient by subtracting the hydrodynamic coefficient of the bow of compound ship type and that of the bow of naked hull: $A_{33}^*, B_{33}^*, A_{35}^*, B_{35}^*, A_{55}^*, B_{55}^*, A_{53}^*, B_{53}^*$

IV. CALCULATION OF LIFT COEFFICIENT OF COMBINATION APPENDAGE

The following calculation is dynamic lift correction coefficient of combination appendage. Dynamic lift correction coefficient of combination appendage can be calculated, of which RANS is adopted to calculate life coefficient $B_{33}^f, B_{35}^f, C_{35}^f, B_{55}^f, B_{53}^f, C_{55}^f, F_{fv}, M_{fv}$ of combination appendage and combination appendage is calculated in infinite flow. The calculated result is as shown in Graph 10. Derivative of lift coefficient to angle of attack is 1.4 by calculation.

Figure 9. Sketch of built-up appendage

Figure 10. Lift coefficients of built-up appendage

V. PREDICTED RESULT OF MOTION

By putting viscous hydrodynamic correction coefficient of combination appendage and dynamic lift correction coefficient of combination appendage obtained through calculation into the motion equation, we can get:

$$\begin{cases} (M + A_{33} + A_{33}^*)\ddot{Z} + (B_{33} + B_{33}^f + B_{33}^*)\dot{Z} + C_{33}Z + (A_{35} + A_{35}^*)\ddot{\theta} \\ + (B_{35} + B_{35}^f + B_{35}^*)\dot{\theta} + (C_{35} + C_{35}^f)\theta = [F_3 - F_{fv}]e^{-j\omega_e t} \\ (I_\theta + A_{55} + A_{55}^*)\ddot{\theta} + (B_{55} + B_{55}^f + B_{55}^*)\dot{\theta} + (C_{55} + C_{55}^f)\theta + (A_{53} + A_{53}^*)\ddot{Z} \\ + (B_{53} + B_{53}^f + B_{53}^*)\dot{Z} + C_{53}Z = [F_5 - M_{fv}]e^{-j\omega_e t} \end{cases} \quad (3)$$

By solving the above equation, we can get motion response of the ship hull. This paper has respectively given the predicted result of horizontal motion of 425-ton basic ship and additionally installed combination appendage ship by adopting potential flow theory, two-dimension viscous correction and three-dimension viscous correction. Corresponding ship of the sailing speed is 24kn, $Fn = 0.382$. And the calculated result has been compared with the test value [6]. The result is as shown from Graph 11 to Graph 13.

(a) 2-D

Figure 11. Pitching respons results of different methods

Figure 12. Heaving respons results of different methods

Figure 13. Bow acceleration results of different methods

VI. CONCLUSIONS

This paper has calculated viscous hydrodynamic correction coefficient of the bow of compound ship by adopting two-dimension and three-dimension RANS method respectively, and the dynamic lift correction coefficient of combination appendage. The correction coefficient obtained has been put into the motion equation for motion prediction. The result has shown that the method of getting the hydrodynamic correction coefficient of hybrid monohull is workable based on the calculation by the way of RANS in horizontal motion prediction of hybrid monohull.

By comparing the predicted result of motion with the model test result, we can know that the difference of predicted result by the two-dimension method and three-dimension method is little, and the predicted anti-pitching effect by the three-dimension method is a bit big, which has something to do with consideration of the ship hull's three-dimension effect. All in all, the method of motion prediction on the basis of viscous correction adopted by this paper can make predictions of horizontal motion function of hybrid monohull effectively.

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