

Research on the Bow Thruster of Large Ship

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Abstract. Based on the 10,000 TEU container ship, the paper makes a research on the characteristics of the bow thruster. According to the open-water propeller characteristic chart of controllable pitch propeller, the paper analyzes the lateral thrust of the bow thruster combining with the data of real ship, builds the bow thruster's mathematical model and simulation model based on MATLAB/Simulink. The Simulation of thrust and torque of the bow thruster, as well the parameter of the propulsion motor is achieved, it is proved the model is correct, and the model could be used to provide theoretical support for improving the maneuverability of a large ship at low speed.

Introduction

The maneuverability performance is extremely important for a large ship. With the rapid development of science and technology, the volume of the container ship increases rapidly. While the large volume and big tonnage make it very hard to control the large container ship when coming in and out of the port, or in the turning operation, so the tugs are necessary when the large container ship is in the maneuvering condition. If the thruster is installed on the bow side of the ship, this kind of problem can be solved effectively [1]. The position of the bow thruster is shown in the Figure 1.

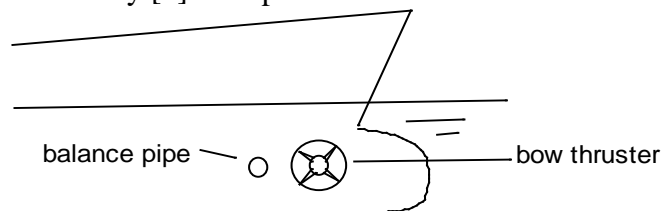


Fig.1. Bow Thruster

In addition, safety operation must be taken into consideration for such large vessels. Because of the power bottleneck of the low voltage generator, the low voltage power system cannot meet the needs of the large vessels. So nowadays the standard configuration for large container ship is 6600V high voltage power system. In order to provide theoretical support for improving the maneuverability of a large ship at low speed, the paper analyzes the lateral thrust of the bow thruster combining with the data of real ship, builds the bow thruster's mathematical model and simulation model based on marine high voltage power system of the 10,000 TEU container ship.

Mathematical model of the bow thruster

The movement between the propeller and seawater relatives to two aspects, one is the translational speed v_p , the other is the revolving speed n_p [2]. Because of the interaction between the propeller and seawater, there will be a thrust T_p and a driving torque M_p from the propeller. According to the working principle of the propeller, the formula of T_p and M_p are as follows:

$$T_p = K_T \cdot \rho \cdot n_p^2 \cdot D^4 \quad (1)$$

$$M_p = K_Q \cdot \rho \cdot n_p^2 \cdot D^5 \quad (2)$$

K_T is the thrust coefficient, it is determined by the pitch angle θ and the speed ratio J ; K_Q is the torque coefficient, it is also determined by the pitch angle θ and the speed ratio J ; ρ is the density of seawater; n_p is the speed of propeller, and its unit is rpm; D is the maximum diameter of the

controllable pitch propeller.

If the pitch angle θ and speed ratio J are known, the thrust coefficient K_T and torque coefficient K_Q can be searched from the propeller open water characteristic curve[3].

The speed ratio of the controllable pitch propeller J can be expressed as:

$$J = \frac{v_j}{n_p \cdot D} \quad (3)$$

v_j is the speed of advance of the propeller.

If the running time of the bow thruster is T , the forward velocity v_p is equal to the integral of the acceleration. Combined with the Newton's second law, v_p can be calculated as:

$$v_j = \frac{\int_0^T (T_p - T_z) dt}{M} \quad (4)$$

T_z is the resistance of the propeller, M is the tonnage of the ship.

Combined with the formula (1), (3) and (4), speed ratio J can be calculated regards to the time t and the pitch angle θ .

$$J = \frac{v_j}{n_p \cdot D} = \frac{\int_0^T (T_p - T_z) dt}{M \cdot n_p \cdot D} = \frac{\int_0^T T_p dt - T_z dt}{M \cdot n_p \cdot D} \quad (5)$$

When the propeller of the thruster begins to run, water will come into the balance pipe, and come out off from the ship at a certain velocity from the other side, therefore the thrust is produced[4]. According to the theorem of momentum, the thrust force acting on the water is equal to the rate of change of the flow momentum, so the thrust from the bow thruster is approximate equal to the counter-acting force of the water to the thruster[5]. And the speed of the water in the balance pipe is approximate equal to the speed of advance of the propeller.

In order to simplify the analysis, the two points are assumed[6]: 1.The water within the thruster is an ideal fluid, and the pressure acting on the propeller disk is uniform distribution; 2.The speed of the ship is zero.

According to the theorem of momentum, when the bow thruster is running, the momentum of the water in the balance pipe can be expressed as:

$$m \cdot v_j = t \cdot \rho \cdot Q \cdot v_j \quad (6)$$

m is the mass of the water passing through the balance pipe, Q is the flow quantity of the water. Assuming that the area of the controllable pitch propeller is A_T , the flow quantity Q can be represented as:

$$Q = A_T \cdot v_j \quad (7)$$

According to the formula (6), the counter-acting force of the water to the thruster can be expressed as:

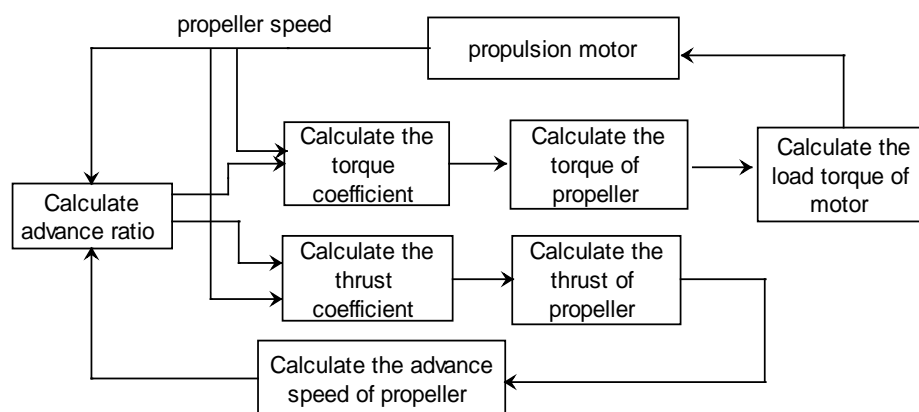
$$F = \frac{m \cdot v_j}{t} = \rho \cdot Q \cdot v_j \quad (8)$$

Combined with the formula (7) and (8), the lateral thrust acting on the ship can be calculated as follows:

$$F = \rho \cdot A_T \cdot v_j^2 \quad (9)$$

Simulation model of the bow thruster

Based on the mathematical model of the bow thruster, the simulation logical model is built, as shown in figure 2.



The three-phase asynchronous motor works as the propulsion motor, and the rated power of the propulsion motor is 2700kW, the rated voltage is 6600V, the tonnage of the ship is 115,776t, the diameter of the propeller is 2.85m, and the critical angle of the propeller pitch angle θ is 19.8°. Based on the mathematical model, simulation logical model, and the data of real ship, the simulation model of bow thruster is built by the tool of the MATLAB/Simulink, as shown in the figure 3.

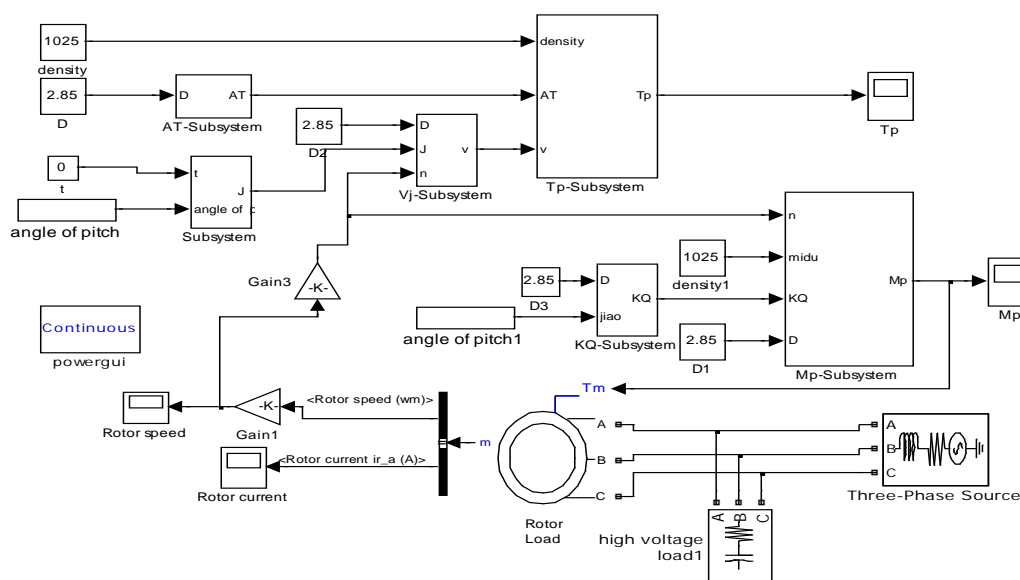
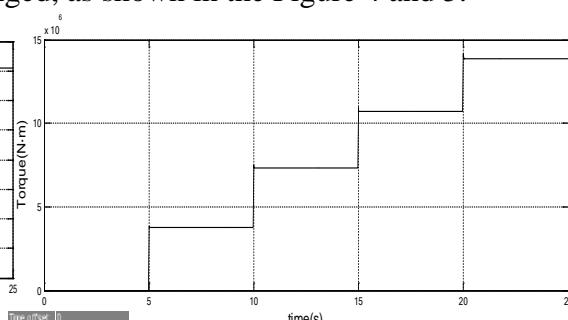
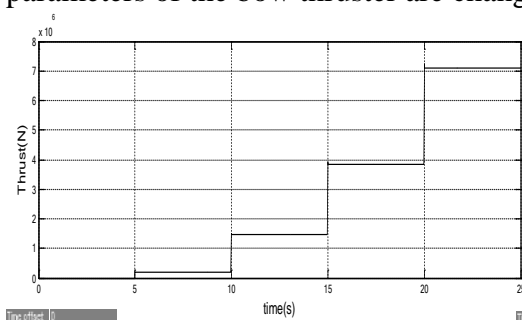


Fig.3. Simulation model of Bow Thruster

Results and analysis

When the simulation model is running, with the increase of propeller pitch angle θ , the different parameters of the bow thruster are changed, as shown in the Figure 4 and 5.



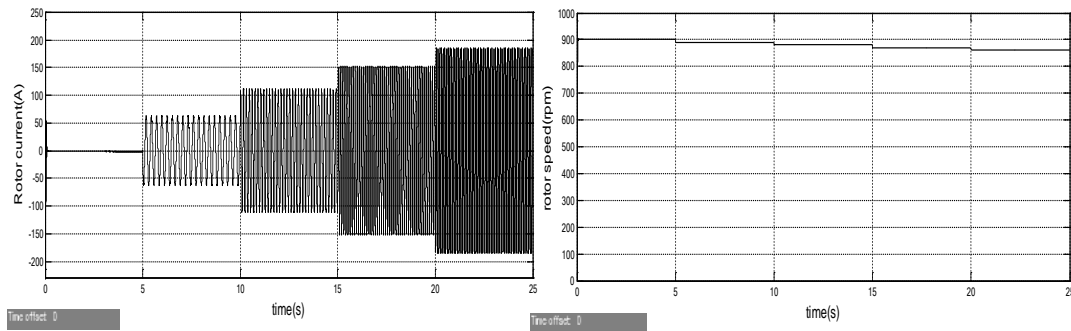


Fig.5(a). Rotor current

Fig.5(b). Rotor speed

Analyzing the four waveforms, when the propeller pitch angle θ changes from $0^\circ \rightarrow 5^\circ \rightarrow 10^\circ \rightarrow 15^\circ \rightarrow 19.8^\circ$, the thrust and torque of bow thruster increase with the pitch angle, as shown in the Figure 4; With the increase of load torque, the slip of the propulsion motor is increased, so the rotor current increases and the rotor speed decreases at every pitch angle θ , as shown Figure 5.

Conclusion

The simulation result shows that the thrust, torque, rotor current and speed of the bow thruster are changed with the propeller pitch angle θ , which is coincident with the real condition. It proves the mathematical model and the simulation model are correct, and the models could be used to provide theoretical support for improving the maneuverability of a large ship at low speed.

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