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Evaluation Method Research of Power of Main Engine for Polar Carrier

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ABSTRACT

In this paper, evaluation methods are established from theory to model test for polar carrier according to balance principle of resistance and thrust. The methods established above are verified for a polar carrier by conjunction with test results of ice resistance which come from the model test of ice tank. It is noted that the interaction between ice and propeller must be considered in the process of power estimation when the theory method is adopted by designer, and it mainly depends on experience of the designer. At the same time, the model test of low speed can also fulfill the requirement of the designer for the power evaluation of main engine in conventional towing tank. The evaluation results indicate that it is very effective to assess power of main engine by the theory and the model test, and it can supply reliable evaluation result for the designer.

KEY WORDS: Powering; Main engine; Theory evaluation; Model test; Polar carrier.

INTRODUCTION

The special requirement must be fulfilled for the polar carrier which voyage in the polar region and ice region. Firstly, the thruster of big power should be met to continuously break ice. Secondly, hull body can effectively resistant ice load. Thirdly, the equipment can adapt lower temperature at the polar region and ice region. So, it is very important for the polar carrier to evaluate power of main engine. However, it is very difficult to assess the power of main engine for the polar carrier. The first difficulty comes from reliability of ice resistance, the model test of ice tank is not suitable in the initial design phase thanks to time and cost, the numerical simulation is developed in recent years, and it needs to be demonstrated on reliability and stability of calculation by the model test, so, the empirical formulas are chosen by the designer in the initial design phase. Hyun-Soo kim (2014), Jian Hu (2015), Kyung-Duk Park (2014 & 2015), Seong-Rak Cho (2015), et al. study empirical formula and semi-empirical formula based on parameters of hull form. The research results show that some empirical formulas, such as Linqvist formula, Risk formula and Keinonen formula, can give reasonable results, but the obvious disadvantages are found in process of estimation thanks to limitation of ship parameters and sea ice conditions. The second difficulty comes from assessment of power of main engine based on ice resistance, and evaluation method for power of main engine is not published in any literature. At present, the direct estimation method of power of main engine in the ice class rules, such as RMRS (2010), CASPPR (2010) and ABS (2010), is suggested, but this method is not suitable for the polar carrier with high ice class condition. In view of mentioned above, it is necessary to develop a new method to evaluate power of main engine of polar carrier.

In this paper, the estimation methods of power of main engine are explored preliminarily based on ice resistance by the theory and the model test, respectively, and it is validated by the model test at ice tank for a polar carrier.

EVALUATION METHOD RESEARCH

Ice Resistance

Jungyong Wang (2011) gives the expression of ice resistance:

$$R_{ice} = C_{BR} S_N^{-\beta} \rho_i B h_i V^2 + C_B \Delta\rho g h_i BT + C_C F_h^{-a} \rho_i B h_i V^2 \text{ [kN]} \quad (1)$$

Where C_{BR} is icebreaking resistance coefficient, C_B is submersion resistance coefficient, C_C is sliding resistance coefficient. B is breath of ship at draught, T is draught, h_i is ice thickness, ρ_i is ice density, $\Delta\rho$ is density difference, g is gravity acceleration, V is ship speed. $S_N^{-\beta}$ is strength coefficient, F_h^{-a} is Froude number of ice thickness.

The ice resistance is influenced by the ship speed, ice thickness and flexural strength when the ship navigates in the polar region and ice region. It can be expressed quadratic polynomial equation between ice resistance and ship speed according to equation above when ice thickness and flexural strength are not changed in ice model test.

$$R_{ice} = a_0 + a_1 V_i + a_2 V_i^2 \text{ [kN]} \quad (2)$$

Where a_0 a_1 a_2 are polynomial coefficient, V_i is ship speed.

Stephen J. Jones (2005) gives nonlinear relationship between ice resistance and thickness with the growth of ice thickness when the ship speed and flexural strength are not changed, and the relationship can be expressed quadratic polynomial equation.

$$R_{ice} = b_0 + b_1 h_i + b_2 h_i^2 \text{ [kN]} \quad (3)$$

Where b_0 b_1 b_2 are polynomial coefficient, h_i is ice thickness.

Stephen J. Jones & Michael Lau (2005) give nonlinear relationship between ice resistance and flexural strength with the growth of flexural strength when the ship speed and ice thickness are not changed, and the relationship can be expressed quadratic polynomial equation.

$$R_{ice} = c_0 + c_1 \sigma_i + c_2 \sigma_i^2 \text{ [kN]} \quad (4)$$

Where c_0 c_1 c_2 are polynomial coefficient, σ_i is flexural strength of ice sheet.

Thruster Hydrodynamics

Theory Prediction of Thruster Hydrodynamics

The hydrodynamics of thruster in ice can be predicted by the lift surface and panel element methods.

It can be expressed higher degree relationship between thrust, torque and revolutions when the advance speed is not changed, as follows:

$$T = d_1 + d_2 N_s + d_3 N_s{}^2 + d_4 N_s{}^3 + d_5 N_s{}^4 \text{ [kN]} \tag{5}$$

$$Q = e_1 + e_2 N_s + e_3 N_s{}^2 + e_4 N_s{}^3 + e_5 N_s{}^4 \text{ [kN.m]} \tag{6}$$

Where $d_1\ d_2\ d_3\ d_4\ d_5\ e_1\ e_2\ e_3\ e_4\ e_5$ are biquadratic coefficient, N_S is propeller revolutions in full scale.

It must be considered for the suction effect of propeller and the interaction between ice and propeller when the thrust is used in the calculation for the power of main engine. The thrust deduction is used to assess thrust loss, and it depends on experience of the designer.

The net thrust of thruster in ice:

$$T_{net} = (1-t)T \text{ [kN]} \tag{7}$$

Where t is thrust deduction, T is total thrust.

Thruster Hydrodynamics behind the Ship in the Model Test

It can be expressed higher degree relationship between thrust, torque and revolutions when the ship speed is not changed in the model test, as follows:

$$T_{pm} = f_1 + f_2 N_m + f_3 N_m^2 + f_4 N_m^3 + f_5 N_m^4 \text{ [N]} \tag{8}$$

$$Q_m = g_1 + g_2 N_m + g_3 N_m^2 + g_4 N_m^3 + g_5 N_m^4 \text{ [N.m]} \tag{9}$$

Where T_{pm} is total thrust, Q_m is torque, N_m is revolution, $f_1\ f_2\ f_3\ f_4\ f_5\ g_1\ g_2\ g_3\ g_4\ g_5$ are biquadratic coefficient. The thrust deduction is expressed as:

$$t = 1 - \frac{T_{BPm}}{T_{Pm}} \tag{10}$$

Where T_{BPm} is bollard pull, T_{Pm} is thruster thrust.

Power Evaluation Based on Theory and Model Test

The revolutions of the propeller will be reduced when the work of main engine deviate the design point. It is very important to solve revolutions of propeller in ice.

Theory Assessment

According to balance of ice resistance and net thrust:

$$T_{net} = R_{ice} \text{ [kN]} \tag{11}$$

The following equation is acquired:

$$(1-t)(d_1+d_2N_s+d_3N_s{}^2+d_4N_s{}^3+d_5N_s{}^4)=a_0+a_1V_i+a_2V_i^2 \quad (12)$$

Or

$$(1-t)(d_1+d_2N_s+d_3N_s{}^2+d_4N_s{}^3+d_5N_s{}^4)=b_0+b_1h_i+b_2h_i^2 \quad (13)$$

Or

$$(1-t)(d_1+d_2N_s+d_3N_s{}^2+d_4N_s{}^3+d_5N_s{}^4)=c_0+c_1\sigma_i+c_2\sigma_i^2 \quad (14)$$

The EQ. (12), (13) and 14 are solved by the method of newton iteration to obtain revolutions of propeller in ice.

The delivered power is:

$$P_D=2\pi nQ\,[\mathrm{MW}] \quad (15)$$

Eq.(6) into Eq.(15):

$$P_D=2\pi n(e_1+e_2(N_s)\ +e_3(N_s)^2+e_4(N_s)^3+e_5(N_s)^4)\,[\mathrm{MW}] \quad (16)$$

The delivered power of thruster is obtained by actual propeller revolutions, and then the power of main engine is

$$P_{MCR}=\frac{P_D}{\eta_S}\,[\mathrm{MW}] \quad (17)$$

Where P_{MCR} is power of main engine, η_S is the shaft efficiency, this value is usually equal to 0.99 in calculation for the conventional ship.

Model Test Assessment at Low Speed Condition in Conventional Towing Tank

The bollard pull at full scale:

$$T_{BPs}=\frac{\rho_s}{\rho_m}\lambda^3T_{BPm}\,[\mathrm{kN}] \quad (18)$$

The torque at full scale:

$$Q_S=\frac{\rho_s}{\rho_m}\lambda^4Q_m\,[\mathrm{kN.m}] \quad (19)$$

The revolutions of propeller at full scale:

$$N_s=\frac{N_m}{\sqrt{\lambda}}\,[\mathrm{RPM}] \quad (20)$$

Where ρ_s is density of sea water, ρ_m is density of fresh water, λ is scale ratio, m denotes model, s denotes full scale.

The propeller revolutions and torque are acquired at work point in full scale according to balance of thrust and ice resistance. The delivered power of thruster at full scale is acquired by Eq.(15), and the power of main engine is acquired by Eq.(17).

EXAMPLE ANALYSIS

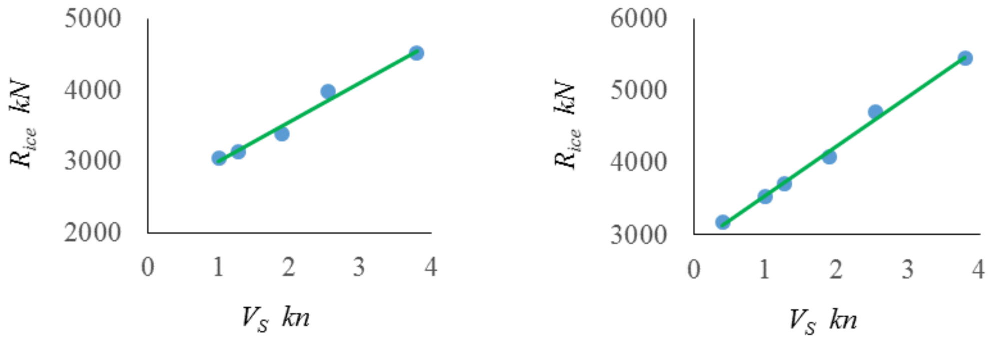
Solve Analysis Based on Theoretical Method

As an application, a polar carrier as a sample is analyzed to confirm evaluation method established above. The requirement of ice class with ARC6 in RMRS is fulfilled for this ship which can voyage in polar region with ice thickness of 1.5m and ship speed of 1.9kn in one year ice at ballast draught. The prediction of model test shows that the power of 32MW can meet requirement of ice class of ARC 6 for this ship at ballast draught.

The model test is conducted with condition of level ice at ice tank, as shown in Figure 1.

Figure 1. Model test in ice

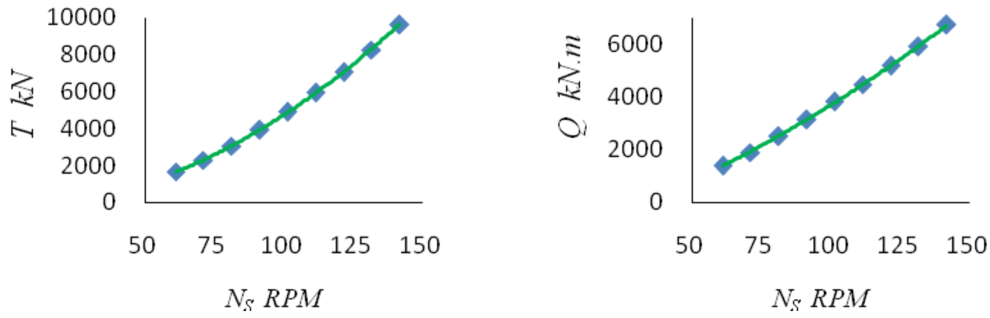
The ice resistance is measured at the condition of ballast draught with ice thickness of 1.3m and 1.6m in model test according to the icebreaking requirement, the model test results of ice resistance are shown in Figure 2.



(a) Ice thickness of 1.3m (b) Ice thickness of 1.6m

Figure 2. Prediction of model test

The propeller diameter of 6.8m with twin screw type for this ship is estimated to meet propelled requirement in ice, the hydrodynamics of propeller are predicted by the lift surface method, and it is expressed four degree polynomial similar to Eq.(5) and (6), the results are shown in figure 3.



(a) Propeller thrust (b) Propeller torque

Figure 3. Prediction of lift surface

The thrust deduction of 0.1 is assumed in calculation according to experience of interaction between ice and propeller. The revolutions of propeller in ice are solved by the method of Newton iteration according to Eq.(13) at two different ice thickness with 1.3m and 1.6m, respectively. The delivered power of propeller and the minimum power of main engine are solved by Eq.(15) and (17), respectively, and the shaft efficiency of 0.99 is considered in calculation. The results of ice thickness of 1.5m are interpolated according to results of ice thickness of 1.3m and 1.6m, the detailed results are listed in table 1.

Table 1. The evaluation results with different ice thickness at the speed of 1.9kn

Ice thickness(m)	Revolutions(RPM)	Delivered power(MW)	Power of ME (MW)
1.3	83.4	26.419	26.686
1.5	88.6	32.115	32.439
1.6	91.2	34.962	35.315

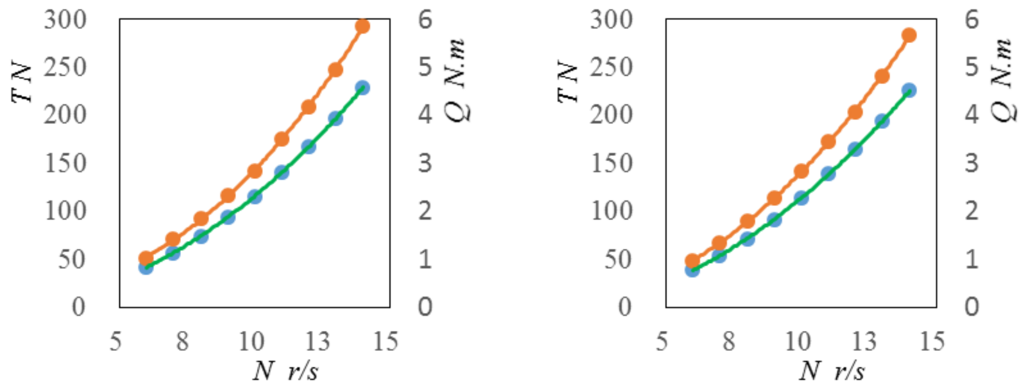
Table 1 show that the minimum power of main engine is 32.439MW, which is close to the power requirement of 32MW. The evaluation method of theory indicates that it is reliable to calculate the power of main engine for the polar carrier.

Solve Analysis Based on Towing Test at Low Speed Condition

The polar carrier at low speed condition are tested in deep water towing tank of china scientific research center (CSSRC), the scale ratio of 35 is chosen in model test. The propeller diameter of 6.8m is adopted in model test according to result of theory evaluation above. The model test is shown in figure 4.

Figure 4. The towing test at speed of 2kn

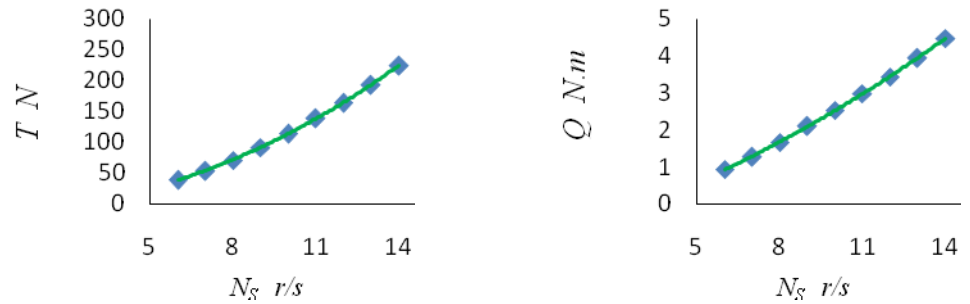
The model test is conducted with towing speed of 1kn and 2kn at ballast draught, respectively. The average results of hydrodynamics between left and right propeller behind the ship model are given in figure 5 with speed of 1kn and 2kn, respectively.



(a) Test results at speed of 1.0kn (b) Test results at speed of 2.0kn

Figure 5. The results of model test behind the ship model

The hydrodynamics results of propeller behind the ship model are fitted using method of least squares. The results at speed of 1.9kn are interpolated in calculation, and it is expressed four degree polynomial similar to Eq.(8) and (9), the results are shown in figure 6.



(a) Propeller thrust (b) Propeller torque

Figure 6. The results of model test at speed of 1.9kn

The propeller revolutions and delivered power are solved in full scale by Eq.(11), (15), (18), (19) and (20). The minimum power of main engine is solved by Eq.(17), the value of 0.99 is used for the shaft efficiency in calculation. The detailed results are listed in table 2.

Table 2. The evaluation results of power of main engine at the speed of 1.9kn

Ice thickness(m)	Thrust deduction	Revolutions(RPM)	Delivered power(MW)	Power of ME (MW)
1.5	0.107	89.1	32.120	32.444

Table 2 show that the minimum power of main engine is 32.444MW, which is close to the power requirement of 32MW.

The evaluation method of model test at condition of low speed indicates that the power of main engine can be evaluated precisely by the towing test at condition of low speed without interaction between ice and propeller in conventional towing tank.

CONCLUSIONS

Comparing to prediction results of model test of ice tank, it is feasible to evaluate the power of main engine by adoption theoretic method and model test of low speed in conventional towing tank. The important conclusions can be obtained:

（1） The propeller revolutions in ice and the value of thrust deduction are main influence factors in process of power assessment of main engine by theoretic method based on lift surface.

(2) Although there is not interaction of ice and propeller, the thrust deduction obtained can fulfill requirement of evaluation in conventional towing tank at low speed condition.

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