Journal of
Ship&Ocean Technology
©MARCH 2002

SOTECH Vol. 6, No. 1, pp. 27~33, 2002

Investigation on the Powering Performance Prediction for Azimuth Thrusters

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Abstract

Recently, the application of the electric propulsion system becomes popular because of its advantage over conventional propulsion. However, the complicated flow mechanism and interaction around the azimuth thruster are not fully understood yet, and the studies on the powering performance characteristics with azimuth/pod thrusters are now in progress. The experimental method developed in KRISO(Korea Research Institute of Ships & Ocean Engineering) is introduced and the results of the powering performance tests, consisting of resistance, self-propulsion and propeller open water tests for a cable layer with two azimuth thrusters are presented. For the analysis of powering performance with azimuth thrusters, it is necessary to evaluate the thrust/drag for components of a thruster unit. Extrapolation results could differ according to the various definitions of the propulsion unit; that is the pod, thruster leg and/or nozzle can be treated as hull appendages or as part of propulsion unit. The powering performances based on several definitions are investigated for this vessel. The results of the measurements for the 3-dimensional velocity distribution on the propeller plane are presented to understand the basis of the difference in propulsion characteristics due to the propeller rotational directions.

Keywords: electric propulsion system, azimuth thruster, powering performance

1 Introduction

The use of the electric propulsion system is continuously increasing for the various types of vessels, for which the course keeping(cable layer, pipe layer), the position keeping(FPSO, drill ship, shuttle tanker) and low level of noise(cruiser) are required to carry out its specified functions. However, the hydrodynamic analysis for the electric propulsors is difficult and incomplete yet because of the complexity of the flows around complicated geometry and the interactions between components. Normally the azimuth thrusters are assembled as a combination of thruster leg, nozzle, pod, and propeller. Also the podded thrusters are assembled with strut, pod and propeller. The interaction between those components, leg, nozzle, pod and propeller, is too significant to be ignored. In case of podded thrusters, the electric motor is installed inside of the pod and its diameter is fairly large to cause notable interaction with the propellers. Furthermore, the interaction between the thruster units is also to be explored, especially when those units are installed close to each other and azimuthing to control or maneuver the ship. For the model test in towing tank and

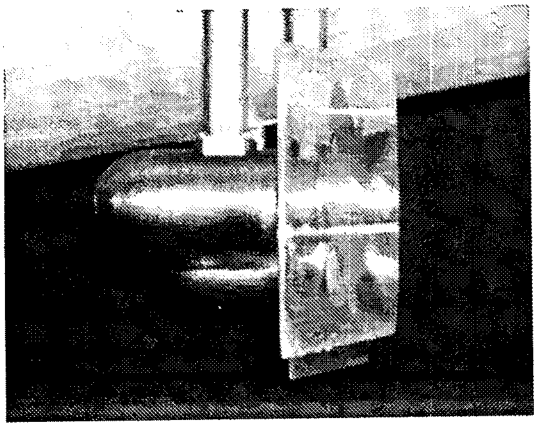

Figure 1: Model-ship with azimuth thruster unit

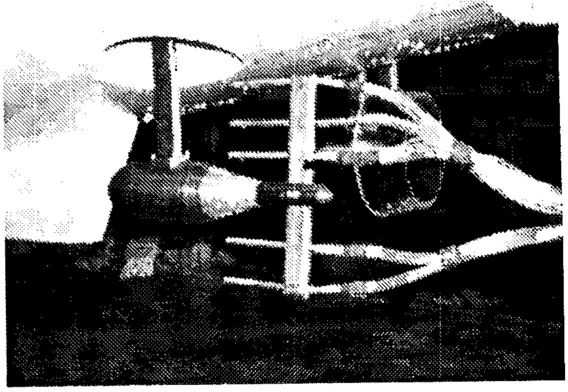

Figure 2: Pitot tube rake attached on model ship

Table 1: Principal Dimensions

Ship		Propeller	
$L_{PP}(m)$	189.0	$D_P(m)$	5.4
$B(m)$	28.0	A_E/A_O	0.68
C_B	0.604	$(P/D)_{mean}$	1.4145
$LCB\%(fwd+)$	-2.82	Z	4

cavitation tunnel, cautiously designed and manufactured equipments are necessary to measure the thrust and torque accurately. Also the extrapolation method based on the model test is another important problem to be studied. In this paper, the model test techniques and equipments developed in KRISO for the powering performance prediction of the azimuth thrusters are introduced and the extrapolation method with several decompositions of the thruster parts is investigated.

2 Experimentation

General description: All the experiments described in this paper are performed in KRISO towing tank of 217 × 16 × 7m in length, breadth and water depth, respectively. Approximately 800 model-ships and 600 model-propellers have been tested in KRISO since 1978. More details can be found in reference(KRISO 1998)

Objective hull form: Powering performance tests, consist of resistance, self-propulsion, propeller open-water and wake measurement, are performed for a cable layer with principal dimensions of 128.6 × 21.0 × 13.2, in length, beam, depth, respectively. The design draft for this ship is 7.36m with the block coefficient(C_B) of 0.794. Estimated design speed is 15.0knots with two 4,500kW azimuth thrusters with propeller diameter of 3.4m and MARIN 19A nozzle.

Experimental equipment: To examine the powering performance of a vessel with electric propulsors, model propulsion units are designed and manufactured with the scale ratio of 17.0. Diameter of the model propeller is determined to be 20cm and the nozzle with MARIN 19A section is adopted because of its popularity in azimuth thrusters. The clearance between the tip of propeller and inside of the nozzle is 1.5mm in model scale. The leg part is designed as thin as possible to minimize the effect of the leg wake which can differ from maker to maker. To measure the thrust and torque of propeller accurately, small sized two-component (thrust and torque) sensor with diameter of 40mm and length 40mm is fabricated and the interference between two components is less than 1.0% FS. This sensor is located just in front of the propeller to minimize the friction and measure the propeller thrust and torque as accurate as possible. The DC input and output voltages are supplied to and collected from the strain gauges through a miniature slip ring whose diameter is 12mm. The thrusts of the nozzle and propeller are measured separately and the total thrust can be obtained by summation of those components. The thrust of the unit is also measured separately by using the three-component balance. The same unit is used for the propulsor open water test and self-propulsion test. A 1.5kW A/C servo motor is used to rotate the propeller and the rpm is controlled by a personal computer. The picture of the unit installed on the cable layer model is shown in Figure 1. For the measurement of the velocity distribution in the propeller plane, a rake with five 5-hole Pitot tubes as shown in Figure 2. The axial, radial, and tangential velocities are measured at 32 circumferential and 5 radial positions, respectively.

3 Results and discussions

Propeller open-water test: As the open-water characteristics of azimuth thruster unit, the thrust coefficient of propeller(K_{TP}), nozzle(K_{TD}), total($K_{TT} = K_{TP} + K_{TD}$), and unit(K_{TU}) are presented in Figure 3, respectively. Also, $10K_Q$ and η_O are plotted together. The difference between total thrust($T_T = T_P + T_D$) and unit thrust(T_U): thrust measured at the top of thruster unit) is due to the drag of thruster leg and pod in front of the propeller. The open-water efficiency in terms of the total thrust is up to 0.60 in maximum, however, maximum efficiency with unit thrust is less than 0.50 as shown in Figure 3. The propeller open-water characteristics according to those two definitions of thrust can be used to analyze the powering performance of a ship.

Wake measurement: The 3-dimensional velocity distribution in the propeller plane without nozzle is measured and presented in Figure 5~8. The axial velocity contours and the transverse velocity vectors are shown in Figure 5 and Figure 6, respectively, for the port side viewed from back. The axial velocity is almost uniform with values(nondimensionalized by ship speed) of 0.9 1.0 except 0^o(top) because of the wake of the thruster leg in front of this position. The axial velocity distributions along the circumferential direction for 5 different radial positions are compared in Figure 7. The wake of the thruster leg is clearly seen around 0^o and this retardation of the velocity will be a source of cavitation and pressure fluctuation, however, the wake value is not so large comparing to that of a hull form with single propeller. Cavitation and fluctuating pressure are to be expected weaker than the single propeller case. In Figure 8, the radial distribution of circumferential mean values of axial, radial, tangential velocities are presented, respectively. The tangential velocity component is not zero and has a value of approximately 0.03, which means that the rotational component of outward direction exists in the inflow field. Because the rotational component is asymmetric, the propulsion characteristics on port and starboard propellers are different if they are rotating in the same direction(clockwise or counterclockwise). Because

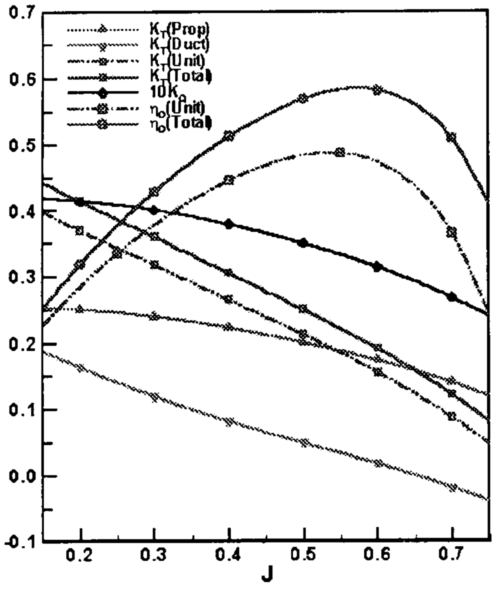

Figure 3: Propeller open water characteristics

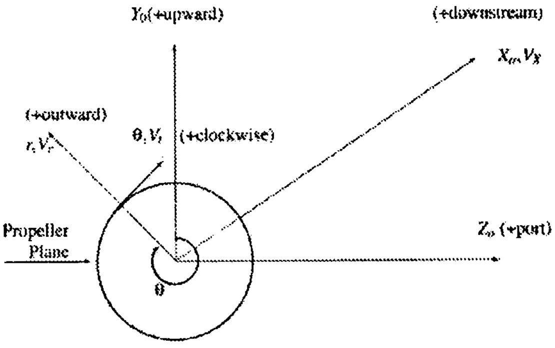

Figure 4: Coordinate system for wake measurement

the 1978 ITTC powering performance prediction method(ITTC 1978) cannot take into account the effect of the rotational component, an alternative method which can consider the effect of the rotational inflow is necessary as discussed in Van et al(1993, 1994).

Powering performance test: Because of the complex geometry and interactions between the components of azimuth thrusters, the extrapolation method for azimuth thrusters is not accomplished yet. Stierman(1984) suggested some extrapolation methods for a ship fitted with ducted propeller, however more complicated interactions among thruster leg, pod, nozzle and propeller are expected for azimuth thrusters(ITTC 2000). Furthermore, since the ITTC 1978 standard prediction method was developed for conventional single screw ships, it is not clear how to apply this method to azimuth thrusters. In this paper, powering performances are compared with three different extrapolation methods according to the definitions of resistance of the hull form and thrust of the propulsor basically based on the standard prediction method. For Method A, all the components of an azimuth thruster are considered as a propulsor and the total thrust($T_T = T_P + T_D$) is defined as the thrust of the propulsor. And resistance of the hull form is defined as that of the bare hull[1]. Method B is based on the same assumption with Method A about the definition of resistance and propulsor, but the unit thrust(T_U) is defined as the thrust of the azimuth thruster. For Method C, the thrust is same as Method A, but the thruster leg and the pod are considered as appendages of the hull. The resistance and thrust combinations used in the respective methods are summarized in Table 2. As an example, test results are introduced for the cable layer propelled by two 4,500kW azimuth thrusters with propellers of 3.4m diameter and MARIN 19A nozzles. The resistance and powering performance of this ship for design (7.36m) and ballast(5.0m) drafts at design speed(15.0knots) are summarized in Tables 3 and 4, respectively. For Method A, because

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[1] It is assumed that the hull form has no other appendages but the components of the azimuth thruster

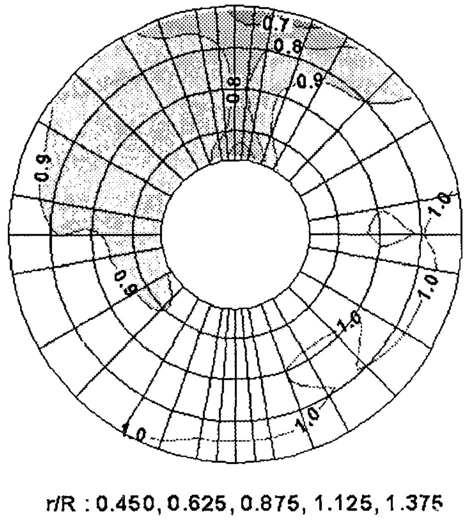

Figure 5: Axial velocity contours

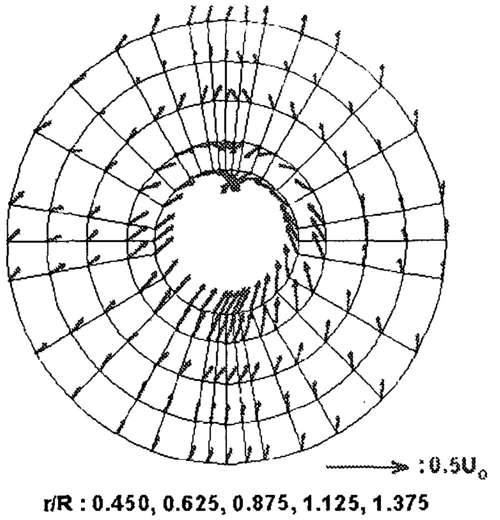

Figure 6: Transverse velocity vectors

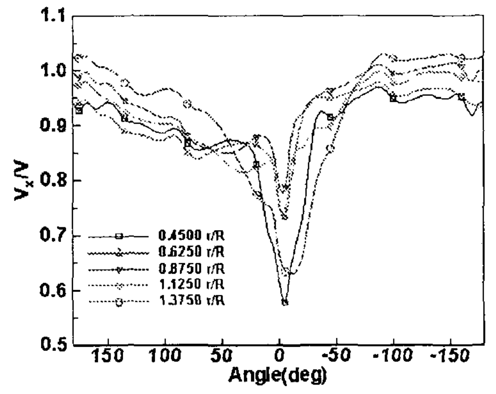

Figure 7: Radial distribution of axial velocity

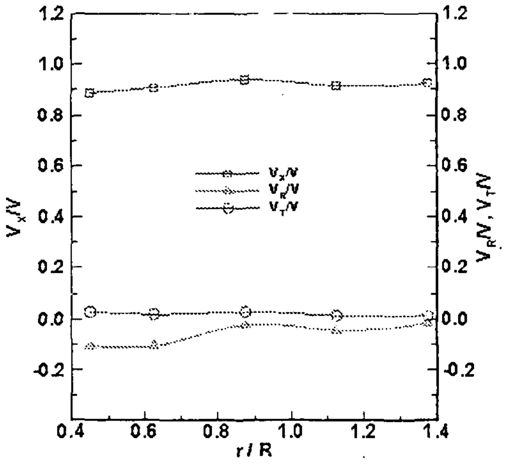

Figure 8: Radial distribution of circumferential mean of velocity components .

Table 2: Definition of thrust and resistance

Method	Resistance of ship	Thrust	Torque
A	Bare hull	Total	Propeller
B	Bare hull	Unit	Propeller
C	Bare hull + drag of thruster leg & pod	Total	Propeller

Table 3: Resistance and self-propulsion characteristics(Design draft)

Method	C_r $\times 1000$	C_{ts} $\times 1000$	EHP (hp)	t	w	η_H	η_O	η_R	η_D	DHP (hp)	RPM
A	1.475	3.391	4,424	0.265	0.111	0.827	0.588	1.025	0.499	8,871	199.9
B	1.475	3.391	4,424	0.077	0.115	1.043	0.475	1.025	0.508	8,714	198.8
C	1.841	3.799	4,955	0.172	0.111	0.932	0.588	1.025	0.561	8,827	199.7

Table 4: Resistance and self-propulsion characteristics(Ballast draft)

Method	C_r $\times 1000$	C_{ts} $\times 1000$	EHP (hp)	t	w	η_H	η_O	η_R	η_D	DHP (hp)	RPM
A	1.140	3.163	3,296	0.275	0.144	0.847	0.576	1.022	0.499	6,611	183.6
B	1.140	3.163	3,296	0.096	0.148	1.061	0.456	1.031	0.499	6,611	183.8
C	1.598	3.684	3,839	0.164	0.144	0.977	0.576	1.022	0.575	6,671	184.0

the drag of the leg and pod in propeller operation is neither counted in resistance of the hull form nor in open water efficiency of the propeller, it causes overestimated thrust deduction of the hull form. Consequently the hull efficiency defined as $\eta_H = (1-t)/(1-w)$ is very low for Method A. On the other hand, since the drag was counted in the definition of unit thrust in method B (i.e. $T_U = T_T - Drag$), thrust deduction and hull efficiency appear reasonable but the propeller open water efficiency is quite small. As a result, the propulsive efficiency($\eta_D = \eta_H \times \eta_O \times \eta_R$) is almost same for both methods and required DHP values obtained by Methods A and B are also very similar to each other. In Method C, the leg and the pod are considered as appendages, and their drag is added to the resistance of the bare hull. So the thrust deduction factor in Method C has an intermediate value. Total thrust is defined as the thrust of the propulsor, the high open-water efficiency can be obtained from the corresponding propeller open-water characteristics. Therefore, the highest propulsive efficiency is expected with Method C. However, the resistance(EHP) is assumed larger than other methods owing to the appendage drag, the finally obtained DHP is again similar to other methods. Same tendency can be found for both design and ballast drafts and it can be deduced that the methods suggested here can be utilized reliably for the extrapolation for a ship with azimuth thrusters.

4 Conclusions

Model test equipments and techniques for a ship with azimuth thrusters are presented. Three extrapolation methods with different definitions of thrust and resistance are compared for the Cable layer with two azimuth thrusters. Although very similar predictions for DHP can be attained with those methods for present work scope, more test cases for model and prototype are necessary to validate the suggested methods. In the present prediction, the scale effect correction is applied only for the propeller blades following the ITTC recommendation. Scale effect correction for other components of the azimuth thrusters(thruster leg, pod, nozzle) should be formulated. In addition, the reliable prediction method that can consider the effect of the rotational inflow should be investigated for twin propellers.

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