第88回（平成30年）マリンエンジニアリング学術講演会

225

Relation between Ship Speed and Horsepower of CPP in Actual Sea Condition

◎Taisuke Inoue, Hiroyasu Kifune, Hideyuki Kashima,
Toshifumi Hayashi, Yosuke Kitano, Ken Katsumi
Tokyo University of Marine Science and Technology

1. Introduction

Authors have developed a simulation program to estimate the FOC (fuel oil consumption) and the SFCS (specific fuel consumption of system) of the propulsion system (1). This simulation has mathematical energy consumption models of engines, alternators, motors, and etc. These models have been developed and improved by using data in several finished drawing books. Therefore, it is static type simulation. In this simulation, SFCS is calculated by using energy consumption models of all devices which consist of the propulsion system at any condition of SHP (shaft horse power).

In general, ships equipped with FPP controls her speed by the propeller speed. SHP for maintaining the required ship speed can be expressed as the function of the ship speed or the propeller speed. On the other hand, ships using equipped with CPP control her ship speed by changing the pitch angle in general. However, the ship speed is controlled by not only the pitch angle but also the propeller speed in some case. The factors that determine the ship speed include not only the pitch angle but also the propeller speed. Therefore, it is necessary to focus on the both those factors when this simulation calculates SHP for maintaining the required ship speed. In several cases, estimated power curves are given in finished drawing books in order to show the relation among ship speed, SHP, propeller speed and pitch angle of CPP. However, as shown in Table 1, SHP and the ship speed are different between estimated value and measured value. Consequently, it is necessary to grasp characteristics of CPP when this simulation calculates SHP for maintaining the required ship speed. Authors performed experimental voyage, to find out the relation among ship speed, SHP, propeller speed and pitch angle of CPP. In this paper, authors report the analysis result.

Table 1 SHP at maximum ship speed

	Estimation	Sea trial
Propeller speed N [rpm]	300	300
Pitch angle θ [deg]	21.5	21.5
SHP [kW]	1084.2	1126.1
Ship speed V [knot]	14.4	14.8

2. Relation between ship speed and horsepower

2.1 Experimental conditions and results

The experimental voyages were carried out by two ships A and B. The ship A has one line shaft propulsion system with CPP. Its rated output power of the main engine is 1029.7 [kW]. The ship B is a two line shafts electric propulsion system with CPP. Its rated output power of propulsion motors are 800 [kW], respectively.

Table 2 shows the experimental conditions in the ship A. The experiments were implemented three times in three days, respectively. Experiment parameters are 24 in total due to the propeller

Table 2 Experiment condition in sample ship A

Parameters

Item	Set Values
Propeller speed N [rpm]	300, 283, 261, 243
Pitch angle θ [deg]	Neutral, 4, 8, 12, 16, 18.5

Environmental conditions

Experiment Number	Relative wind (mean value)	
	Direction [deg]	Speed [m/s]
A-Ⅰ	180.6	7.8
A-Ⅱ	41.5	8.6
A-Ⅲ	56.9	5.1

Table 3 Experiment condition in sample ship B

Parameters

Item	Experiment Number	Set Value
Propeller speed N [rpm]	B-Ⅰ	249, 166
	B-Ⅱ	
Pitch angle θ [deg]	B-Ⅰ	Neutral, 5, 10, 15, 19, 22
	B-Ⅱ	Neutral, 4, 9, 13, 17, 21

Environmental conditions

Experiment Number	Relative wind (mean value)	
	Direction [deg]	Speed [m/s]
B-Ⅰ	84.2	4.0
B-Ⅱ	324.5	4.4

speed was changed at 4 conditions and the pitch angle was changed at 6 conditions. Table 3 shows the experimental conditions in the ship B. Experiment parameters are 12 in total due to the propeller speed was changed at 2 conditions and the pitch angle was changed at 6 conditions.

Figure 1 shows the result of the third experiment on the ship A. It has to pay attention to plots which are circled dotted line in Fig. 1. Since the pitch angle is neutral, the trust is zero. However, SHP is not zero. The energy of this SHP is not consumed as the propulsion force of the hull. It is thought that the energy is dissipated in seawater because of friction and other reason. Hereinafter, SHP at zero thrust is called RHP (rotational horse power) in this paper.

2.2 Rotational horsepower

Figure 2 shows the relation between propeller speed and RHP in third experimental result on the ship A. As mentioned above, RHP is assumed to energy consumption of friction between propeller and seawater. In general, fluid friction loss is strongly to related velocity. Therefore, it can be expressed as a function of the propeller speed in seawater. From the trend of measured values, RHP is simply proportional to the cube of the propeller speed N. Therefore, RHP is expressed by the following equation.

$$RHP = f(N) = \mathrm{a}N^3 \qquad (1)$$

where, "a" is a constant. It is thought that the difference between SHP and RHP is required energy for propelling the hull. In this paper, the difference between SHP and RHP is defined as the power X.

$$X = SHP - RHP \qquad (2)$$

2.3 Power X

Figure 3 shows the relation between ship speed and power X in third experimental result on the ship A. It is thought that the power X strongly correlates with the ship speed irrespective of the pitch angle and the propeller speed of CPP.

Ship resistance is divided into viscous resistance and wave resistance (2). They are expressed by the following equation.

$$R_v = \frac{1}{2}\rho V^2 S(1+\mathrm{K})C_f \qquad (3)$$

$$R_w = \frac{1}{2}\rho V^2 S C_w \qquad (4)$$

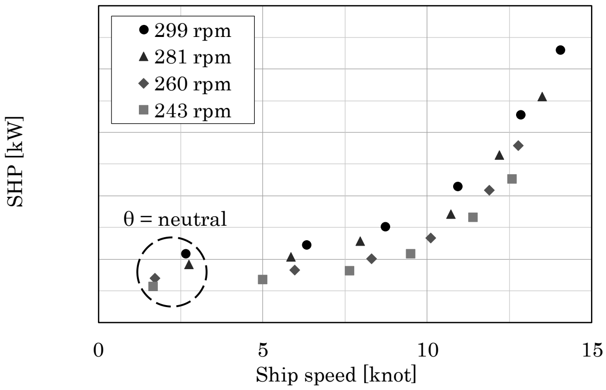

Fig. 1 Ship speed and SHP in Ex. A-Ⅲ

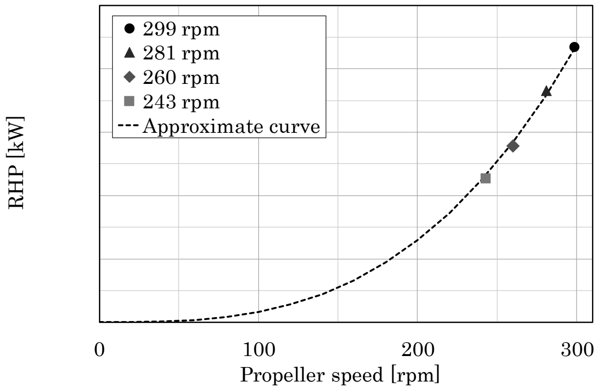

Fig. 2 Propeller speed and RHP in Ex. A-Ⅲ

where, R_v is the viscous resistance [kN], ρ is the density [kg/m^3], V is the ship speed [m/sec], S is the representative area [m^2], K is the form factor, C_f is the friction resistance coefficient, R_w is the wave resistance [kN], C_w is the wave resistance coefficient. Now, C_f is monotone decreasing function of Reynolds number. Furthermore, if it is the same ship, Reynolds number depends only on the ship speed. In this paper, C_f is simply expressed by the following equation.

$$C_f = \mathrm{p}\, V^{-1} \qquad (5)$$

where, p is a constant. On the other hand, C_w tends to increase with increasing Froude number. Furthermore, if it is the same ship, Froude number depends only on the ship speed. In this paper, C_w is simply expressed by the following equation.

$$C_w = \mathrm{q}V + \mathrm{r} \qquad (6)$$

where, q and r are the constant. From equations (3) to (6), ship resistance is expressed by the following equation.

$$R = R_w + R_v = \mathrm{b}V^3 + \mathrm{c}V^2 + \mathrm{d}V \qquad (7)$$
$$\mathrm{b} = \frac{1}{2}\rho\mathrm{Sq}, \quad \mathrm{c} = \frac{1}{2}\rho\mathrm{Sr}, \quad \mathrm{d} = \frac{1}{2}\rho\mathrm{S}(1+\mathrm{K})\mathrm{p}$$

where, R is ship resistance [kN]. As mentioned above, it is thought that the power X is required energy for propelling the hull. Therefore, the power X is calculated by the product of ship resistance and the ship speed.

$$X = RV = \mathrm{b}V^4 + \mathrm{c}V^3 + \mathrm{d}V^2 \qquad (8)$$

In fig. 3, the power X which is calculated by using actual measurements data fits the approximation curve of the equation (8). Therefore, it is assumed that the power X is represented by a function of only the ship speed V irrespective of the propeller speed and the pitch angle. Expressing the function of the power X as $g(V)$, equation (2) can be expressed as follows.

$$SHP = f(N) + g(V) \qquad (9)$$

2.4 Power X and effective horsepower

It is well known that EHP (effective horse power) shows the estimated power by model experiment. It is the definition of it in the product of ship resistance and the ship speed. Figure 4 and 5 show the power X and EHP to the ship speed, respectively. EHP data are described in finished drawing books of the ship A and B. The power X and EHP increase with increasing the ship speed in a similar trend. Especially plots of the power X agree with EHP in low ship speed range. If the power X stands for EHP, it may be used for evaluating EHP estimation as one of criteria. However, over 10 [knot] range, variation of them tends to be large. It is seen that several plots higher than EHP in Fig. 5. Therefore, it cannot be judged that EHP is expressed as the power X simply.

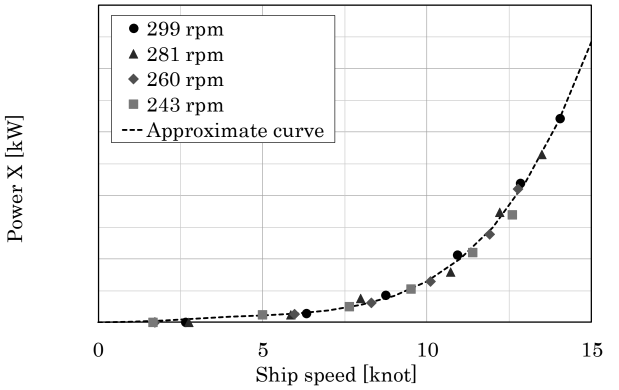

Fig. 3 Ship speed and Power X in Ex. A-Ⅲ

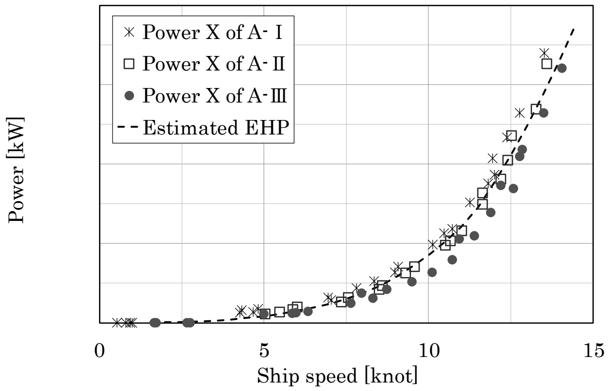

Fig. 4 Power X and EHP to ship speed in ship A

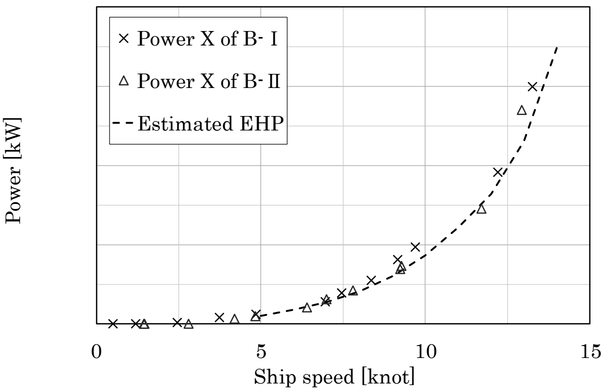

Fig. 5 Power X and EHP to ship speed in ship B

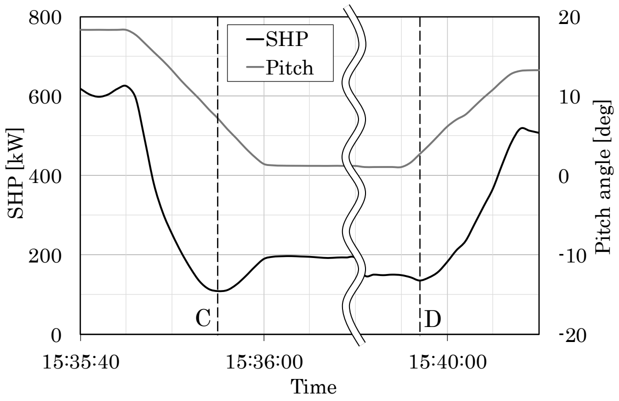

Fig. 6 Starboard SHP and Pitch angle

It is thought that other factor should be considered to clarify the relation between power X and EHP. Following the equation (1), RHP does not depend on the pitch angle. However, as the pitch angle increases, the propeller will paddle more seawater. It may be natural to think that frictional force between propeller and seawater increases with the pitch angle. Therefore, authors implemented another experiment by using the ship B to find out the relation between pitch angle and RHP.

3. Relation between pitch angle and rotational horsepower

The experiment was implemented as following procedure. 1. Ship goes on steady speed at θ = 18.3 [deg]. 2. Decreasing the pitch angle to neutral rapidly. 3. Keeping the pitch angle at neutral for several minutes. 4. Increasing the pitch angle to θ = 13.3 [deg] rapidly. Figure 6 shows measured data of starboard side in the experiment. At time C, SHP drops to around 100 [kW]. It is thought that the speed of seawater flowing into the propeller corresponded with the propeller advancing speed of θ = 7.2 [deg]. At this time, the propeller does not produce thrust forth because the propeller slip became zero instantaneously. Therefore, SHP at time C can be regarded as RHP with θ = 7.2 [deg]. As a same manner, SHP at time D can be regarded as RHP with θ = 2.7 [deg]. These results show that, surprisingly, RHP has a negative correlation to the pitch angle. This result was contrary to our expectation. Judging from experimental results, RHP decreases as the pitch angle increases. As shown in equation (2), what RHP becomes smaller means that the power X becomes larger than the conventional value. Consequently, the power X increases more than the conventional value as the pitch angle increases. An increase in the pitch angle represents an increase in the ship speed. Therefore, the power X becomes larger than the conventional value as the ship speed increases. In consequence, the power X is further away from EHP.

4. Conclusion

In this paper, authors conducted several experiments to clarify the relation between ship speed and horsepower by using ships equipped with CPP. In these experiments, it revealed the following. For ships equipped with CPP, SHP is required even at zero thrust. This horsepower, defined as RHP, is expressed as a function of the propeller speed and the pitch angle. Moreover, the power X which is the difference between SHP and RHP takes a value close to EHP. However, it was found that the power X and EHP tend to be apart from each other in a high ship speed area. In near future, it should be discussed further by increasing the number of experimental samples.

Reference

(1) Hiroyasu Kifune, Takaaki Nishio, “A Study of Consumption Model Using Tugboat’s Propulsion System”, J. JIME, Vol. 50 No. 4 (2015), pp. 129-136

(2) John Carlton, “Marine Propellers and Propulsion Second Edition”, (2007), Butterworth-Heineman