Study of Ship Main Engine Dynamic Fuel Consumption Model

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Abstract. In this paper, a type of understudied Inland Shallow and wide ship is studied. Combined with the real ship design parameters and ship model test data, the ship dynamic fuel consumption model is established. The ship's speed and fuel consumption are quantitatively calculated and predicted, provides basic data for determining ship economic speed.

Keywords: Ship, Dynamic Fuel, Consumption, Output Power, Model.

Introduction

At present, the unit consumption of inland navigation energy in China is about 50% higher than that of foreign countries and the advanced energy conservation and emission reduction technology at home and abroad is not applied widely. As major industry of energy consumption, shipping enterprises desperately need to realize energy conservation and emission reduction by certain technologies and management means. So, we need to increase investment in manpower and material resources, start from technology, management and personnel, research on related technologies of shipping energy saving, improve energy saving and environmental protection level of ships and promote the construction and development of green shipping in China.

At the present stage, the most direct, convenient and effective way for energy conservation and emission reduction of inland ships is to navigate by adopting economic speed. The relationship of ship navigational speed and fuel consumption, inland water velocity, freight period and other factors shall be considered comprehensively for the determination of economic speed of inland ship. The relationship of ship navigational speed and fuel consumption is the basis for determining economic speed.

Study of Ship Mathematic Relationships

Taking related information in professional skill fields such as shipping principle, ship design, main engine model selection and mathematical modeling as references, this paper selects critical limiting factors related with ship fuel consumption. Taking a 6700 tons broad-shallow bulk carrier as modeling project and taking ship design data, related data of ship main engine as modeling basis, a quantitative ship main engine dynamic fuel control model is built by applying mathematical modeling method and instrument. This model indicates there is quantitative relation between ship speed and fuel consumption.

Propeller efficiency

Based on ship principle, the propeller efficiency is:

$$\eta_p = \frac{K_T}{K_Q} \frac{J}{2\pi} \quad (1)$$

Where:

K_T — thrust coefficient

K_Q — torque coefficient

J — advance coefficient

Movement condition

Advance coefficients J of propeller, its diameter D , ship speed V_s and wake factor ω have the following relationship:

$$J - \frac{(1-\omega)}{n_p D} g V_s = 0 \quad (2)$$

Where:

D — diameter of propeller, (m);

n_p — revolving speed of propeller;

ω — wake factor;

V_s — speed (km/h).

Force balance condition

The effective thrust T_e of propeller must be equal to the hull resistance R at a corresponding speed V_s , which is:

$$T_e - R = 0 \quad (3)$$

$$T_e = (1-t) K_T g \rho g_p^2 D^4 \quad (4)$$

$$R = \frac{1}{2} C g \rho g S V_s^2 \quad (5)$$

Where:

ρ — water density (kg/m³);

t — thrust deduction coefficient;

C — hull resistance coefficient;

S — hull area of water surface (m²).

After transformation:

$$K_T - \frac{R}{(1-t) g \rho g_p^2 D^4} \frac{J^2}{V_s^2} = 0 \quad (6)$$

Energy conservation condition

The power absorbed by propeller N_p is equal to the power consumed by propeller, which is:

$$N_p - 2\pi K_Q g \rho g_p^3 D^5 = 0 \quad (7)$$

After transformation:

$$K_Q - \frac{N_p}{2\pi \rho g_p^3 D^5} = 0 \quad (8)$$

Ship fuel consumption

When the ship is sailing at a certain speed V_s , the unit time fuel consumption is:

$$b_e = N_e g_e = \left[\frac{EHP(V_s)}{\eta_e \eta_r \eta_h \eta_p} \right] g_e \quad (9)$$

Where:

b_e — unit time fuel consumption of main engine (kg/h)

N_e — output power of main engine (kW)

g_e — fuel consumption rate of main engine (kg/km.h)

$EHP(V_s)$ —effective thrust power (kW);

η_e —shaft transmission efficiency;

η_r —relative rotative efficiency;

η_h —hull efficiency;

η_p —rotative efficiency of propeller

The following relationship is deduced from the above formulas:

$$EHP(V_s) = T_e g V_s = (1-t) K_T g \rho g_p^2 D^4 g V_s \quad (10)$$

$$EHP(V_s) = N_e = 2\pi K_Q g \rho g_p^3 g D^5 \quad (11)$$

Because

$$n_p = \frac{(1-\omega)V_s}{JD} \quad (12)$$

Put it into the above two formulas:

$$EHP(V_s) = (1-t) K_T g \rho g \left(\frac{1-\omega}{J} \right)^2 g D^2 g V_s^3 = 2\pi K_Q g \rho g \left(\frac{1-\omega}{J} \right)^3 g D^2 g V_s^3 \quad (13)$$

Study of Propeller Characteristics

The curve of propeller characteristics of diesel selected in this ship research project is as shown in Figure 1:

Figure 1 Curve of propeller characteristics of diesel

Select a group of corresponding fuel consumption of main engine g_e (kg/kw.h) and output power of main engine P (kW) at different rotate speeds from the curve, their relationship is as follows:

Table 1 Main Engine Relationships of Fuel Consumption and Output Power

Power of main engine (kw)	184	203	225	279	308	368	405	440	480
Fuel consumption rate (kg/kw.h)	248	246	242.5	236	233	227	224	222	219
Power of main engine (kw)	520	567	610	658	704	716	735	753	808
Fuel consumption rate (kg/kw.h)	217.5	215	213	212	210.8	210.3	210	210.8	212

Based on the above data, the relationship between the fuel consumption rate of main engine and output power of main engine is as follow:

$$g_e = 0.291 - 3.291e^{-4}N_e + 6.427e^{-7}N_e^2 - 7.373e^{-10}N_e^3 + 3.65e^{-13}N_e^4 \quad (14)$$

So the fuel consumption in unit time when the ship is sailing at V_s is:

$$b_e = N_e g_e = 0.291N_e - 3.291e^{-4}N_e^2 + 6.427e^{-7}N_e^3 - 7.373e^{-10}N_e^4 + 3.65e^{-13}N_e^5 \quad (15)$$

Where

$$N_e = \left[\frac{EHP(V_s)}{\eta_e \eta_r \eta_h \eta_p} \right] = \frac{2\pi K_Q g \rho g \left(\frac{1-\omega}{J} \right)^3 g D^2 g_s^3}{\eta_e \eta_r \eta_h \eta_p} \quad (16)$$

Conclusions

The research and establishment of dynamic fuel consumption model of ship main engine provide the most basic data for inland ship to sail at economic speed and work out trip planning. By the calculation and prediction of model, we can get the fuel consumption data at different ship speeds. Under the condition that the freight period and voyage of ship are known, we can divide the ship voyage into several parts, with water velocity of specific voyage part and ship fuel consumption, we can plan the ship speed in order to let the ship sail at economic speed in the whole voyage and realize energy conservation and emission reduction of the ship.

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