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Study of Engine Propeller Matching for High-Speed Vessel with Gawn Series Propeller

Nurhadi,[a,]* Hardi Zen,[b] Sumarsono,[c]

[a]Balai Teknologi Hidrodinamika, BPPT. Email: nrhadi@gmail.com
[b]Balai Teknologi Hidrodinamika, BPPT.
[c]Balai Teknologi Hidrodinamika, BPPT.

Abstract

At the design stage, model testing is required to verify the results of the numerical calculation, such as resistance test, open water test, and self-propulsion test, which associated to the powering of the ship. Besides, engine propeller matching is required to determine the engine load characteristics. In this study, a high-speed vessel with Gawn series propeller type is used. Based on Engine Propeller Matching (EPM) results, it is known that at 28 knots of speed, the propeller has a high enough efficiency which is around 0.56 in rough hull condition. By using the CAT 280-8 engine, at 1000 rpm, ship speeds can reach about 30.5 knots and power requirements are 2400 kW.

Keywords: Engine matching; Gawn series propeller; high-speed vessel

1. Background

The development of ship design has progressed very rapidly. Some ship design software emerges with many features and advantages that are very useful for the designers to design ships.

At the design stage, model testing is required to verify the results of the numerical calculation, such as resistance test, open water test, and self-propulsion test, which is related to the ship powering [1].

From the model test results, it is important to calculate the matching point between the propeller load and the engine which will use the ship. The optimal operational and optimal load engine will know also the efficiency of propeller used. Engine propeller machine graph will facilitate the ship operation based on the desired engine load and speed of the ship [2].

Desired ship speed cannot be achieved in some cases because there is no matching between the propeller and the engine, not cause of the design of propeller or engine that used is to low [3].

Given the importance of engine propeller matching (EPM), this paper will discuss EPM on a high-speed vessel that uses Gawn series propeller type. The selection and use of Gawn series propeller are due to its high-rotary propeller design to get high thrust and torque to achieve the desired service speed.

*Corresponding author. Tel.: +62811328567
Jl. Hidrodinamika, Kompleks ITS, Sukolilo
Surabaya, 60111

2. Literature review

The ship design is expected to be able to maintain the speed of service (Vs) on the operation. The design of drive system that can overcome the total resistance at such speed is necessary.

One of the stages of ship design evaluation is EPM (engine propeller matching). Matching point is an operating point of the engine rotation speed that matches the character of the propeller load. The operating point of rotation where the engine power is absorbed by the propeller is equal to the power that is generated by the engine. It produces the speed of the vessel corresponding to the planned speed of the shipping vessel.

In general, ships that move in water media with a certain speed will experience opposite resistance to the direction of motion of the ship. The amount of resistance that occurs should be able to be overcome by thrust that is generated by the propulsion system. Delivered Power (DP) is the power of the ship that drove from the Shaft Power (SP). The shaft power is getting from Brake Power (BP) that come from ship engine [4].

The forces and moments generated by the propeller can describe in terms of the principal quantities, which is presented in a series of nondimensional characteristics. These characteristics are used to describe in general the performance of a propeller [5]. These characteristics are:

Thrust Coefficient:

$$K_T = \frac{T}{\rho n^2 D^4} \tag{1}$$

Torque Coefficient:

$$K_Q = \frac{Q}{\rho n^2 D^5} \tag{2}$$

Coefficient Advance:

$$J = \frac{Va}{nD} \tag{3}$$

Where, D (propeller diameter), Va (advance velocity), n (propeller rotational velocity), ρ (fluid density).

The hull and propeller interaction is obtained from calculation to gain propeller performance characteristics when propeller operated as a propulsor of the ship [6]. The calculation method uses the following formula:
From the ship, it is known that:

$$R_T = 0.5\ \rho\ C_T\ S\ V_S^2 \quad \text{with} \quad \alpha = 0.5\ \rho\ C_T\ S \tag{4}$$

The ships thrust can be calculated by the formula:

$$T = \frac{R}{(1-t)}; \quad T = \frac{\alpha\, V_S^2}{(1-t)} \quad \text{with} \quad w = 1 - (Va/Vs) \tag{5}$$

$$Tship = \frac{\alpha Va^2}{(1-t)(1-w)^2} \tag{6}$$

$$K_T = \frac{\alpha Va^2}{(1-t)(1-w)^2 \rho\ x\ n^2\ x\ D^4} \tag{7}$$

$$\text{So, } K_T = \frac{\alpha\ V_A^2}{(1-t)(1-w)^2\ \rho\, n^2\, D^4} \quad \text{if } \beta = \frac{\alpha}{(1-t)(1-w)^2\ \rho\ D^2} \tag{8}$$

$$K_T = \beta \frac{V_A^2}{n^2\, D^2}; \quad K_T = \beta J^2 \tag{9}$$

Where, t (thrust deduction factor), w (wake factor), C_T (total resistance coefficient), S (ship wetted surface area).

3. Methodology

The research will use data analysis based on the obtained model test results. From the data model test, it will calculate the interaction between propeller load and the propulsion engine to know how many matches of them. For more details, it can be seen in the following diagram at Fig. 1.

4. Results and Discussion

When designing a ship, the propulsion engine is predicted from the value of the resistance of the ship. The values can be obtained through numerical approaches or ship model test in the towing tank [7].

This study uses a high-speed vessel with Lpp (55.35 m), B (8.10 m), T (2.6 m), block coefficient (0.395), midship section coefficient (0.567), prismatic coefficient (0.696), wetted surface area (457.3 m^2). The propeller used is Gawn series type with a diameter (1.5 m), P / D at 0.7R (0.954), Ae / Ao (1.1), with a number of blade 3, as shown in Fig. 2.

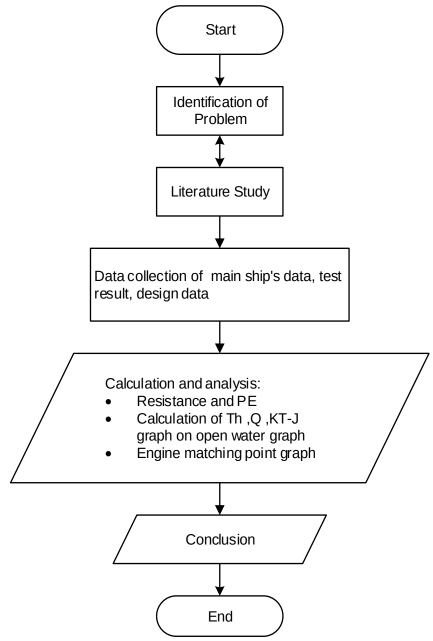

Figure 1. Diagram of the test methodology.

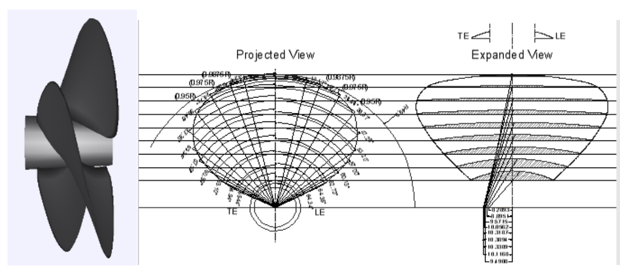

Figure 2. Used Gawn series propeller geometry.

Based on the results of the resistance test of a high-speed vessel model, the obtained of the effective power value are listed in Table 1.

Table 1. High-speed vessel resistance and PE prediction values

Vs Knots	Fn	RT **kN**	PE **kW**
27.07	0.6038	294.63	4102.9
28.09	0.6265	307.35	4440.9
29.07	0.6484	317.82	4752.3

For open water diagrams, they are obtained from open water test shown in Fig. 3.

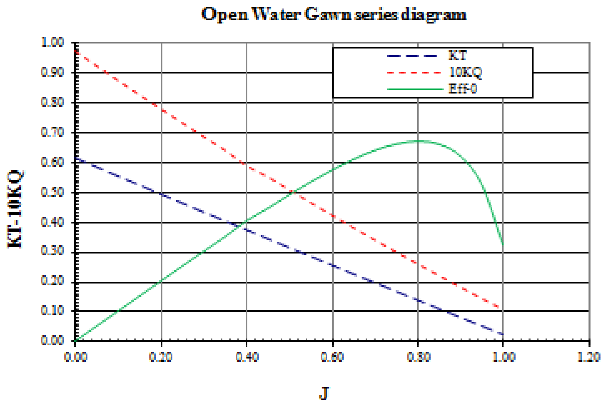

Figure 3. Gawn series open water test chart

With resistance and open water data, the KT-J value of the ship propeller load can be calculated to obtain the open water graph. For calculation of α, β with the existing formulas, the results obtained according to Table 2.

Table 2. α and β calculation of speed

VS Knots	RT /2 kN	α RTs/Vs^2	β	
			Clean	Rough hull-15%
27.07	147.3	759.640	0.698	0.803
28.09	153.7	736.076	0.676	0.778
29.07	158.9	710.705	0.653	0.751

The RT is divided by two, according to the twin-screw ship (two propeller movers), so for the calculation of one propeller, the total load resistance of the vessel is divided equally into 2. By varying the value of J from 0 – 1, the KT-J diagram can be calculated on clean hull condition and rough hull condition that a margin by 15%, it gets result according to Table 3.

The result of plotting propeller loads on open water propeller diagram shown in Fig. 4 is called KT-J graph.

Table 3. Calculation results of KT in Clean Hull and Rough Hull conditions

No	J	KT Clean Hull			KT Rough hull-15%		
		27 knots	28 knots	29 knots	27 knots	28 knots	29 knots
1	0.1	0.007	0.007	0.007	0.008	0.008	0.008
2	0.2	0.028	0.027	0.026	0.032	0.031	0.030
3	0.3	0.063	0.061	0.059	0.072	0.070	0.068
4	0.4	0.112	0.108	0.105	0.129	0.125	0.120
5	0.5	0.175	0.169	0.163	0.201	0.195	0.188
6	0.6	0.251	0.244	0.235	0.289	0.280	0.271
7	0.7	0.342	0.332	0.320	0.394	0.381	0.368
8	0.8	0.447	0.433	0.418	0.514	0.498	0.481
9	0.9	0.566	0.548	0.529	0.651	0.630	0.609
10	1	0.699	0.677	0.654	0.803	0.778	0.752

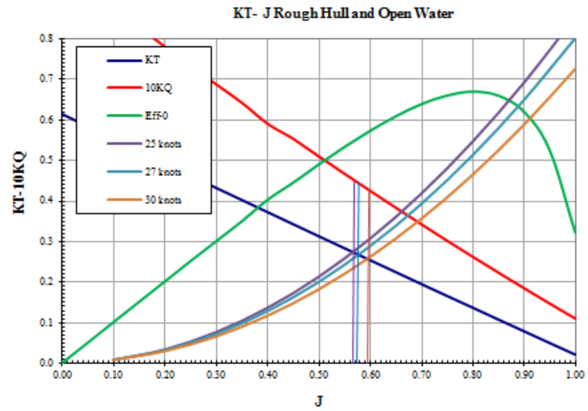

Figure 4. KT- J propeller load of rough hull conditions.

The KT-J on Fig. 4 at rough hull condition:

- At 28 knots of the KT-J and open water charts, it is known that the intersection of KT-J lines with open water graph is intersected by the KT line at the value of J = 0.585 where the value of KT is 0.265 and the value of 10KQ at the value of 0. 44
- By knowing the value of J, the optimum rotation of the propeller can be calculated

where $J = \frac{V_A}{nD}$ or $n = \frac{V_A}{J.D}$ so Q can be calculated with the formula $the\ K_Q = \frac{Q}{\rho\, n^2\, D^5}$ and $Q = K_Q\, \rho\, n^2\, D^5$

4.1. Calculation of DHP and BHP

In developing the propeller load characteristics, the variables involved are propeller torque and propeller speed. Propellers torque are calculated from the graphical processing of hull and propeller interaction which get by self-propulsion test. While the calculation of Power required is calculated by the formula $P = 2.\ \pi.Q.\ n$

Calculation results for each speed in clean hull condition is shown in Table 4 and rough conditions in Table 5.

4.2. Engine Propeller Matching

From the calculation, it is known that for the condition of Rough Hull, at 28 knots the required power of 2074 kW so that if the speed is at 85% MCR then the required engine power is 2074 x 1.15 = 2440 kW. From the existing engine specifications, obtained Caterpillar engine, Cat 280-8 type of propulsion engine which 2460 kW power [8]. The engine is working at 1000 rpm, so the reduction gearbox with a ratio of 1.28: 1 is needed.

Based on the results, a graph of propeller load, speed, and power is made to see the characteristics of the engine when loaded as shown in Fig. 5. This figure shows the propeller load power requirement is still below the maximum power generated by the engine and coincide with propeller load.

Table 4. DHP and BHP rotation on speed variation of clean hull condition

Speed	KT-J			Va	n-prop		Q- clean hull	DHP-clean hull	BHP- clean hull
Knots	J	KT	10KQ	m/s	rps	rpm	kN	kW	HP
27.07	0.602	0.252	0.4250	10.42	11.5	692	22.03	1597	1646
28.09	0.605	0.250	0.4200	10.81	11.9	715	23.21	1736	1790
29.07	0.612	0.248	0.4150	11.19	12.2	731	24.00	1837	1894

Table 5. DHP and BHP rotation on speed variation of Rough hull condition

Speed	KT-J			*Va*	n-prop		Q- Rough hull	DHP-Rough hull	BHP-Rough hull
Knots	J	KT	10KQ	m/s	rps	rpm	kN	kW	HP
27.07	0.602	0.27	0.442	10.42	12.0	719	24.68	1857	1914
28.09	0.605	0.265	0.44	10.81	12.3	739	26.00	2012	2074
29.07	0.612	0.26	0.435	11.19	12.6	759	27.07	2149	2215

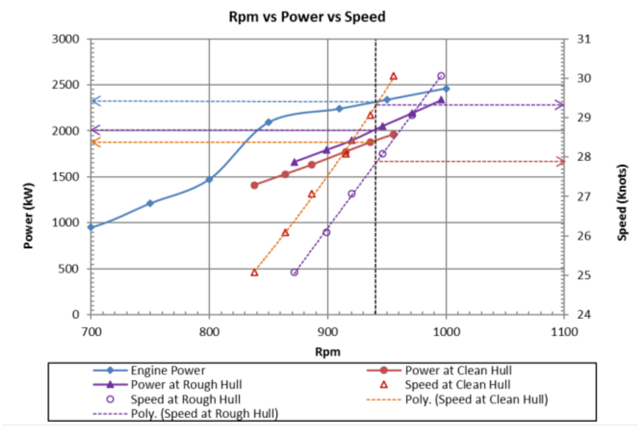

Figure 5. CAT engine matching C280-8 with propeller load on rough condition

In addition, the relationship between RPM, power, and speed are shown in Fig. 5. At 940 rpm engine speed (black dash line) will intersect with the line of speed at rough hull conditions (purple dash line). It is known the speed is 27.8 knots (the right y-axis), intersecting with the speed at clean hull (orange dash line) known that the speed is 29.3 knots. The line intersects with the clean hull (orange line) power line, so it is known that the power requirement is 1900 kW and the rough hull condition is 2050 kW. At 940 rpm. The black dash line cut the engine power curve, it is known that engine can generate power up to 2350 kW.

5. Conclusion

From the discussion and calculation of Engine-Propeller Matching on the high-speed vessel using propeller Gawn series and 280-8 Cat engines known that:

- From the calculations, it is known that to achieve 28 knots at Clean Hull condition the required power is 1736 kW (DHP) and at Rough Hull condition power requirement is 2012 kW (DHP).
- The propeller efficiency at 28 knots rough hull condition, is relatively good enough that is around 0.56.
- From EPM diagram at 1000 rpm, the obtained speed is about 30.5 knots with a power requirement of 2400 kW in rough hull conditions.
- From the calculations performed, engines and propellers are properly used to high-speed vessel type.

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