The Selection of Fast Patrol Boat (FPB) Propeller Ship to Optimize Machine Usage of MTU 16V 595 TE 70l Using Harvald Guldhamer Method and Engine Propeller Matching (EPM)

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Abstract

To actualize a large, strong and professional Navy force, the Fast Patrol Boat ship repowering Diesel engine without replacing the ship propeller was done. Harvald Guldhamer Method and Engine Propeller Matching methods were used to obtain optimum results on the propulsion system and determine ship resistance. The analysis refers to machine diagram performance of MTU 16V 595 TE 70L. The calculation result was used as an alternative comparison to Wageningen propeller series type B 4-85 at 91.975% propeller load with speed of 25 knot. It was still in a work area propeller engine which was outside of world market area of 89.650%. Based on the fact that the propeller wageningen series type B 4-70 was still in the propeller engine working area of 94.909% propeller load, it can be concluded that there was a suitability between the power characteristics of the machine with propeller power.

Keywords: Ship Resistance, Power Boats, Propeller, Ship Propulsion, Engine propeller matching.

1. Introduction

Fast Patrol Boat (FPB) is a type of ship that have combat capability, limited great strike power and ideal avoidance speed to hide among the islands [1]. This paper have any literature to support the research about it, for example paper with title An Approximate Method For Calculation of Mean Statistical Value of Ship Service Speed on a Given Shipping Line, Useful in Preliminary Design Stage [2]. Experimental Investigation on Stern-Boat Deployment System and Operability For Korean Coast Guard Ship [3]. Performance of VLCC Ship with Poodded Propulsion System and Rudder [4]. Introduction to Naval Architecture [5]. Basic Ship Theory [6]. Practical Ship Design [7]. Ship Resistance and Propulsion : Practical Estimation of Ship Propulsive Power [8]. Practical Ship Hydrodynamics [9]. Effect of Fluid Density on Ship Hull Resistance and Powering [10]. Ship Design and Contraction [11]. Resistance Propulsion and Steering of Ship [12]. Predictive Analysis of Bare-Hull Resistance of a 25,000 Dwt Tanker Vessel [13]. Resistance and Propulsion of Ships [14]. Hydrodynamic of Ship Propellers [15]. Ship Design for Efficiency and Economy [16]. Design of Propulsion Systems for High-Speed Craft [17]. Method of Calculation of Ship Resistance on Calm Water Useful at Preliminary Stages of Ship Design [18]. Increase of Ship Fuel Consumption Due to the Added Resistance in Waves [19]. An Invetigation Into The Resistance Components of Converting a Traditional Monohull Fishing Vessel Into Catamaran Form [20]. Simulation of a Free Surface Flow over a Container Vessel Using CFD [21]. Empirical Prediction of Resistance of Fishing Vessels [22]. Designing Constraints in Evaluation of Ship Propulsion Power [23]. Coefficients of Propeller-hull Interaction in Propulsion System of Inland Waterway Vessels with Stern Tunnels [24]. Cost optimization of marine fuels consumption as important factor of control ship’s sulfur and nitrogen oxides emissions [25]. Numerical Investigation of the Influence of Water Depth on Ship Resistance [26]. The Wageningen Propeller Series [27]. Principles of Naval Architecture Second Revision [28]. Marine Propulsion [29].

The current condition did not meet the combat capability as expected in terms of weaponry and machinery. There was speed reduction, the original cruising speed was 25 knots, and the actual speed was only 20 knots only. Thus, it was necessary to analyze the vessel by using propeller matching engine process, in which the process of propeller matching engine was expected to have compatibility between power engine characteristics with propeller power [30]. This Paper is organized as follows. Section 2 review about the basic ship theory. Section 3 gives result and 4 discussion of research. Finally, in section 5 present conclusion of this paper.

2. Research Methodology

2.1. Technical Concept

In the selection of propellers according to the characteristics of the ship's propulsion engine, it is expected to have great combat capability and have such conditions:

1. High Accuracy, It allows the tactical and technical information to deliver quickly so that decisions can be obtained accurately and rapidly.
2. High Acquisition, This ensures control over the threat better, it requires the sewaco system and platform to be reliable.
3. High Speed, With the speed and agility of the vessel,
it allows to conduct amore dynamic and combat capability.

2.2. Propulsion System of The Ship
The ship propulsion system, which is the exact matching between prime mover (diesel engine, gas turbine, steam turbine) and propeller from ship [31]. Matching completion is not only seen from the engine or propeller point of view, but both are an integrated problem. In FIG. 1 there is provided a definition of the variables in terms of power, torque, and velocity.

![Fig. 1. Variable related with Matching Problems](image)

2.3. Ship Resistance
The ship's resistance (R) at a certain velocity is the fluid force acting opposite the movement of the vessel. The resistance will be the same as the fluid force component working parallel to the axis of the ship's movement. The required power (effective power) to drive the ship in water or to draw the vessel at speed $V_s$ is:

This is true only for relatively low velocity ships with froude number of ($F_n = 0,1-0,2$) and depends on the hull shape [32]. For high speed vessels, ship resistance is no longer a quadratic relationship of speed or with the rank of more than two.

![Fig. 2. Resistance-Speed Curve](image)

![Fig. 3. The Relationship Between Total Resistance and Speed of The Ship](image)

2.4. Displacement
Displacement is the weight of liquid displaced by the hull under the water surface. When the vessel floats in the balance state/motionless then the downward pressure equal to the pressure of the liquid to the hull. Thus the overall weight of the vessel and its contents at that time equal to the weight of liquid displaced by the hull immersed in a liquid in which the vessel is located [8].

Displacement : $LWL \times B \times T \times CB \times$ density of sea water (ton)

2.5. Volume Displacement
The volume of liquid displaced by the hull under the surface water where the ship is located [8].

Volume displacement: $LWL \times B \times T \times CB$

2.6. Selection of The Main Engine
In the selection of the main engine, it is necessary to calculate the need of power engine. There are several indicators that need to be sought in order to obtain the desired results, those are effective horse power (EHP), thrust horse power (THP), delivery horse power (DHP), shaft horse power (SHP) dan brake horse power (BHP) [8]:

![Fig. 4. Ship propulsion system](image)

2.7. Propeller
In propeller selection, there are some characteristics that must be considered and will be the main consideration, namely: propeller type, propeller diameter, pitch ratio and the number of propeller propeller blade. The propeller type selection with the most optimal level of efficiency, can be found using the Bp-δ diagram. The steps in propeller selection is as follows:

a. Bp Calculation

$$Bp = \frac{Np \times \sqrt{P_d}}{V_s^{3/2}}$$  \hspace{1cm} (1)

b. Cut off the Bp with optimum line propeller of efficiency.

c. $(P/D)\delta$ and $\delta_o$ value interpretation
d. Do value determination

$$Do = \frac{\delta_o \times V_s}{Np}$$  \hspace{1cm} (2)

e. Determination of Db value (behind the hull. For ship using

Single Screw $D_B = 0,95$ , Do and Double Screw $D_B = 0,97$ , Do
In the calculation of ship power needs, the propeller matching process becomes complex with changes in its service conditions. They are the changes in ship resistance due to fouling of ships, weather and ship-laden changes.

### 2.9. Method of Research
Fast Patrol Boat (FPB) and MTU 16V 595 TE 70L engine resistance analysis to propeller with supporting theory. Propeller analysis would be selected against optimum installed engine power. The method used in this research is literature study, field study, maxsurf program calculation, engine propeller matching and numerical calculation [33].

### 3. Result and Discussion
#### 3.1. Calculation of Ship Resistance
In the calculation of ship resistance, beside using formulas that exist in the resistance ship book with the help of excel program on the computer, maxsurf program was also used for comparison so that the accurate results could be obtained.

#### 3.2. Propeller Selection
The calculation results to find the efficiency of Wageningen series was performed using the data presented below:

#### Table 1. Propeller Wageningen Series Calculation Results

| Type Propeller | B4-40 | B4-55 | B4-70 | B4-85 | B4-100 |
|----------------|-------|-------|-------|-------|--------|
| 1/Jo           | 2.08  | 2.11  | 2.09  | 2.02  | 1.94   |
| δ              | 210,6329114 | 213,670886 | 211,6455696 | 204,557 | 196,4557 |
| eff            | 57,503 % | 57,109 % | 56,100 % | 54,803 % | 53,215 % |
| P/D            | 0,751 | 0,745 | 0,770 | 0,823 | 0,871 |
| P              | 1,171 m | 1,178 m | 1,206 m | 1,246 m | 1,266 m |
| D              | 5,114 ft | 5,188 ft | 5,139 ft | 4,967 ft | 4,770 ft |
| D_B            | 1,559 m | 1,581 m | 1,566 m | 1,514 m | 1,454 m |
| D_m            | 5,012 ft | 5,084 ft | 5,036 ft | 4,867 ft | 4,675 ft |
| D_max          | 1,528 m | 1,550 m | 1,535 m | 1,484 m | 1,425 m |
| δ_B            | 206,420 | 209,397 | 207,413 | 200,466 | 192,527 |
| ε              | 2,038 | 2,068 | 2,048 | 1,980 | 1,901 |
| (P/D)_θ        | 0,764 | 0,761 | 0,780 | 0,850 | 0,890 |
| εθ             | 58,450 % | 57,904 % | 56,902 % | 55,065 % | 54,270 % |

#### 3.3. Recalculation of Ship Power Needs
This was performed to find out whether the above propeller efficiency was still sufficient to the main engine power. Because in the calculation of power needs before, the assumption np = 0.6 was still used. Then, the efficiency obtained of propeller B4-70 was 56.9%. So it can be concluded that the basic assumptions of power requirements for engine selection still meet the available BHPSCR = 10673.026 HP (sufficient).

#### 3.4. Cavitation Calculation
The calculation of cavitation needs to be done in order to ensure a free propeller of cavitation that causes fatal damage to the propeller. Determining the relationship between the ship's resistance and the speed of the vessel will be implemented in the form of the relationship between KT (Thrust coefficient) and J (Advance Coefficient).

#### Table 2. Relationship Between Kt and J in Trial Condition (Clean Hull)

| J   | KT trial |
|-----|----------|
| 0   | 0,11379  |
| 0,2 | 0,045516 |
| 0,3 | 0,102412 |
| 0,4 | 0,182066 |
| 0,5 | 0,284478 |
| 0,6 | 0,409648 |
| 0,7 | 0,557576 |
| 0,8 | 0,728263 |
| 0,9 | 0,921708 |
| 1   | 1,137911 |
| 1,1 | 1,376872 |

The relationship between KT and J above was the relationship obtained in the trial condition (Clean Hull), to get the operation point of the propeller at the service condition then the sea margin price must also be considered. The price of sea margin would affect the size of the ship's resistance, therefore the relationship between KT and J would also change. The amount of sea margin suitable for cruise ships was 15% - 30% for Asia-pacific [14].
Furthermore, based on the data that had been obtained, graph of the relationship between KT and J on the condition of trial (Clean Hull) can be made as presented below:

![Graph KT-J on Trial Condition (Clean Hull)](image)

### 3.5. Propeller Characteristic

In designing the characteristics of propeller type B series 4-70 Wageningen series for fix propeller was used.

| J     | KT   | 10 KQ | Efisiensi |
|-------|------|-------|-----------|
| 0,000 | 0,350| 0,430 | 0,000     |
| 0,100 | 0,320| 0,400 | 0,130     |
| 0,200 | 0,288| 0,365 | 0,252     |
| 0,300 | 0,250| 0,328 | 0,368     |
| 0,400 | 0,210| 0,280 | 0,471     |
| 0,500 | 0,169| 0,231 | 0,568     |
| 0,600 | 0,120| 0,182 | 0,627     |
| 0,700 | 0,070| 0,131 | 0,621     |
| 0,800 | 0,0250| 0,078 | 0,432     |
| 0,900 | 0,000| 0,027 | 0,000     |
| 1     | 0    | 0     | 0         |
| 1,1   | 0    | 0     | 0         |

Then, a curve graph between KT - KQ - J - ηo on open water test B4-70 in the table above was made and presented in the figure below:

![Graph KT- KQ - J - ηo in Open Water Test B4-70](image)

### 3.6. Engine-Propeller Matching

The graph of resistance KT-J characteristic with open water test curve B4-70 was presented as follows:

![Graph KT-J Curve in Open Water Test B4-70](image)

### 3.7. The Calculation of Delivered Power in Trial Condition (Clean Hull)

Based on the table delivered power on the above trial conditions, it could be described in the form of diagrams below:

![Propeller B4.70 Load Curve](image)

### 4. Discussion

Engine load characteristics obtained from the main engine data MTU 16V 595 TE 70L was described as follows:
Table 5. Engine Load Characteristic Data

| Rpm ME | Power (Kw) | Power (Hp) | % Power | % Rpm  |
|--------|------------|------------|---------|--------|
| 500    | 0          | 0          | 0       | 27,778 |
| 500    | 400        | 543,845    | 10,1910828 | 27,778 |
| 600    | 566        | 769,546    | 14,42038217 | 33,333 |
| 700    | 760        | 1033,312   | 19,36305732 | 38,889 |
| 800    | 950        | 1291,64    | 24,20382166 | 44,444 |
| 900    | 1170       | 1590,757   | 29,8089172 | 50     |
| 1000   | 1425       | 1937,46    | 36,30573248 | 55,556 |
| 1100   | 1700       | 2311,356   | 43,31210191 | 61,111 |
| 1200   | 1970       | 2678,454   | 50,1910828 | 66,667 |
| 1300   | 2300       | 3127,129   | 58,59872611 | 72,222 |
| 1400   | 2615       | 3555,409   | 66,62420382 | 77,778 |
| 1500   | 2960       | 4024,479   | 75,41401274 | 83,333 |
| 1600   | 3355       | 4561,529   | 85,47770701 | 88,889 |
| 1700   | 3740       | 5084,983   | 95,286624 | 94,444 |
| 1800   | 3925       | 5336,513   | 100     | 97,222 |

Then, the data for propeller load characteristics of the MTU machine 16V 595 TE 70L was described as follows:

Table 6. Propeller Load Characteristic Data

| Rpm ME | Rpm propeller | Propeller Power (Kw) | Propeller Power (HP) | % Power | % Rpm |
|--------|---------------|----------------------|----------------------|---------|-------|
| 500    | 235,960       | 95                   | 129,164              | 2,420382 | 27,778 |
| 600    | 283,152       | 130                  | 176,7508             | 3,312102 | 33,333 |
| 700    | 330,344       | 210                  | 285,5204             | 5,350318 | 38,889 |
| 800    | 377,536       | 315                  | 428,2807             | 8,025478 | 44,444 |
| 900    | 424,728       | 450                  | 611,8295             | 11,46497 | 50    |
| 1000   | 471,920       | 625                  | 849,7632             | 15,92357 | 55,556 |
| 1100   | 519,1128      | 760                  | 1033,312             | 19,36306 | 61,111 |
| 1200   | 566,3049      | 1060                 | 1441,198             | 27,00637 | 66,667 |
| 1300   | 613,4969      | 1350                 | 1835,489             | 34,3949 | 72,222 |
| 1400   | 660,689       | 1700                 | 2311,356             | 43,3121 | 77,778 |
| 1500   | 707,8811      | 2090                 | 2841,608             | 53,24841 | 83,333 |
| 1600   | 755,0731      | 2533                 | 3443,92              | 64,53503 | 88,889 |
| 1700   | 802,2652      | 3050                 | 4146,845             | 77,70701 | 94,444 |
| 1750   | 825,8613      | 3300                 | 4486,75              | 84,07643 | 97,222 |
| 1800   | 849,4573      | 3610                 | 4908,232             | 91,97452 | 100   |

Based on the data about the main engine above, we could make the engine envelope curve to be plotted with propeller load B4.70. This was done to determine whether the selected stapler and propeller had been matched or matched. Here is the curve of the basic machine data above:

Fig. 9. Engine Load Characteristic Curve

Fig. 10. Propeller Load Characteristic Curve

Furthermore, the engine and propeller load characteristics curve above was plotted with the result of propeller load calculation from the selected propeller that was propeller type B4.70. The plot was described as follows:
The results of the engine-propeller matching curve readings could be expressed as follows:

| Analysis       | % Rpm | Power (Hp)   | % of power |
|----------------|-------|--------------|------------|
| Engine Load    | 100   | 5336,513     | 100 %      |
| Propeller Load | 100   | 4908,232     | 91,975 %   |

5. Conclusion

Based on the calculation results data above, the Propeller load of 5064.836 Hp and the power percentage of 94.909% were obtained. When compared to the propeller load characteristics of the MTU 16V 595 TE 70L 4908.232 machine with the power percentage of 91.975%, then wageningen series type B4.70propeller meets the propeller work area. The power margin above 90% in a clean hull condition indicated that it is very capable to keep the ship service conditions as expected at a maximum speed of 25 knots.

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In marine engineering, the efficiency of a ship is determined by various parameters. The nomenclature for the discussed concepts includes:

- **R**: Ship Resistance
- **\( V_S \)**: Speed of The Ship
- **\( P_E \)**: R.Vs
- **\( P_D \)**: Delivered Power
- **\( \eta_P \)**: \( \eta_P \) \( \eta \) \( \eta \)
- **\( T \)**: Thrust Force Propeller
- **\( P_S \)**: Shaft Power
- **\( V_A \)**: Speed of Advance
- **\( Q \)**: Torque Propeller \([N.m]\) in Open Water Condition
- **\( P_B \)**: Brake Power
- **\( n \)**: RPM Propeller per Second \([s^{-1}]\)
- **\( \eta_T \)**: Total Efficiency
- **\( \eta_H \)**: Hull Efficiency = \( (1-t) / (1-w) \)
- **\( t \)**: Thrust Deduction Factor
- **\( i \)**: Gear Ratio : \( i = n/ne \)
- **\( w \)**: Wake Fraction
- **\( \eta_D \)**: Propeller Efficiency in a Mounted State in The Back of The Ship
- **\( \eta_O \)**: Open Water Propeller Efficiency
- **\( \eta_R \)**: Relative Rotative Efficiency
- **\( \eta_A \)**: Axis Efficiency
- **\( \eta_M \)**: Mechanical Efficiency
- **\( \eta_{gear} \)**: Gear Efficiency
- **\( P_{PTO} \)**: Power Take Off
- **\( \omega \)**: Angular Speed of Propeller Axis \([s^{-1}] = 2\pi n \)
- **\( n_e \)**: Rotational Speed of Engine (Prime Mover), \([s^{-1}]\)