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TECHNICAL ANALYSIS OF ENGINE PROPELLER MATCHING KRI X AFTER MAIN ENGINE REPOWERING

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ABSTRACT

The gas turbine, which is one of the main engines of KRI X, is not used anymore because of the amount of damaged material. In 2017, it was decided to replace its main engine. Ships that previously used gas turbines and two diesels as the main engines are replaced with four MTU diesel engines with 4000 HP power and 2100 rpm rotation per engine. With a fixed propeller and a power change on the main engine, the matching point of the main engine also changes. Referring to the problem, this study conducted an assessment of engine propeller matching obtained after repowering the main engine, by calculating the pricing of the ship and calculating the power required by the ship. The calculation of ship resistance is done in two ways: with the help of running software Maxsurf with the Holtrop method, and by using an empirical formula. Having known the price of the ship's resistance and power required, then calculated the speed of the ship with the new main engine and the variation of the pitch propeller. The result of this research obtained the operating point (matching point), which resulted in optimum speed obtained at the main rotation condition of 1974 rpm, propeller rotation 452,666 rpm, with 85% power loading that is 6152,426 kW, ship speed reached 17,855 Knot, and in this condition is deemed to be by the operation of the continuous service rating.

Keywords: Engine propeller matching, repowering, pitch propeller

Introduction

KRI X previously used a CODOG (Combined Diesel or Gas) model thruster system. But in 2009, the gas turbine, which is one of the main engines of this ship, was no longer used because of the many damaged materials. Due to the age of this ship, in 2017, it was decided that a complete overhaul of KRI X would be carried out due to material fatigue on the plates, buildings, and engines.

Due to the difficulty of obtaining spare parts, expensive maintenance costs, and wasteful fuel, the relevant parties finally decided to repower the main engine. The ship, which previously used one gas turbine and two diesels as main engines, was replaced with four MTU brand diesels and used the CODAD (Combined Diesel and Diesel) system.

With a fixed propeller and a change in the power of the main engine, the matching point of the main engine also changes. Referring to these problems, this study examines the engine propeller matching obtained after repowering the main engine by calculating the price of ship resistance in two ways, namely with the help of running Maxsurf software with the Holtrop method and calculations using empirical formulas. After knowing the price of ship resistance and the required power, the calculation of ship speed with the new main engine and variations in the magnitude of the propeller pitch are carried out. The object that will be used in this research is KRI X.

Methodology

a. Controllable Pitch Propeller

A controllable Pitch Propeller is a propeller whose pitch can be adjusted. Pitch is the axial distance traveled or taken by the propeller at one full rotation (3600). In general, the CPP system consists of several components:

1. A propeller hub with a blade whose pitch can be moved from full ahead to full astern.
2. Propeller shaft with oil distribution box.
3. Hydraulic system.
4. Remote control system

Its operation can be done with two systems, namely the pull-push rod system and the hub piston system. In the pull-push rod system, a long rod is used, which is connected from the ship's shaft to the propeller hub. In the hub piston system, the piston rod is placed on the propeller hub. The advantages of using a controllable pitch propeller, namely:

1. It can be used to accelerate, stop, and process ship movements properly.
2. The thrust force can be kept constant under changing load conditions.
3. It is economical for ships working at different speeds and load conditions.

The disadvantages of using a controllable pitch propeller namely:

1. CPP construction is quite complicated.
2. The price is relatively high.
3. Requires more attention in terms of maintenance than a regular propeller. This is due to the complexity of the hub construction and the hydraulic system.

b. Ship Resistance

According to Harvard (1992) [1], Ship resistance is the fluid force acting on the ship in such a way that it opposes the ship's motion. The total resistance itself is broken down into several different components that result from a variety of causes and interact with each other in a truly complex way.

The faster the movement of the ship, the greater the resistance it receives. So, to keep moving at its speed, the ship must be able to overcome these obstacles with the thrust generated by the performance of the propeller. Which thrust comes from the brake force (PB), which is the power released by the propulsion motor and is channeled to the ship's propeller and then converted into thrust (PT).

By using the Holtrop method, the total resistance of the ship can be obtained with the equation as follows:

$$RT = \frac{1}{2} x\ \rho\ x\ V^2\ x\ S_{tot}\ x\ (C_F(1+K)C_A) + \frac{R_W}{W}$$

c. Drive Motor Power

In general, a ship that moves in the water medium at a certain speed will experience a drag (resistance) that is opposite to the direction of motion of the ship. The amount of drag that occurs must be able to be overcome by the thrust of the ship (thrust) resulting from the work of the ship's propulsion device (propulsor). The power supplied (PD) to the ship's propulsion is derived from the shaft power (PS), while the shaft power itself comes from the brake power (PB), which is the output power of the ship's propulsion motor. Several notions of power are often used in estimating the power requirements of ship propulsion systems, among others:

- Effective Horse Power (EHP)

  Is the amount of power needed to overcome the drag force of the hull so that the ship can move from one place to another with a service speed of VS. This effective power is a function of the total drag and ship speed. To get the effective power of the ship, the following equation can be used:

$$EHP = R_T\ x\ V_S$$

- Thrust Horse Power (THP)

  Is the amount of power generated by the work of the ship's propulsion device (propulsor) to push the ship's body. Thrust is a function of the thrust force and fluid flow rate that occur when the ship's propulsion device works. The equation. Thrust can be written as follows:

$$THP = \frac{EHP}{\eta \text{HULL}}$$

- Delivery Horse Power (DHP)

  Is the power absorbed by the ship's propeller to produce thrust of PT, or, in other words, PD, the power supplied by the propulsion motor to the propeller, which is then converted into the ship's thrust (PT).

  The variables that affect this power are the torque delivered and the propeller turn, so the equation for calculating PD is as follows:

$$PD = 2\pi\ x\ QD\ x\ nP$$

- Shaft Power (Ps)

  The power is measured up to the area in front of the stern tube bearing of the ship's propulsion system. For ships powered by gas turbines, in general, the power used is PS. Meanwhile, the term brake power (PB) refers to the power generated by the main engine motor with a type of PS. motor (main engine) in marine diesel engines.
- Efficiency in ship propulsion systems

  Ship propulsion systems have several definitions of transmitted power, ranging from the power released by the propulsion motor to the power delivered by the ship's propulsion to the surrounding fluid. The ratio of these powers is often expressed by the term efficiency, although in some cases it is not a direct power conversion value. In assessing propulsion efficiency, other technical factors are taken into account due to the operation of the propeller and the shape of the ship, so that propulsion efficiency can be viewed from several aspects, namely:
  - ❖ Hull Efficiency ($\eta HULL$)

    It is the ratio between effective power (PE) and thrust (PT). Hull efficiency is a measure of the suitability of the hull design (stern) to the propulsor arrangement, so this efficiency is not a form of actual power conversion. So even though this Hull Efficiency value can be more than one, generally a number around 1.05 is taken.

    Calculations that are often used in obtaining hull efficiency are as follows:

    $$\eta\text{HULL} = \frac{(1-tt)}{(1-w)}$$
  - ❖ Propeller Efficiency (ηPROP)

    It is the ratio between the thrust (PT) and the power supplied (PD). This efficiency is power conversion, and the difference in value that occurs is located where the propeller torque measurement is carried out. Specifically, whether in open water conditions (Q0) or conditions behind the ship (QD), the following equation shows both conditions of propeller efficiency, as follows:

    Efficiency propeller of open water

    $$\eta_0 = \frac{T\ x\ V_A}{2\ x\ \pi\ x\ Q_0\ x\ n}$$

    The efficiency propeller behind the ship

    $$\eta_B = \frac{P_T}{P_D} = \frac{T\ x\ V_A}{2\ x\ \pi\ x\ Q_0\ x\ n}$$

    Because there are two conditions, an efficiency ratio appears, known as Relative-Rotative Efficiency, $\eta\eta RR$, which is a comparison between the Propeller Efficiency in conditions behind the ship with the Propeller Efficiency in conditions in open water, as follows:

    $$\eta_{RR} = \frac{\eta_B}{\eta_0} = \frac{T\ x\ {V_A}/{2}\ x\ \pi\ x\ Q_D\ x\ n}{T\ x\ {V_A}/{2}\ x\ \pi\ x\ Q_D\ x\ n} = \frac{Q_0}{Q_D}$$

    Therefore, ηRR is not a property of the actual efficiency (not a power conversion). This efficiency is only a comparison of different efficiency values. So, the magnitude of relative rotative efficiency can also be greater than one, but generally, the value is taken to be around one.
  - ❖ Shaft Transmission Efficiency (ηS)

    Shaft Transmission Efficiency, ηS, can generally be defined mechanically with more than one type of efficiency, which is highly dependent on the configuration of the stern arrangement. This efficiency is the product of the overall efficiency of each component installed. Efficiency can be expressed as an equation, as follows:

    $$\eta_S = \frac{P_D}{P_S}$$
  - ❖ Overall Efficiency (ηP)

    Also known as propulsive efficiency, or propulsive coefficient, is the result of the overall efficiency of each power phase that occurs in the ship's propulsion system. The overall efficiency can be obtained with the equation as follows:

    $$\eta_P = \frac{P_E}{P_T} x \frac{P_T}{P_D} x \frac{P_D}{P_S} = \eta\text{HULL x}\ \eta_B\ x\ \eta_S$$

    $$= \eta\text{HULL}\ x\ \eta_0\ x\ \eta_{RR}\ x\ \eta_S$$
- Installed Motor Power

According to S. W. Adji (2005) [2], the ship propulsion motor power (PB) in question is brake power, or power received by the transmission shaft of the ship propulsion system (PS), which is then operated continuously to move the ship at its service speed (VS). If the amount of mechanical efficiency in the gearbox arrangement, which serves to reduce and reverse the rotation of the drive motor, is 98 percent, Then the driving motor power ship can be calculated, as shown in the equation below:

$$P_B - CSR = \frac{P_S}{0{,}98}$$

The power on the PB-MCR can then be used as a reference in carrying out the drive motor selection process (Engine Selection Process).

- Hull and Propeller Characteristics

According to S. W. Adji (2005) [2], one of the most influential stages in carrying out the engine-propeller matching analysis process is the modeling stage of the characteristics of the designed or observed ship body. This is because the characteristics of the ship's body have a direct effect on the characteristics of the propeller.

❖ Characteristics of Ship Propellers

In general, the characteristics of ship propellers under open water test conditions are as represented in Diagrams KT- KQ - J. Each type of ship propeller has different performance curve characteristics. So, the study of the characteristics of ship propellers cannot be generalized for the entire shape or type of propeller. The equation model for propeller characteristics is as follows:

$$K_T = \frac{T_{prop}}{\rho \; x \; n^2 \; x \; D^4}$$

$$K_Q = \frac{Q_{prop}}{\rho \; x \; n^2 \; x \; D^5}$$

$$J = \frac{V_A}{n \; x \; D}$$

$$\eta_O = \frac{J \; x \; K_T}{2\pi \; x \; K_Q}$$

❖ Hull-Propeller Interaction

Hull and Propeller Interaction is an on-paper approach to efforts to obtain the performance characteristics of the propeller when operating in behind-the-ship conditions. The method is to process the equation as follows:

$$T_{SHIP} = \frac{\alpha \, V_A^2}{(1-t)(1-w)^2}$$

$$T_{prop} = K_T \; x \; \rho \; x \; n^2 \; x \; D^4$$

$$\mathbf{T_{Ship} = T_{Prop}}$$

$$K_T = \frac{\alpha \, V_A^2}{(1-t)(1-w)^2 \, \rho \, n^2 \, D^4}$$

$$\beta = {}^{\alpha}/_{(1-t)(1-w)^2 \rho D^2} \; \ldots\ldots\ldots (2.84)$$

Then it becomes,

$$K_T = \beta \; x \; \frac{V_A^2}{n^2 D^2}$$

So that the equational relationship is obtained as follows:

$$K_T = \beta \; x \; J^2$$

The next step is to make a 'tabulation'. The "J" price is taken from the open water test diagram of the propeller that will be used on the ship, which is from the lowest number, moving gradually to the highest number. Then, the tabulated results are plotted on the open-water test diagram of the propeller, as illustrated in the figures below. illustrated in the following figures below.

$$\beta = {}^{\alpha}/_{(1-t)(1-w)^2 \rho D^2}$$

Then it becomes,

$$K_T = \beta \; x \; \frac{V_A^2}{n^2 D^2}$$

So that the equation relationship is obtained as follows:

$$K_T = \beta \; x \; J^2$$

❖ Propeller Load Characteristics

In developing the 'trend' propeller load characteristics, the variables involved are propeller torque and propeller speed. For propeller torque is the result of graphically processed from the hull & propeller interaction, namely KQ and KQ-SM, which are then developed as the equation below:

$$Q_{\,Prop} = K_Q \times \rho \times n^2 \times D^5$$

$$Q_{\,Prop} = K_{Q\text{-}SM} \times \rho \times n^2 \times D^5$$

From the two equations above, the characteristic trend of propeller power (∞ Propeller Load) can be obtained as follows:

[Power] = [Torque] * [Speed]

The next step is to tabulate the trend of propeller power characteristics with the inputs of "propeller speed," which is obtained from "engine speed" after being reduced by mechanical gears (note the gear ratio). The figure below illustrates the tabulation and trend of the propeller power developed.

- Drive Motor Characteristics Ship

  The method of combustion and atomizing of fuel in diesel motors is not the same as in gasoline motors. In gasoline motors, a mixture of fuel and air through the carburetor is put into the cylinder and burned by an electric flame from the spark plug. In diesel motors, which are sucked by the piston and put into the combustion chamber, only air is compressed until it reaches a high temperature and pressure. A few moments before the piston reaches the top dead point (TMA), diesel fuel is injected into the combustion chamber. With a high enough temperature and air pressure in the cylinder, the fuel particles will ignite by themselves to form a combustion process. For the diesel fuel to burn itself, it must have a compression ratio of 15–22 and an air temperature of approximately 600ºC.
- Combination of Engine and Propeller Characteristics

  Matching Point According to S. W. Adji (2005) [2], the operating point of the ship's propulsion motor rotation (engine speed) is such that it matches the character of the propeller load, namely the operating point of the motor rotation, where the power absorbed by the propeller is equal to the power produced by the engine and produces a ship speed that is close to (the same) as the planned ship service speed. Propeller characteristics are as shown in Figure 2.6, while engine characteristics are represented in Figure 2.9. To be able to equate the two trendlines into the same plotting means, first, the price of the two trendlines is expressed in a percentage (%). At engine speed, n is the operating point of the propulsion motor rotation that corresponds to the propeller load condition, because the power generated by the propulsion motor is equal to the power absorbed by the propeller. This will certainly provide optimal consequences for the use of fuel consumption by the propulsion motor of the ship against the desired service speed of the ship.

Result and Discussion

a. Calculating Ship Resistance

Of the two methods used to get the value of the total resistance of the ship, the results obtained are:

1. Determining the value of ship resistance with help from Maxsurf software, 64-bit resistance resulted in a total resistance of 265.1 kN.
2. Calculation of the ship resistance value with an empirical formula resulted in a total resistance value of 286.375 kN.

b. Calculation of KT, KQ, J

The next step after calculating the value of ship resistance is to get the values of KT, KQ, and J. Where KT is the thrust coefficient, KQ is the torque coefficient, and J is the advance coefficient. The first step is to use interpolation taken from the open-water test propeller diagram. The second, by calculating the value of the thrust coefficient during trial conditions (KT-trial) and the thrust coefficient during service conditions (KT-SM). when service conditions (KT-SM).

- Open water test propeller KT - KQ - J value

  It can be seen that the pitch ratio (P/D) value on the controllable pitch propeller can change, but it is still one type of propeller (B.5-75). By looking at the Wageningen B-Screw series propeller open-water test diagram, a table is made showing the KT-KQ-J value interpolated from the open-water test propeller diagram with a pitch ratio value variation from 0.6 to 1.21 with an increase of 0.1 per level of variation, as shown in tables 4.3 to 4.9, respectively. After obtaining the KT - KQ - J value, a graph is made showing the value of the open water test propeller diagram tabulation, which is shown in Figures 4.10 to 4.16, respectively.

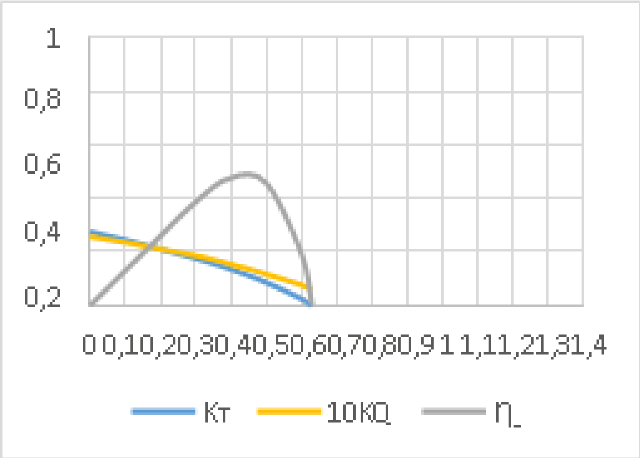

Figure 1. Graph of Openwater Test Propeller at P/D 0.6

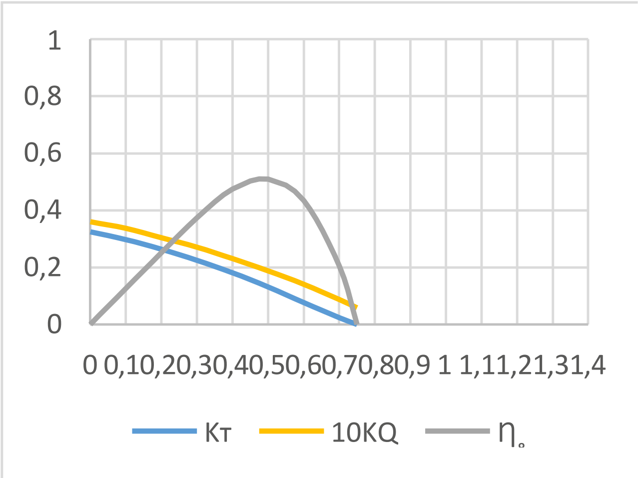

Figure 2. Graph of Openwater Test Propeller at P/D 0.7

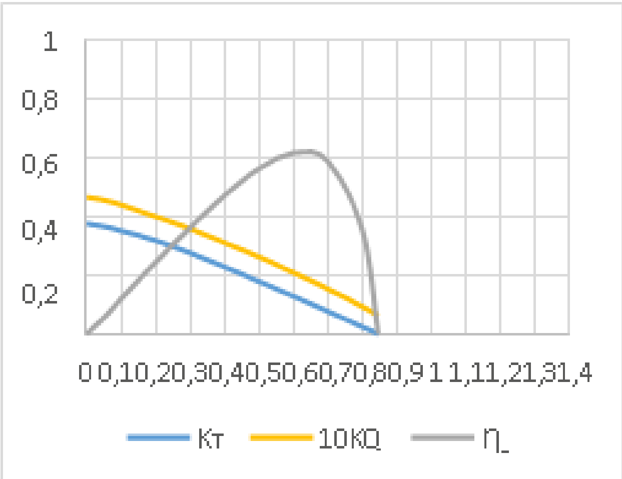

Figure 3. Graph of Openwater Test Propeller at P/D 0.8

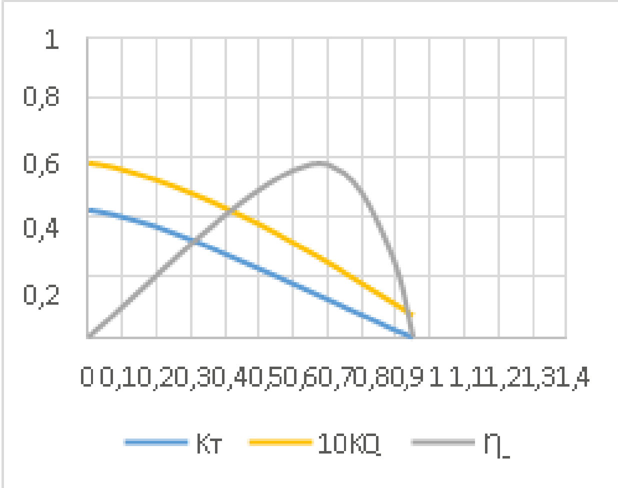

Figure 4. Graph of Openwater Test Propeller at P/D 0.9

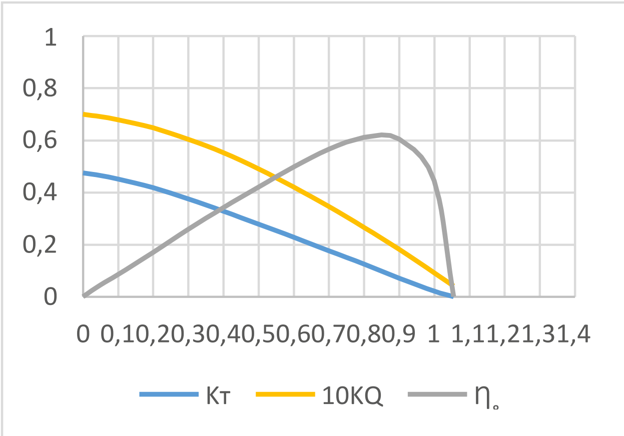

Figure 5. Graph of Openwater Test Propeller at P/D 1.0

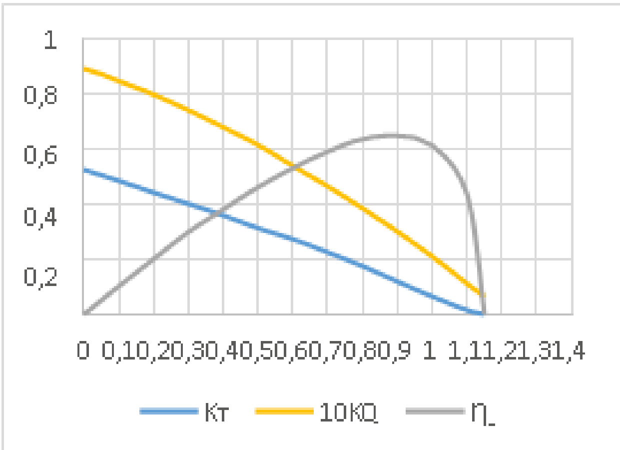

Figure 6. Graph of Openwater Test Propeller at P/D 1.1

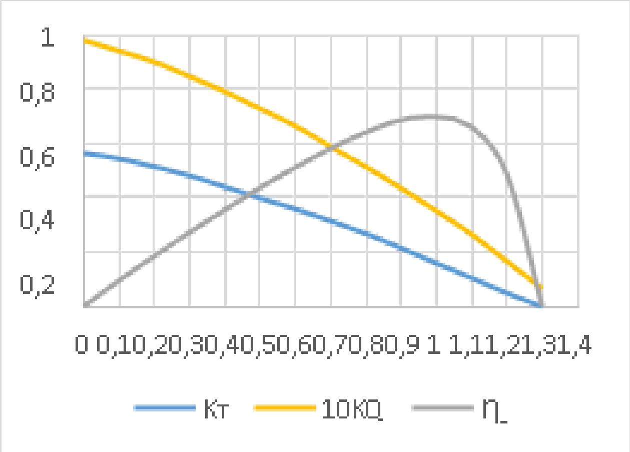

Figure 7. Graph of Openwater Test Propeller at P/D 1.2

- Calculation of KT-trial and KT-SM Values

The calculation of the thrust coefficient value is carried out under trial conditions (KT-trial) and service margin conditions (KT-SM). By using equations 2.86 and 2.87, the KT and KT-SM values are obtained:

$$KT = \beta \ x \ J^2$$
$$= \frac{\alpha}{(1-t)(1-w)^2 \ x \ \rho \ x \ D^2} x \ J^2$$
$$= 1{,}274 \ x \ J^2$$
$$K_{T-SM=120\% \ x \ \beta \ x \ J^2}$$
$$= 120\% \ x \ 1{,}274 \ x \ J^2$$

The next step is to calculate the value of KT and KT-SM by varying the advanced coefficient (J). The J value is taken from the open-water test propeller diagram, which moves from the lowest number to the highest number. Then the results of the tabulation of the KT and KT-SM values are plotted in a graph that shows the trendline of the thrust trial condition coefficient (KT) and the thrust service margin coefficient (KT-SM), as shown in Figure 8.

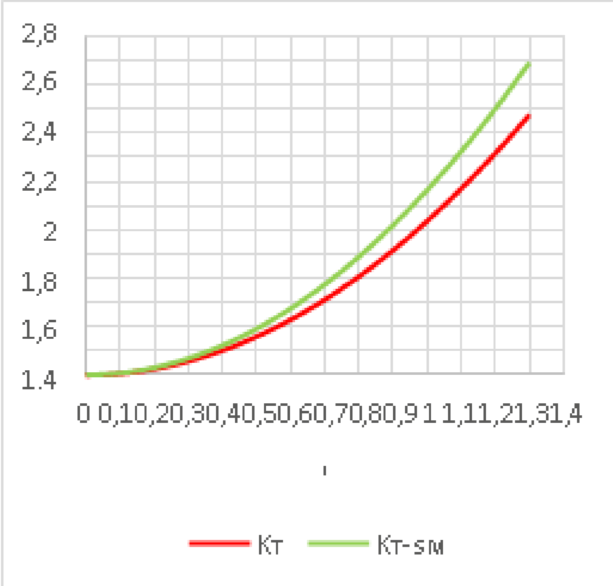

Figure 8. Graph KT-trial and KT-SM

From the graph above, the trendlines of the trial condition thrust coefficient (KT) and service margin thrust coefficient (KT-SM) can be seen. The greater the value of the advanced coefficient (J), the higher the value of KT and KT-SM.

- Relationship graph of KT, KQ, J, and ηo

To determine the relationship between KT, KQ, J, and ηo, obtained from the intersection of the KT and KT-SM graphs and the open-water test propeller graph with variations in pitch ratio (P/D), the next step is to determine the intersection point between the KT open-water test propeller curve and the KT-SM curve. After obtaining the intersection point, a vertical line is drawn until it intersects the KQ curve. After that, a horizontal line is drawn from the KQ curve, and the value of the torque coefficient (KQ) is obtained. The same steps are also carried out on the KT curve of the open-water test propeller, and the KT curve in the trial conditions is shown in Figures 9 to 15, respectively.

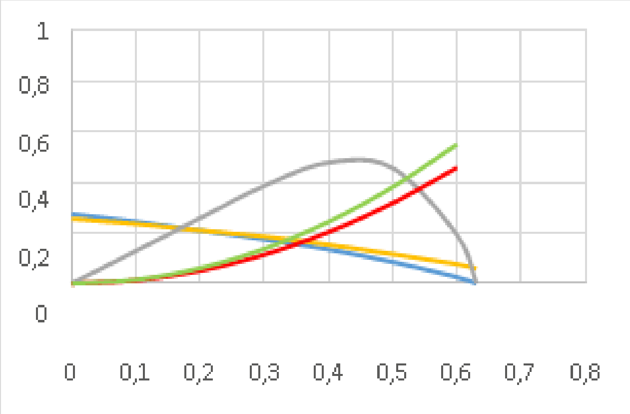

Figure 9. Openwater Test Propeller at P/D 0,6

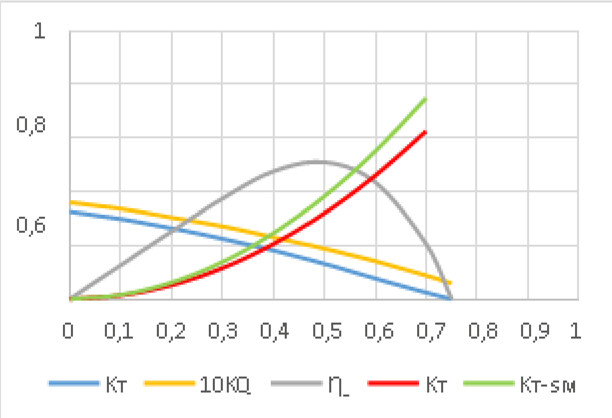

Figure 10. Openwater Test Propeller at P/D 0,7

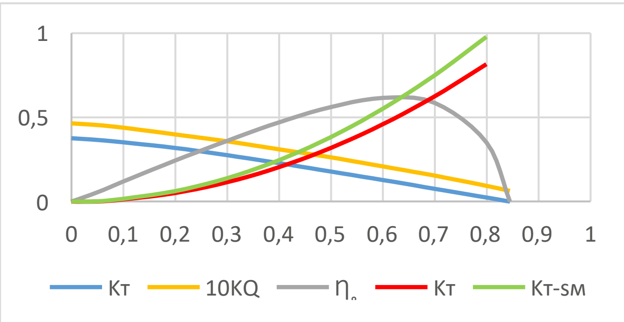

Figure 11. Openwater Test Propeller at P/D 0,8

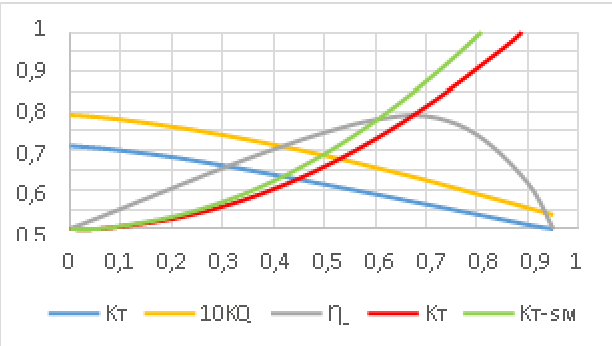

Figure 12. Openwater Test Propeller at P/D 0,9

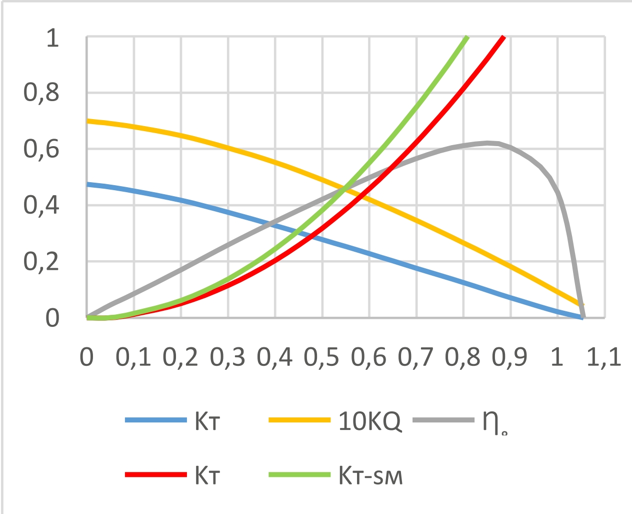

Figure 13. Openwater Test Propeller at P/D 1.0

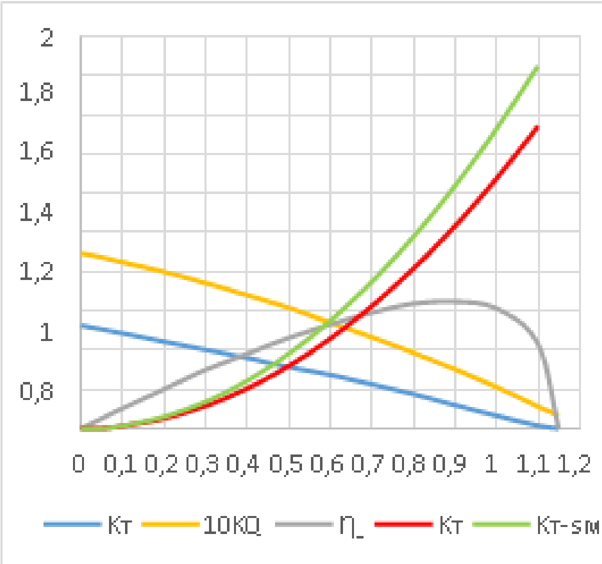

Figure 14. Openwater Test Propeller at P/D 1.1

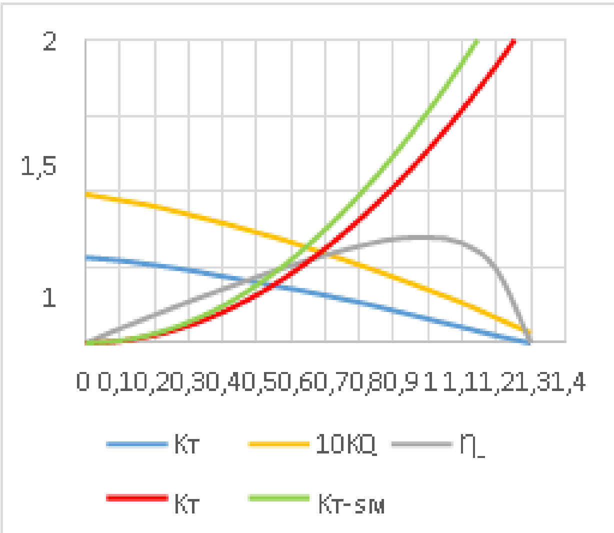

Figure 15. Openwater Test Propeller at P/D 1.2

From the intersection of the KT and KT-SM graphs with the open-water test propeller graph shown in Figures 9 to 15, the obtained torque coefficient (KQ) data on trial and service conditions are presented in Table 1.

c. Engine Power Calculation

By knowing the values of J and KQ above, it can be calculated the amount of torque (Q), power (DHP), and BHP produced by the propeller using the equation that has been mentioned. The next step is to tabulate the results of the equation with variations in engine rpm, as shown in Tables 4.12 and 4.13. Then, the tabulated results are made into a graph showing the relationship between power (BHP) and engine RPM, as shown in Figure 16.

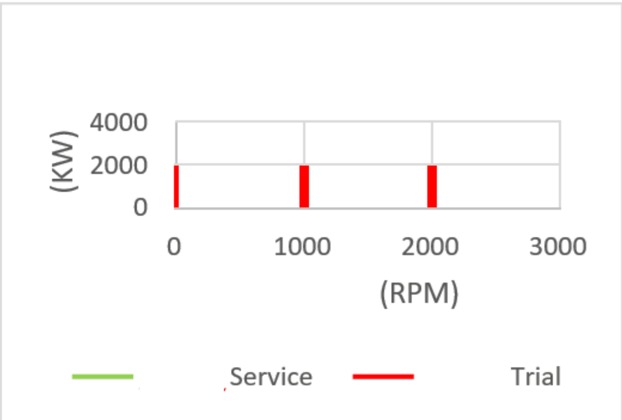

Figure 16. Graph of Power Relationship with Engine RPM

From the graph of the relationship between power and engine rpm above, it can be seen that the greater the engine speed, the higher the power. In other words, engine speed is proportional to the value of the power produced.

d. Matching Point

Because of the difference between engine speed and propeller speed, the matching process assumes that the magnitude of engine speed is equal to propeller speed, or that 100% engine speed is equal to 100% propeller speed. To plot the propeller load curve in the working area of the main engine, the curve is the amount of engine speed and propeller rotation expressed on the abscissa axis of the curve, expressed in percentage scale (%) [3]. The results of depicting the propeller curve into the main engine characteristics are shown in Figure 17, and after the matching points are found, each of these points is analyzed to find out: Motor power, engine speed, propeller speed, and propeller load. Ship speed achieved from the graph above, several matching points are obtained between the old propeller and the new main engine after repowering, as follows:

Titik	Kondisi	Rpm *Engine*	Rpm *Propeller*	% Rpm	% Daya	Daya (kW)	Vs
A	*Service* CSR	1974	452,666	94	85	3076,213	17,855
B	*Trial* CSR	1911	438,666	91	85	3076,213	17,461
C	*Service* MCR	2100	466,666	100	98	3925,158	20,582
D	*Trial* MCR	2100	466,666	100	92	3684,843	20,122

Figure 17. Matching point result

From the matching points that have been obtained, which are analyzed only under service conditions and are expressed as follows:

1. Point A is the propeller load point at 3076.213 kW, or 85% (service rating), with a propeller rotation of 452.666 rpm. Produces a speed of 8.927 knots, which corresponds to the speed in free-running conditions. In this condition, the matching point is in the engine envelope working area. So, this condition is considered safe for continuous service rating (CSR) operations.
2. Point C is the propeller load point at 3925.158 kW, or 85% (service rating), with a propeller rotation of 466.666 rpm. Resulting in a speed of 10.291 knots. In this condition, the matching point is in the maximum working area of the engine envelope. Therefore, this condition is only permitted during sea trials.

Conclusion

Based on the analysis and discussion, The matching point obtained after repowering the main engine between the old propeller and the new main engine on KRI X which produces the optimum speed of two engines and one propeller is obtained under the condition that the main engine rotation is 1974 rpm, the propeller rotation is 452.666 rpm reaching 94% of its maximum rotation, with a power loading of 85% which is 6152.426 kW, the ship's speed reaches 17.855 Knots, in this condition it is considered by the continuous service rating operation and by the desired speed. This thesis can be developed by conducting further studies on the re-planning of the engine mount construction due to changes in the main engine dimensions.

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