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# STUDY CASE ON THE CHARACTERISTICS AND PERFORMANCES OF A PROPULSION SYSTEM FOR A CRUDE OIL TANKER

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## ABSTRACT

*This paper presents aspects regarding the analysis of the characteristics and performances of a propulsion system for a crude oil tanker. The study involved several steps: first, the ship's resistance and the necessary propulsive power were calculated to choose and design the main components: engine, transmission and propeller; to obtain maxim propulsive efficiency at the desired speed, with low fuel consumption and reduced $CO_2$ emissions. Four slow Diesel engines were selected and the optimal propellers were designed to analyse and adopt the more efficient solution. A number of factors were taken into account for ship propulsion system components selection such as: required power, revolution rate to ensure an optimal propeller diameter to be located behind the ship, the specific fuel consumption parameters, desired ship speed, etc.*

**Keywords:** ship propulsion system, propeller design, EEDI

## 1. INTRODUCTION

The preliminary design of a naval propulsion system involves the component elements choosing (prime mover, transmission, propulsor) to find an optimal configuration that ensures maximum propulsion efficiency at the required speed, with improved fuel economy and reduced pollutant emissions. The purpose of the present work was to analyse, in a preliminary design stage, the main characteristics and the performances of a propulsion system for a crude oil tanker. The study involved several steps: first, the ship resistance and necessary propulsive power were calculated to choose and design the main components: engine, transmission and propeller.

The aim was to obtain maxim propulsive efficiency at the desired speed, with lower fuel consumption and reduced $CO_2$ emissions, without neglecting aspects related to reduction of the engine compartment space to increase the cargo space, reduced operational costs, etc. Four slow Diesel engines were selected and the optimal propellers have been designed to analyse and adopt the most efficient solution. A number of factors were taken into account for the ship propulsion system components selection, such as: required power, revolution rate to ensure an optimal propeller diameter to be located behind the ship, the specific fuel consumption parameters, required ship speed, etc.

## 2. GEOMETRICAL AND HYDRODYNAMIC CHARACTERISTICS OF THE TANKER SHIP HULL

The study has been carried out for a 35200 tdw crude oil tanker [1], having the main characteristics presented in Table 1.

**Table 1**. Tanker main geometrical characteristics

| | | |
|---|---|---|
| Length over all | 185.3 | [m] |
| Length waterline | 180 | [m] |
| Beam | 28 | [m] |
| Draught | 10.5 | [m] |
| Block coefficient | 0.89 | [-] |

In a first step, the calculation of the total hydrodynamic resistance of the ship was carried out by empirical methods, using the Holtrop-Mennen method. The resulting data are presented in Figure 1 and they were used to estimate the propulsion power on board and to choose the engine to power the ship.

To determine the total ship resistance $R_T$, the Holtrop Mennen calculation method was applied in a Microsoft Office Excel code developed by the first author and the PHP program was also used to verify the correctness of the computation. The calculation was carried out for a range of speeds V around 14.5 knots, and the input data were taken from Dragomir Compendium Forms [1].

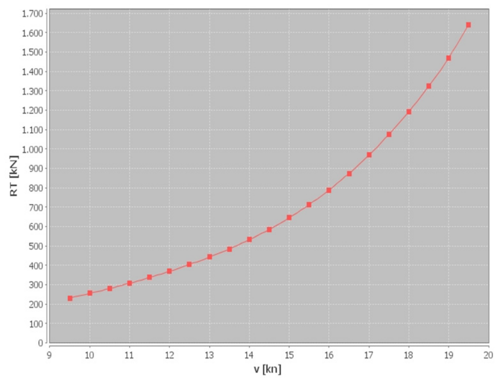


**Fig. 1.** Hydrodynamic ship resistance

## 3. PROPULSIVE CHARACTERICSTICS AND PERFORMANCES ANALYSIS

The estimation of the necessary power on board ship was performed with PHP Propulsion Power code developed and available at Naval Architecture Faculty, from which the graphs regarding propeller delivered power $P_D$ versus ship speed V were plotted and presented in Figure 2.

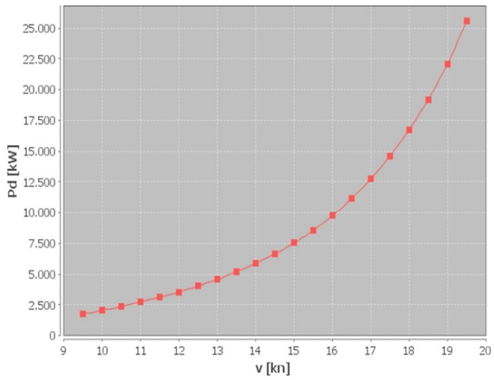


**Fig. 2.** Propeller delivered power

In the next stage, based on the power results, four slow Diesel engines with similar characteristics have been chosen for the propulsion performances study. The main characteristics of the selected engines are presented in Table 2. Three engines were selected from the catalogue of the manufacturer MAN [2] and one from the engine manufacturer Wartsila [3], all of which produced in 2022. These met the requirements related to the necessary propulsive power at ship board and, at the same time, through the combination between power and engine speed, allowed the location of an optimal propeller diameter behind the stern of the ship, taking into account the propeller clearance rules.

In the following step, for all four selected engines, the optimal propellers from efficiency point of view have been designed to consume the delivered power. For each individual engine, 2 propellers were designed in 2 distinct propeller design points (cu=0.75 and cu=0.85, considering Sea Margin=15% and Engine Margine = 0-10%).

Based on the B Wageningen screw series diagrams and using as input data the previously determined hydrodynamic ship resistance and the hull propeller interaction coefficients, the geometrical characteristics of four blades optimal propeller (D-diameter, P/D-pitch ratio, Ae/Ao – blade area ratio) have been determined.

The hydrodynamic performances such as optimal open water propeller efficiency $\eta_0$ and the speed of the ship propelled by the designed propeller have been determined (Figure 3). The results obtained for all 8 analysed cases are presented in Table 3, this summarizes, for each studied case, the characteristics of the engines used, the results of the calculation of the optimal propeller and the ship's speed performance.

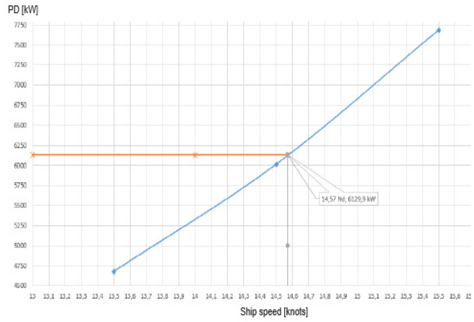


**Fig. 3.** Propeller delivered power versus ship speed (Case1.2)

**Table 2**. Main engines characteristics

| Case | Engine type | Brake Power $P_B$ [kW] | Speed [rpm] | Number of cylinders $n_{rc}$ | Manufacturing Year |
|---|---|---|---|---|---|
| 1 | MAN 6G45ME-C9.7 | 8340 | 111 | 6 | 2022 |
| 2 | MAN 5S50ME- C8.5 | 8300 | 127 | 5 | 2022 |
| 3 | MAN 6S46ME-C8.6 | 8340 | 130 | 6 | 2022 |
| 4 | Wartsila RT-flex50DF | 8640 | 124 | 6 | 2022 |

**Table 3**. Ship Propulsion System: Characteristics and Performaces

| Case | | Engine | | | | | Propeller | | | | | Ship |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Engine type | $P_B$ | $n_0$ | $n_{rc}$ | $c_u$ | D | P/D | $A_E/A_0$ | $\eta_0$ | $n_{el}$ | V |
| 1 | 1 | MAN 6G45ME-C9.7 | 8340 | 111 | 6 | 0,85 | 6,36 | 0,671 | 0,55 | 0,55 | 111 | 15,04 |
| | 2 | MAN 6G45ME-C9.7 | 8340 | 111 | 6 | 0,75 | 6,27 | 0,649 | 0,55 | 0,56 | 107,1 | 14,57 |
| 2 | 1 | MAN 5S50ME-C8.5 | 8300 | 127 | 5 | 0,85 | 5,86 | 0,631 | 0,55 | 0,53 | 127 | 14,83 |
| | 2 | MAN 5S50ME-C8.5 | 8300 | 127 | 5 | 0,75 | 5,83 | 0,636 | 0,55 | 0,54 | 122,6 | 14,41 |
| 3 | 1 | MAN 6S46ME-C8.6 | 8340 | 130 | 6 | 0,85 | 5,79 | 0,667 | 0,55 | 0,527 | 130 | 14,82 |
| | 2 | MAN 6S46ME-C8.6 | 8340 | 130 | 6 | 0,75 | 5,77 | 0,637 | 0,55 | 0.54 | 125,5 | 14,43 |
| 4 | 1 | Wartsila RT-flex50DF | 8640 | 124 | 6 | 0,85 | 6 | 0,663 | 0,55 | 0,53 | 124 | 15 |
| | 2 | Wartsila RT-flex50DF | 8640 | 124 | 6 | 0,75 | 5,97 | 0,638 | 0,55 | 0,54 | 120 | 14,57 |

Analysing the results regarding the propulsive performance of the studied cases, it was found that the optimal ship propulsion system resulted from the combination of the engine, case 1, with the propeller at the design point cu=0.75 (case1.2). This version was chosen because the ship's speed of 14.57 knots obtained with the designed propeller, is very close to the required speed of 14.5 knots.

At the same time, the optimum propeller diameter is the largest of all compatible cases, ensuring a higher propeller efficiency. Analysing the results from Table 3, it can be seen that the slow engines with the lowest speeds allow the vessel to be fitted with larger propeller diameters to give maximum propulsive efficiency, the obtained diameters being within the safety limits for the location of the propeller.

In terms of the size and weight of the studied engines, their dimensions and weight fall roughly within the same limits (Table 4). It is known that the reduction of the space occupied by the ship propulsion system in favour of increasing cargo capacity is a current trend in ship propulsion system design. The propulsion system arrangement for the selected case 1.2 is given in Figure 4.

With regard to specific fuel consumption, it appears that the engines of cases 1 and 3 with lower values at maximum continuous power have low fuel consumption. They are more efficient in operation than the engines from cases 2 and 4 which will generate additional costs to the shipowner due to the high fuel consumption, expressed by the specific fuel consumption parameter given in grams/kilowatt-hour (Table 4). As can be seen, the power of engines 1,2,3 is approximately the same, at around 8340 kilowatts, while the case 4 engine has an extra power of around 300 kilowatts.

**Table 4**. Main engines characteristics

| Case | Engine type | Power $P_B$ [kW] | Specific fuel consumption 100% MCR [g/kW*h] | Weight [t] | Length [m] | Width [m] | Height [m] |
|---|---|---|---|---|---|---|---|
| 1 | MAN 6G45ME-C9.7 | 8340 | 166 | 186 | 5984 | 3260 | 9250 |
| 2 | MAN 5S50ME- C8.5 | 8300 | 170 | 180 | 5542 | 3150 | 8250 |
| 3 | MAN 6S46ME-C8.6 | 8340 | 167 | 168 | 5882 | 2924 | 7925 |
| 4 | Wartsila RT-flex50DF | 8640 | 184,1 | 225 | 6456 | 3150 | 7646 |

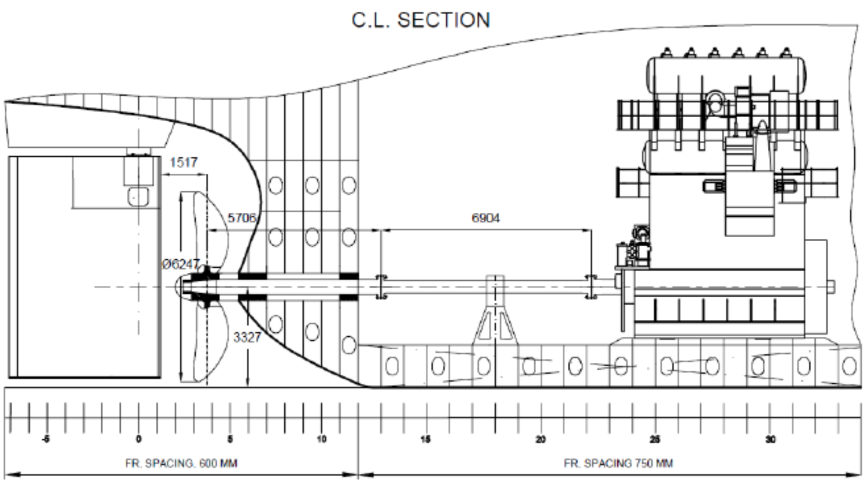


**Fig. 4.** Ship propulsion system arrangement (Case1.2)

Taking into account the mandatory IMO requirements related to $CO_2$ emissions from ships, the Energy Efficiency Design Index EEDI have been computed, for the four engines selected, at the propeller design points cu=0.75 (cases in which the obtained ship's speed is closed to the desired speed).

For EEDI calculation expressed as the ratio between $CO_2$ emissions and the transport work, important parameters such as: ship speed, deadweight, engine power and specific fuel oil consumption (for the propulsion and auxiliary engines) were required.

For every case, the ship attained EEDI was computed and plotted versus the required EEDI (Figure 5). The upper horizontal line indicates the reference line for a tanker "with the DWT value in question" [6] calculated with the tanker EEDI baseline formula and corresponding to phase 0, 2013-2014. The lower horizontal lines indicate the maximum EEDI values for next phases: phase 1, 2015-2019, 10% reduction; phase 2, 2020-2024, 20% reduction; phase 3, 2025-…, 30% reduction.

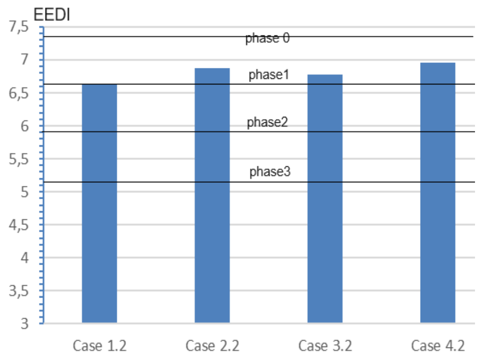


**Fig. 5.** Attained EEDI versus required EEDI reference lines

It was observed that the lowest attained EEDI value has been obtained in case 1.2, for the same engine selected according the ship speed performance, the engine with the lower specific fuel consumption. The attained EEDI values are higher than the required EEDI corresponding to phase 2 (2020-2024) and this impose to find solutions and to take measures that may lead to EEDI reduction.

Solution for EEDI reduction, such as: ship speed and power reduction, placing a shaft generator, utilisation by the engine manufacturer of diverse range of alternative fuels [4] will be the subject for the following stage of the work.

## 4. CONCLUDING REMARKS

The paper was focused on the analysis of the propulsion system characteristics and performances for a crude oil tanker. The study has been carried out in several steps: first, the ship resistance and the necessary propulsive power were calculated to choose and to design the main components: engine, transmission and propeller; to obtain maxim propulsive efficiency at the desired speed, with low fuel consumption and reduced $CO_2$ emissions.

Different factors were taken into account for ship propulsion system components selection such as: required power, revolution rate to ensure an optimal propeller diameter to be fitted behind the ship, the specific fuel consumption parameters, required ship speed, etc.

Four slow Diesel engines were selected and for each of them, 2 propellers were designed using B Wageningen screw series in 2 distinct propeller design points. The propulsive performances for the studied cases have been analysed and the more efficient solution have been chosen. It was found that the optimal ship propulsion system resulted from the combination of the engine case 1, with the propeller at the design point cu=0.75 (case1.2) obtaining a ship speed of 14.57 knots close to the required speed of 14.5 knots.

Aspects regarding engine main dimensions, fuel consumption and the IMO Energy Efficiency Design Index EEDI requirements were taken into account and analysed. The lowest attained EEDI value has been obtained for the same case 1.2, for the engine with the lower specific fuel consumption. The attained EEDI values are higher than the required EEDI corresponding to phase 2 (2020-2024) and this impose to find solutions and to take measures that may lead to EEDI reduction, solutions which will be the subject for the following stage of this work.

## Acknowledgements

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