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ASSESSING THE INFLUENCE OF THE GLOBAL EMISSIONS REDUCTION TARGETS ON THE DESIGN AND PERFORMANCES OF A SHIP'S PROPULSION SYSTEM

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ABSTRACT

The paper presents aspects related to the influence of the global gas emissions reduction targets on the design and performance of a propulsion system for a bulk carrier. In the first stage, the key elements of the ship's propulsion system: main engine and propeller have been chosen and designed. The aim was to obtain the maximum propulsive efficiency at the owner's desired speed. Different combinations: diesel engine-optimal propeller have been designed and analysed from the efficiency point of view. In the second stage, considering the mandatory IMO regulations concerning CO2 emissions, the EEDI (Energy Efficiency Design Index) has been computed for every designed case. To comply with the EEDI targets, it was necessary to reduce the ship's speed, and a new propulsion system with lower speed performance has been designed. In this study, ship hull shapes were given and EEDI became an important and critical factor in the design of the ship propulsion system. Other potential pathways to achieve emissions reduction targets will need to be identified in a future study.

Keywords: ship propulsion system, Energy Efficiency Desin Index EEDI

1. INTRODUCTION

The shipping industry has an important role in international trade, but also contributes to global greenhouse gas emissions, accounting for approximately 3% of the total. To address this challenge, the IMO (International Maritime Organization) has introduced technical and operational measures to reduce ship emissions [1]. As technical measures, the EEDI (Energy Efficiency Design Index) has become mandatory for newly constructed ships, and all existing ships must comply with EEXI (Energy Efficiency Existing Ship Index) requirements. SEEMP (Ship Energy Efficiency Management Plan) and CII (Carbon Intensity Indicator) are related to operational measures.

EEDI represents a technical measure to reduce Green House Gas (GHG) emissions from ships that is applied for new ships and its compliance is evaluated in the design stage. Thus, EEDI becomes an important tool in the propulsion system design for the new, more energy efficient, and less pollutant ships.

The paper presents a study focused on the influence of the global gas emissions reduction targets on the design and performance of a propulsion system for a 28000 tdw bulk carrier. The work was initially carried out for the preparation of a bachelor's thesis and then it has been developed to add new research data on the topic of reducing gas emissions for different types of ships and capacities. Such studies have also been performed in the previous years in the Centre of Research of the Naval Architecture Faculty of "Dunarea de Jos" University in Galati.

The main geometrical characteristics of the ship are given in Table 1 and the hull shapes are plotted in Figure 1.

Table 1. Ship main dimensions

Lenght over all	175,9	[m]
Length waterline	166,3	[m]
Beam	28	[m]
Draught	9,5	[m]

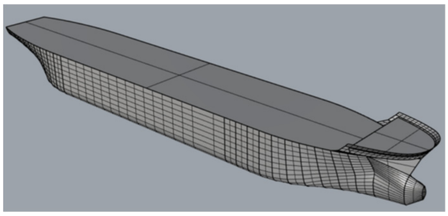

Fig.1 Ship hull shapes

In the first stage, the key elements of the ship's propulsion system, main engine and propeller, have been chosen and designed. The aim was to obtain the maximum propulsive efficiency at the owner's required speed. Usually, for bulk carriers, slow speed, two stroke Diesel engine direct coupled with Fixed Pitch Propellers are used to propel the ships, with speeds ranging between 12-15 knots.

Different combinations: diesel engine-optimal propeller have been analysed from the efficiency point of view. In this stage, the investigation into propulsion efficiency has been performed in eight cases: four selected diesel engines, each engine with two propellers designed and optimized for different operational conditions (two different propellers design points).

In the next stage, the mandatory IMO regulations concerning CO2 emissions have been taken into account, and the EEDI (Energy Efficiency Design Index) has been computed for every designed case. Noting that, from the perspective of the EEDI, the desired speed was not feasible to meet the EEDI targets, it was necessary to reduce the ship's speed. Additionally, a ninth case has been analyzed, where a new propulsion system with lower ship speed performance was designed.

In this study, ship hull shapes were given and EEDI became an important and critical factor in the design of the ship's propulsion system. Other potential pathways to achieve emissions reduction targets will need to be identified in future research. The study has shown one more time that the relationship between ship propulsion systems and EEDI regulatory targets is a complex and interesting challenge for naval architects and designers. On the other hand, EEDI allows ship owners to opt for the most economical and convenient technological solutions to achieve the emission reduction objectives [2].

2. SHIP'S PROPULSION PERFORMANCES ASSESSMENT

In the first stage of the present work, the preliminary design of the propulsion system for the given deadweight bulk carrier has been performed and the propulsive performances for different combinations of diesel engine – optimal efficiency propeller have been analyses. For this purpose, initially, the total hydrodynamic ship resistance has been carried out using empirical methods such as the Holtrop-Mennen approach. The results for a range of ship velocity around the owner's desired speed have been plotted in the diagram from Figure 2.

These results have been used as initial data for necessary propulsion power computation, in order to select the appropriate main engine for this vessel. Four two-stroke slow-speed Diesel engines were selected, and for each main engine, two propellers were designed at different design points, resulting in eight analysis cases.

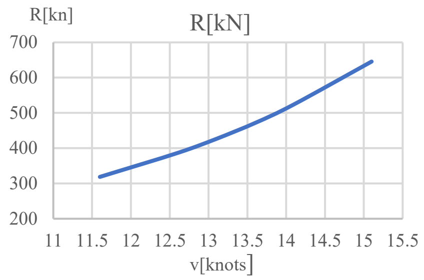

Fig. 2. Hydrodynamic ship resistance

Usually, in propeller design, two propulsion margines are added to the design point (PD): SM-Sea Margin and EM-Engine Margin (Figure 3 [3]).

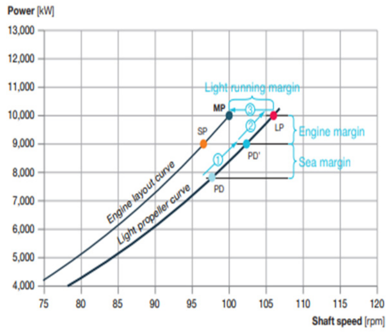

Fig. 3. Example for Propeller design points selection [3]

Sea Margin (SM) takes into account the increase of the ship resistance caused by wind, waves, and hull fouling, ensuring the ship maintains design speed under these conditions. SM is commonly estimated at 15%. The propeller is often designed to the alternative design point PD' including SM. Engine Margin (EM) is recommended for economical operation, lower fuel consumption and a power reserve for increased speed and it is typically around 10%. A trend in increasing the Engine Margine has been observed to meet IMO requirements regarding ship emission reduction.

In the present study, these propulsion margins were introduced in a so-named power utilization coefficient (cu). For each selected engine, two optimal propellers were designed to consume the delivered power in two design points, for cu=0.85 and cu=0.75. Diagrams for the B Wageningen series were used to find the optimum efficiency propellers (ɳo – open water efficiency) and their geometry (diameter-D, number of blades-z, pitch ratio-P/D, blade area ratio Ae/Ao) to achieve the required ship speed V. The characteristics and performances of the designed ship propulsion systems are presented in Table 2 in the report with the ship's speed performances.

Table 2. Ship propulsion systems characteristics and performances

		Case1	Case2	Case3	Case4	Case5	Case6	Case7	Case8
Engine		MAN B&W S46ME C8.6		WARTSILLA RTA48T		WARTSILLA RT-flex50		MAN B&W G40ME B9	
	Power[kw]	6300		6990		6100		6510	
	Speed [rpm]	105		102		99		106	
	No.cyl.	7		6		5		7	
	SFC[g/kWh]	163		171		167		171	
Propeller	cu	0,75	0,85	0,75	0,85	0,75	0,85	0,75	0,85
	D [m]	5,873	6,09	6,06	6,08	5,922	6,02	6,09	6,16
	Z	4	4	4	4	4	4	4	4
	Ae/Ao	0,55	0,55	0,55	0,55	0,55	0,55	0,55	0,55
	P/D	0,679	0,737	0,756	0,755	0,799	0,756	0,682	0,670
	ɳo	0,57	0,58	0,56	0,58	0,58	0,59	0,57	0,58
Ship	V[knots]	13,56	13,97	13,96	14,46	13,44	13,91	13,67	14,12

In the first stage, the study aimed to design a propulsion system to achieve a velocity speed of around 14.1 knots ± 0.2. From the velocity required point of view, good results have been obtained in cases 2,3,6, and 8, respectively in the cases of engines with lower powers and cu=0.85, and for the engine with highest power and cu=0.75. It must be taken into account that, power utilization coefficient cu =0.75 (including SM=15% and EM=10%) is usually recommended for bulk carrier propeller design, and in recent decades, an increas in EM has been practiced to fulfil the EEDI objectives.

For each selected engine, by using a power utilization coefficient cu = 0.75, a speed decrease of around 0.5 knots (3%) was obtained in comparison to the design cases with cu = 0.85. Related to optimal propeller performances, good values of the open water efficiency (0.56-0,59) were obtained for a Bulc carrier. The placement of an optimal propeller of maximum diameter was possible in all analysed cases.

In the following stage of this research, the results related to ship propulsive efficiency were assessed in the context of Energy Efficiency Design Index requirements, analysing the impact of EEDI targets on the propulsion system design for the given bulk carrier.

3. ASSESSING SHIP PROPULSIVE PERFORMANCES IN THE CONTEX OF EEDI TARGETS

EEDI represents a technical measure introduced by IMO to reduce gas emissions from new ships. Its compliance is evaluated in the design stage, becoming a benchmark and a real challenge for the ship designer. The relationship between ship propulsion systems and EEDI requirements is complex, the propulsive performances influencing energy and fuel consumption and implicit the CO_2 emissions from ships. EEDI is defined as the ratio between CO_2 emissions and transport work. An attained EEDI may be computed and compared with a required EEDI based on ship type and size, with emission reduction targets phased in over the years [4].

For attained EEDI computation, the following simplified formula may be used, based on power, fuel type and consumption, ship capacity, and speed. The formula is more complex, including specific correction factors and coefficients.

$$EEDI = \frac{Power\ x\ \ CF\ x\ \ SFC}{Capacity\ x\ Speed} \tag{1}$$

The main engines' propulsive power and auxiliary engines' power too are taken into account in EEDI calculation, as well as the CO_2 conversion factor (CF) depending on the type of fuel used and the Specific Fuel Consumption (SFC) as a characteristic of the engine. The transport work in the denominator is given by the ship's capacity, typically defined as the ship's deadweight multiplied by the ship's speed under specified conditions..

In the second stage of the present study, the mandatory IMO regulations concerning CO2 emissions have been taken into account for the designed ship propulsion systems, and the EEDI has been computed for every designed case. The results related to attained EEDI in comparison with the required EEDI corresponding to Phase 2 (plotted as a line) are given in Figure 5.

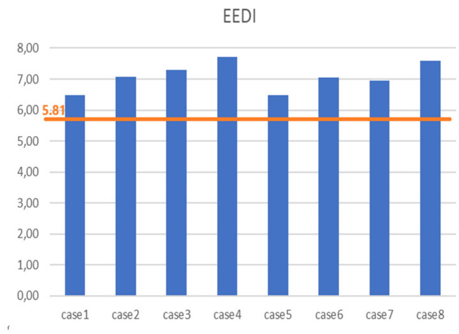

Fig.5. Study cases results - attained EEDI versus required EEDI

It was found that, from the perspective of the Energy Efficiency Design Index, the speed of 14.1 knots is not feasible and none of the analysed cases comply with the CO_2 emissions targets. Therefore, the study continued to find solutions that would lead to EEDI's reduction and to fall within the allowed limits.

If we analyse the EEDI formula only from a mathematical point of view, as a fraction, to decrease its value (Figure 6), it would be necessary to decrease the numerator and increase the denominator.

$$EEDI = \frac{Power \cdot CO_2\ conversion\ factor \cdot Specific\ fuel\ consumption}{Capacity \cdot Speed}$$

Fig.6. EEDI formula as a mathematical fraction

But, taking into consideration the power-speed cube law, this mathematical rule does not seem very easy to apply in ship propulsion system design, with the EEDI reduction becoming a real challenge for a naval architect. By increasing the denominator, respectively the ship's capacity and speed, high propulsive power will be necessary, fact that can lead to the denominator's rising, which is an unfavourable situation from a mathematical point of view.

During the last years, various technological innovations, strategies, and factors with impact on ship propulsion design were explored to reduce EEDI: ship hull optimization, engine technology, alternative fuels, propeller efficiency, energy-saving devices.

It should be noted that the ship hull was given and the engines were not chosen from the latest catalogues of the engine manufacturers. Thus, the influence of some factors such as improvement in engine technology or dual fuel usage was not taken into account and these may be the subject of future work.

In the present study, the solution to reduce fuel consumption and CO2 emissions was to decrease the ship's speed and power. Thus, the question arises as to how much the power and ship speed should be reduced to ensure that the attained EEDI is within the admissible limits. For ship speed and power reduction, cases 1 and 5 were analysed, corresponding to the propulsion systems with the lowest power engines and optimal propeller designed at cu=0.75 design point. In these cases, the difference between the attained EEDI and the required EEDI are 11.611% (case 1) is 11.6% (case 5) respectively. The new ship's propulsion performances were estimated by a step-by-step decrease in the ship's speed and power. In the first step, a 0.5 knot reduction of the ship's speed and around 11-12% in the propeller delivered power led to a reduction of the difference between the required EEDI and attained EEDI between 1.84% and 2.2%. In a second step, for case 1, a new 0.5 knot reduction of the ship's speed and by about 22% in the delivered power to propeller led to an attained EEDI = 5,498 with 5,5% lower than the required EEDI =5,819.

The propulsive performances and EEDI results after power-speed decreasing for case 1 are presented in Table 3. The delivered power to the propeller was calculated as a function of engine power, shaft efficiency, and the power utilization coefficient.

Table 3. EEDI versus ship propulsion system performances after power-speed reduction

MAN B&W S46ME C8.6			cu	SM	EM
	MCR[kW]	6300			
Case1a	PD [kW]	4536	0,75	0,15	0,1
	V [knots]	13,56			
	EEDI	6,495			
Case1b	PD [kW]	3977,1	0,66	0,15	0,19
	V [knots]	13,1			
	EEDI	5,92			
Case1c	PD [kW]	3528,8	0,58	0,15	0,27
	V [knots]	12,6			
	EEDI	5,498			

The results show that for study case 1, selected for the present analysis due to reduced engine power and lower specifical fuel consumption, it was necessary to increase the Engine Margin from 10% to 27% to meet EEDI requirements. In practice, an engine margin of 10-15% is recommended. Using a 20-30% Engine Margin is not the most efficient practice in normal operational conditions, leading to inefficiency in fuel consumption and higher operational costs,

Finally, in the present study, the solution to reduce fuel consumption and CO2 emissions was to adopt a lower ship speed, select another engine with lower power and design a new optimal propeller. A diesel engine MAN

B&W S40ME-C9.5, with a power of 4860 kW, 104 rpm, and 6 cylinders was chosen. The geometrical characteristics of the optimal efficiency propeller designed at cu=0.75 design point, were: diameter D=5,8m, pitch ratio P/D=0,68. The resulting ship speed was 12,6 knots. The computed EEDI value for this new ship propulsion system was 5,62, lower by 3,55% than the required EEDI corresponding to Phase 2 (Figure 7).

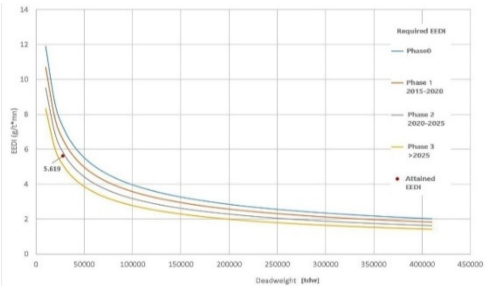

Fig.7 Attained EEDI versus Reference EEDI for the new propulsion system

4. CONCLUDING REMARKS

The paper presents a study focused on the influence of the global gas emissions reduction targets on the design and performance of a propulsion system for a 28000 tdw bulk carrier. In the first stage, the key elements of the ship’s propulsion system: main engine and propeller have been chosen and designed. The aim was to obtain the maximum propulsive efficiency at the owner’s required speed 14.1 knots ± 0.2. After the hydrodynamic ship’s resistance and necessary propulsive power estimation, four two-stroke Diesel engines were selected, and for each engine, two propellers were designed at different design points, resulting in eight analysis cases.

In the second stage, the results related to the ship’s propulsive efficiency were assessed in the context of Energy Efficiency Design Index requirements. The EEDI was computed for every study case, and it was found that from the perspective of EEDI, the speed of 14.1 knots was not feasible. None of the analysed cases comply with the CO_2 emissions targets.

The adopted solution to reduce fuel consumption and CO2 emissions was to decrease ship speed and power. Initially, it was estimated how much the ship's speed and engine power should be reduced to fulfil the EEDI requirements. Finally, the solution was to adopt a lower ship speed of 12,6 knots, to select another engine with lower power, and to design a new optimal propeller.

The work was initially carried out for the preparation of a bachelor's thesis and has since been developed to include new research data on the topic of reducing gas emissions for different types of ships and capacities. Other potential pathways to achieve emissions reduction targets will need to be identified in future studies.

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