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A STUDY ON SHIP PROPULSION PERFORMANCES CONSIDERING EEDI REGULATIONS

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ABSTRACT

Ship emissions represent a significant source of air pollution with harmful environmental impact. Therefore, the International Maritime Organization (IMO) adopted mandatory technical and operational measures to reduce CO_2 emissions from ships. The paper is focused on the study of ship propulsive performances taking into account the EEDI regulations. The Ship propulsion system has indirect impact on EEDI: CO_2 emissions from ship are the result of fuel burning; the fuel consumption depends on the installed power. Ship propulsion system for a 45000 tdw bulk carrier was designed, several combinations main engines/propellers were analysed and EEDI was computed. Propellers were redesigned for every engine, in different design conditions and influence of design parameters on EEDI was analysed.

Keywords: ship emissions, ship propulsion system, Energy Efficiency Design Index (EEDI)

1. INTRODUCTION

Ship emissions represent a significant source of air pollution with harmful environmental impact. According with the third IMO GHG 2014 report, for the period 2007-2012, on average, shipping accounted around 3.1% of annual global CO_2 emissions. Therefore, the International Maritime Organization (IMO) adopted mandatory technical and operational measures to reduce CO_2 emissions from ships.

Applicable for new ships, the Energy Efficiency Design Index (EEDI) is a technical measure intended to reduce CO_2 emissions and represents an important tool in the design stage by "promoting the use of more energy efficient (less pollution) equipments and engines" [1]. EEDI can be expressed as the mass of CO_2 emitted per unit of transport work [g/tone-mile] and it is a function of fuel consumption, installed power, ship speed and cargo capacity. An attained EEDI has to be calculated for every new ship using IMO guidelines and the value must be below a certain required EEDI value.

The ship propulsion system has an indirect impact on the EEDI: CO_2 emissions from ship are the result of fuel burning; fuel consumption depends on the installed power. Actual trends in shipbuilding and EEDI requirements demand propulsion systems designed to give maximum efficiency with minimum fuel consumption and associated CO_2 emissions.

The paper focuses on the study of propulsive performances for a 45000 tdw bulk carrier, taking into account the EEDI regulations. The ship propulsion system was designed, several combinations main engines/propeller were analysed and EEDI was computed. Propellers have been redesigned for every engine, in different design conditions and influence of design parameters on EEDI have been analysed.

2. GUIDELINES FOR THE ENERGY EFFICIENCY DESIGN INDEX (EEDI) CALCULATION

Energy Efficiency Design Index may be expressed as the ratio of the environmental impact and the benefit for society.

In another train of thoughts:

$$EEDI = \frac{CO_2 Emission}{TransportWork} \quad (1)$$

EEDI can be calculated using the relationship:

$$EEDI = \frac{A * B + C + D - E}{f_i * capacity * v_{ref} * f_w} \quad (2)$$

where A, B signify the CO_2 emissions from the main engine and C, D are the CO_2 emissions from auxiliary engines

$$A = \prod_{j=1}^{M} f_j \quad (3)$$

$$B = \sum_{i=1}^{nME} P_{ME(i)} * CF_{ME(i)} * SFC_{ME(i)} \quad (4)$$

$$C = P_{AE} * CF_{AE} * SFC_{AE} \quad (5)$$

$$D = ((\prod_{j=1}^{n} f_j) * \sum_{i=1}^{nPTI} P_{PTI(i)} - \sum_{i=1}^{neff} f_{eff(i)} * P_{AEff(i)}) * CF_{AE} * SFC_{AE} \quad (6)$$

- P_{ME} - 75% of the main engine MCR in kW and P_{AE} signify auxiliary engine power.
- P_{PTI} - 75% of rated power consumption of shaft motor.

E signifies the reduction of CO_2 emissions due to innovative technologies.

$$E = \sum_{i=1}^{neff} f_{eff(i)} * P_{eff(i)} * CF_{ME} * SFC_{ME} \quad (7)$$

- P_{eff} - output of innovative mechanical energy efficient technology for propulsion at 75% main engine power.
- P_{AEeff} - auxiliary power reduction due to innovative electrical energy efficient technology.
- SFC- the Specific Fuel Consumption in g/kWh.

Other two important parameters in EEDI formula (2) are:

- v_{ref} - ship speed [knots]
- Capacity – deadweight in the case of bulk carriers

A reference line (baseline) is defined as a curve representing a middle index value fixed on a set of values for a defined group of ships.

$$BaseLine = a * Capacity^{-c} \quad (8)$$

where a, c are parameters given function of ship type, for bulk carriers a = 961.79 and c = 0.477.

For each new ship, an attained EEDI should be below a required EEDI:

Attained EEDI ≤ Required EEDI

Required EEDI = F

$$F = (1 - \frac{x}{100}) * a * 100\% DWT^{-c} \quad (9)$$

where X is an estimated reduction factor with the following values for bulk carriers:

- X = 10 - phase 1 (2015-2019)
- X = 20 - phase 2 (2020-2024)
- X = 30 - phase 3 (2025-…).

3. SHIP PROPULSION PERFORMANCE ANALYSIS

Bulk carriers represent an important part of the world fleet (41 %). Generally, they are single screw ships characterized by high block coefficients. Low speed diesel engines directly coupled with fixed pitch propellers are used for propulsion, to operate for long time at a medium required speed.

Taking into account EEDI requirements, the study of propulsive performances has been performed for a 45000 tdw bulk carrier.

The main dimensions of the ship are:

- Length between perpendiculars 183 [m]
- Breadth 30.5 [m]
- Draught 11.0 [m]

The bulk carrier propulsion system has been designed, several combinations between main engines and optimal propellers were analysed and EEDI was computed. Propellers were redesigned for every engine, in different design conditions and influence of design parameters on EEDI have been analysed.

To select the engines, ship resistance was computed and plotted in Figure 1.

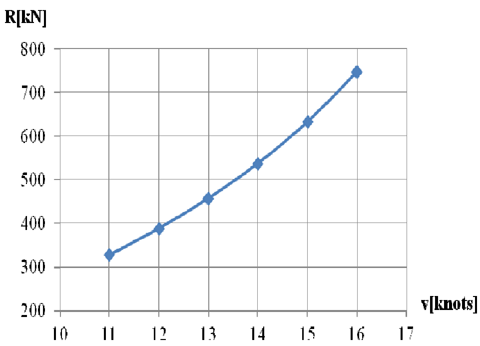

Fig. 1. Ship resistance

The necessary brake power and an optimal shaft revolution rate were computed using as initial data: ship resistance, required ship speed, preliminary propeller diameter (adopted taking into account the after body form of the hull and ship draught). The ship curve intersected with preliminary propeller thrust curves are plotted in Figure 2.

Three slow diesel engines were selected to analyse the propulsive performances for the given bulk carrier. For each main propulsion engine selected, optimal propellers were designed in two cases:

- Sea margin = 15%, Engine margin = 0%;
- Sea margin = 15%, Engine margin = 10%.

The main geometrical characteristics of the designed propellers are presented in Tables 1, 2 and 3 where ship speed performances are related to propeller efficiency.

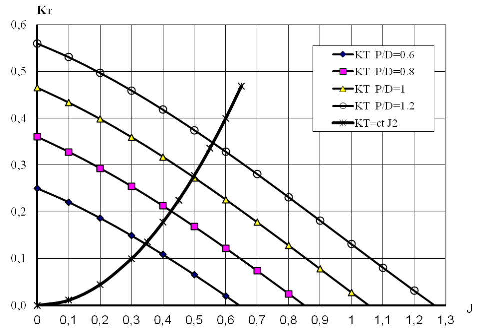

Fig. 2. Ship/preliminary propeller characteristics

Table 1. Ship/propeller propulsive performances –Engine1

Engine 1	MAN B&W G50ME-C96	
Power [kW]	8600	
Speed [rpm]	100	
Cylinder	5	
Sea margin SM [%]	15	15
Engine margin EM [%]	0	10
Propeller		
Diameter [m]	6.2	6.2
Revolution rate	100	96.55
Number of blades z	4	4
Pitch ratio P/D	0.837	0.829
Ship		
Ship speed [knots]	14.99	14.5

Table 2. Ship/propeller propulsive performances –Engine2

Engine 2	MAN B&W S46ME-B85	
Power [kW]	6900	
Speed [rpm]	111	
No. cylinder	5	
Sea margin SM [%]	15	15
Engine margin EM [%]	0	10
Propeller		
Diameter [m]	6.02	6.0
Revolution rate	111	107.17
Blade area ratio	0.55	0.55
Pitch ratio P/D	0.686	0.6851
Ship		
Ship speed [knots]	13.92	13.33

Table 3. Ship/propeller propulsive performances –Engine3

Engine 3	MAN B&W G40ME-G95	
Power [kW]	5500	
Speed [rpm]	125	
No. cylinder	5	
Sea margin SM [%]	15	15
Engine margin EM [%]	0	10
Propeller		
Diameter [m]	5.4	5.38
Revolution rate	125	120.68
Number of blades z	4	4
Pitch ratio P/D	0.652	0.651
Ship		
Ship speed [knots]	12.7	12.2

4. EEDI CALCULATION

For the EEDI calculation some important parameters are required: ship speed, deadweight, engine power and specific fuel oil consumption, power take out and special design criteria such as ice class.

For each main propulsion engine, the EEDI was computed for every propeller design cases:

- Sea margin = 15% , Engine margin = 0%;
- Sea margin = 15%, Engine margin = 10%.

The results were plotted in diagrams from Figures 3, 4, 5, 6, 7 and 8.

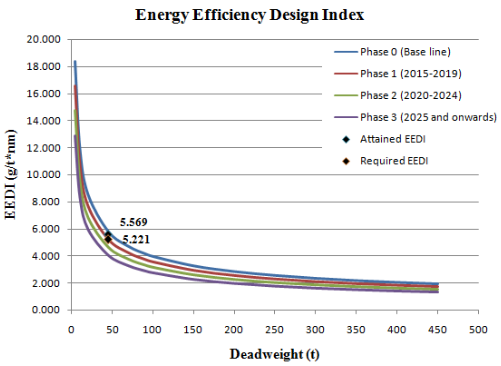

Fig. 3. Energy Efficiency Design Index (SM = 15%) Engine 1 MAN B&W G50ME-C96

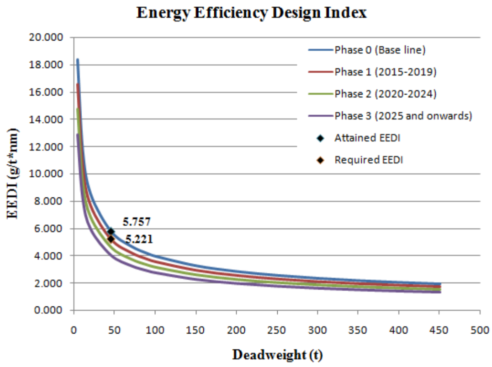

Fig. 4. Energy Efficiency Design Index (SM = 15% and EM = 10%) Engine 1 MAN B&W G50ME-C96

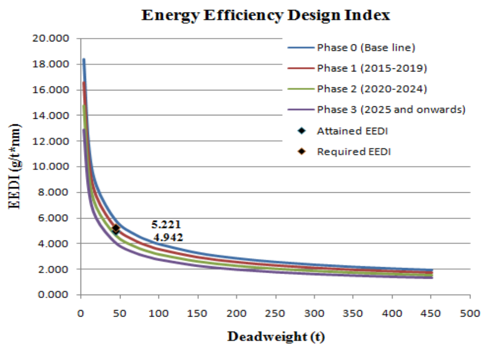

Fig. 5. Energy Efficiency Design Index (SM=15%) Engine 2 MAN B&W S46ME-B85

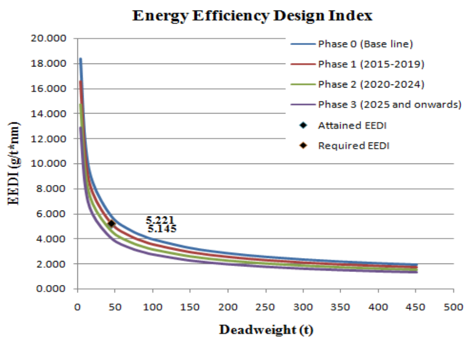

Fig. 6. Energy Efficiency Design Index (SM = 15% and EM = 10%) Engine 2 MAN B&W S46ME-B85

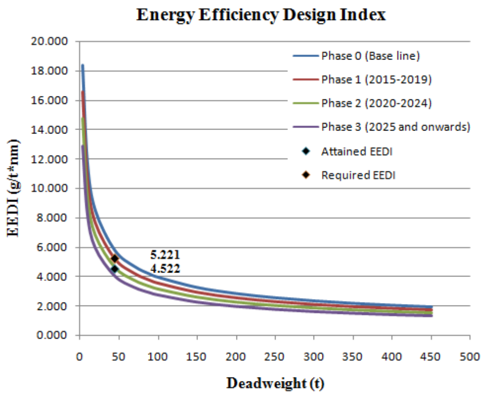

Fig. 7. Energy Efficiency Design Index (SM = 15%) Engine 3 MAN B&W G40ME-G95

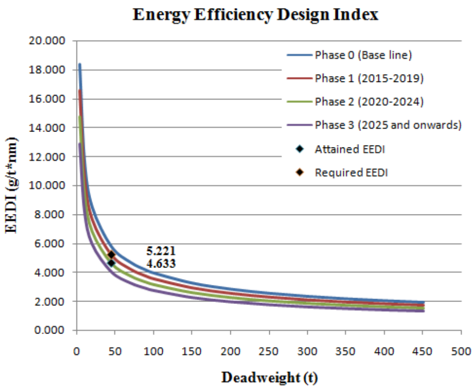

Fig. 8. Energy Efficiency Design Index (SM = 15% and EM = 10%) Engine 3 MAN B&W G40ME-G95

Table 4 presents the results regarding the attained EEDI and the required EEDI for several combinations between main engines and optimal designed propellers. For the first engine, MAN B&W G50ME-C96, the computed EEDI value is greater than the required EEDI which fits index much more towards Phase 0 (the unfavourable phase).

For the second engine MAN B&W S46ME-B85, the value of calculated EEDI is closer to Phase 1, the favourable phase.

In case of the third engine MAN B&W G40ME-G95, the value of calculated EEDI is around Phase 2.

The value of calculated EEDI for the engine MAN B&W S46ME-B85 with optimum designed propeller falls within the normal phase values: required EEDI is 5.221 g/t*nm, attained EEDI is 4.942 g/t*nm and the ship velocity is 13.9 knots, close to the required speed.

Table 4. EEDI calculation results

Phase	Ship built	Reduction factor	Required EEDI
Phase	2013-2014	0%	5.8
Phase	2015-2019	10%	5.221
Phase	2020-2024	20%	4.64
Phase	2024 -	30%	4.06

	Propeller condition design		Attained EEDI
	SM	EM	
Engine 1	15%	0%	5.569
	15%	10%	5.757
Engine 2	15%	0%	4.942
	15%	10%	5.145
Engine 3	15%	0%	4.522
	15%	10%	4.633

5. CONCLUDING REMARKS

A ship and its propulsion plant can be defined as a system where the best balance of performances is given by: cargo capacity, power, speed, minimum fuel consumption and a smallest amount of gases emitted into the atmosphere.

The Energy Efficiency Design Index (EEDI) is a technical measure to reduce CO_2 emissions from ships becoming an important tool in the design stage to improve the energy efficiency of the ship.

The paper was focused on study of propulsive performances for a 45000 tdw bulk carrier, taking into account EEDI regulations. Ship propulsion system has been designed for several combinations main engine/optimal efficiency propeller. Three slow diesel engines have been selected. For each main engine, the most efficient propeller has been designed in two conditions and EEDI has been computed for each case.

For the first engine selected, the values of attained EEDI were greater than the required EEDI. With the second engine and the optimal efficiency propeller, the attained EEDI has been reduced with 11.2%, close to Phase 1 compliance and the ship speed performances are in agreement with shipowner's requirements. In case of the third engine the value of attained EEDI is around Phase 2 but the ship speed is lower.

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