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INFLUENCE OF THE ELEMENTS OF THE SHIP PROPULSION COMPLEX ON THE EEOI (ENERGY EFFICIENCY OPERATION INDEX) OF A PASSENGER SHIP TYPE IB

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Key words: *Energy Efficiency Operation Index; Hybrid energy system; Ship-engine-propeller complex; Ship energy efficiency.*

Abstract: *The propulsion system of the new hybrid ships plays an important role in reaching increasingly higher requirements of international regulations on greenhouse gas emissions. Compliance with the Energy Efficiency Operation Index (EEOI) regulation used to calculate the ship's CO_2 emissions is essential, and the match between the ship and the engine and propeller must be done taking the EEOI into account. In this paper, a comprehensive analysis is performed to obtain the relationship between EEOI and system matching parameters such as ship speed, effective power and propeller diameter, reflecting the trend and degree of EEOI when these three parameters change. Regarding EEOI, the lower the values, the better the performance of the ship and since EEOI takes into account the passengers being transported, the more passengers the better the EEOI.*

I. INTRODUCTION

The purpose of this report is to provide functional specifications for the IB type passenger ship. All systems on board the ship must comply with IMO standards to ensure proper functionality and operation of the vessel. With the introduction of increasingly stringent international regulations on greenhouse gas emissions, higher requirements are placed on the propulsion system design of ships with conventional and hybrid energy systems. Setting measures at project level can reduce CO_2 emissions by 10% to 50% in operation. The most important parameters for the energy efficiency of the ship are the main dimensions of the ship: length, width, depth and displacement. From an energy point of view, the electrical equipment of the ship, the hull and the engine, together with their service systems, can be united under the name "propulsion equipment". It is one of the complexes in which the most serious profits and losses determining the efficiency of shipping should be sought. The propulsion sys-tem of passenger ships with a hybrid electric system consists of main engines, electric motors, a system of shafts and propellers.

II. ENERGY TRANSFER WHEN THE SHIP MOVES AT DIFFERENT SPEEDS

The philosophy of the systems in the new modern passenger ships is to use less than 40% of the energy contained in the fuel to drive the ship. These are key solutions of functional topics at the system design level. The details of setting upthe systems components are not covered in this report. The system is designed in accordance with IEC norms and,where relevant, DIN norms and classification societies. Figure 1 below shows an illustration of the ship's power system.

Fig. 1. Illustration of the ship's power system.

The importance of shaft motors, innovative energy-efficient solutions and improvements in electrical equipment can be defined by formula 1 [1] [2] [4] .

$$\left(\prod_{j=1}^{n} f_j \cdot \sum_{i=1}^{n_{PTI}} P_{PTI(i)} - \sum f_{eff(i)} \cdot P_{AEeff(i)} \right) \cdot C_{FAE} \cdot SFC_{AE} \quad (1)$$

Where: fj [-] - correction factors for taking in to account specific decisions in ship design. If there are none, they are taken equal to 1; PPTI(i) [kW] - 75% of the rated mechanical power of the shaft engines.

This hybrid passenger vessel contains a SAVe CUBE power system that is designed for variable speed engine opera-tion. The SAVe CUBE hybrid system uses a common DC bus system powered by the hybrid shaft generators (HSGs) in combination with a double Generating System (DGS). The vessel also has a 3-phase 50 Hz AC system with isolated neutral earthing system. Propulsion of the vessel includes:

- Main propulsion system (Twin Screw with Rudder & Steering Gear)
- Prime Movers
- Tunnel thrusters
- Propulsion & Thruster Control System

The main propulsion system consists of two controllable pitch main propellers, each rated 2665kW. The main propulsion systems are driven by prime movers coupled to a reduction gearbox with clutches both for propeller and prime mover. Hybrid Shaft Generator PTO/PTI is connected between the two clutches, making it possible to run the Hybrid Shaft Generator in PTO mode with the propeller in standstill. Forward there are two fixed pitch bow thrusters, each rated 419kW. The bow thrusters are driven by speed controlled electric prime movers that are fed from converters integrated in the SAVe CUBE (One connected to each part). Aft there are two pump jets, each rated 350kW. The pump jets are driven by speed controlled electric prime movers that are fed from converters integrated in the SAVe CUBE (One connected to each part).

The power system configuration for this vessel has been designed for various operations, depending on the different types of operations to be performed. The operational modes presented in this chapter visualizes the different operations by illustrating the power flow in the system graphically. To save energy in Dinamic Position (DP) operations, there will be a relaxed control function available in the Dinamic Position system. In operations where position deviations are tolerated, the relaxed control function can be used. With this function enabled, the controller gains in positioning and heading control will be decreased, which will make the system less aggressive in keeping the heading and position of the vessel. This leads to less dynamical use of thrusters and therefore reduced fuel consumption, which in turn means a more economical and environmental friendly usageof the Dinamic Position system. The normal operational modes for the vessel are summarized in Table 1 below.

Table 1 – Normal Operational modes

Operational Modes	Main Propulsion	DGS	HSG PTO	HSG PTI	Thrusters	Emergency Generator	Shore Supply
Berthed		X					
Anchor			X				
DP	X		X		X		
Manoeuvring	X		X		X		
Transit 5 ÷ 8 km	X		X	X			
Transit 9 ÷ 11 km	X		X	X			
Transit 12 ÷ 14 km	X		X				
Transit 15 ÷ 17 km	X		X				
Diesel Electric	X	X		X			
Harbour Shore Connection							X
Emergency						X	

III. ENGINE POWER AND SPEED SETTING

When the ship is moving at a certain speed, the conversion of fuel into energy is corrected by the efficiency of the energy converter (ηec). For the ship's motion relative to the amount of fuel consumed, the efficiency of the conversion itself (ηec) can be divided into four parts [3] :

- enclosure efficiency (ηE),
- propeller efficiency (ηO ·ηR),
- transmission efficiency (ηS ·ηGB),
- engine efficiency (ηE).

The engine speed demand is set by the CUBE controller as a function of measured power generated from the engine and propeller load. The engine speed accounts for any expected load increase by setting the engine to an appropriate speed following power change. This logic assures that the engine will always be at an appropriate speed for the current and foreseen power in all circumstances. For all cruises, the average EEOI index is calculated according to formula 2, and the data for its calculation is taken from the SCADA system on board and is calculated at a value for CF=3.20, corresponding to HFO fuel used in navigation. Accepting m_{cargo}=9427 [GT]. [4] [3]

$$EEOI = \frac{\sum_j FC_j \cdot C_{Fj}}{m_{cargo} \cdot D} \qquad (2)$$

where: j - type of fuel; i - course number; FCi,j - fuel consumption [t], CF,j - environmental impact factor of the j-th type of fuel [tCO2/tFuel]; mcargo - mass of the transported cargo [t] or number of passengers [pcs.]; D - distance traveled in nautical miles to perform the specified work [n.m.]. In order to calculate the EEOI for a longer period of time e.g. a year, a quarter, all voyages of the ship in that period should be summed up along with those where the ship did not carry any cargo. [7]

The ratio between the actual work of the main blower and the energy of the fuel is expressed by the so-called energy efficiency: ηE, which is related to the indicated efficiency ηi and the mechanical efficiency ηm. [6] [9]

$$\eta_E = \frac{W_{ef}}{Q_f} \qquad (3)$$

$$\eta_i = \frac{W_{in}}{Qf} = n_{cb}\ n_q\ \ n_{th} \qquad (4)$$

where: Wef –effectiv work on engine; Qf -amount of energy; ηi – indicate efficiency; ηm - mechanical efficiency; ηq - input efficiency; nth - thermodynamic efficiency; ηcb - combustion efficiency; ηE - effective efficiency; Win- the network (Win) produced by a single cylinder cycle. [6]

$$n_m = \frac{W_{ef}}{W_{in}} = \frac{n_e}{n_i} \qquad (5)$$

In order to have constant thrust, the propulsion system will automatically compensate for pitch to compensate for the variable speed of the main engine. The maximum power available from the engine is calculated as a function of engine speed, taking in to account any limitations imposed by the engine controller. The specified efficiency ηi represents the thermodynamic characteristics of the engine, including heat and combustion losses, while the mechanical efficiency ηm indicates the mechanical characteristics of the engine. The maximum power available from the motor is calculated as a function of motor speed, taking in to account all the constraints imposed by the motor controller shown in Fig. 2.

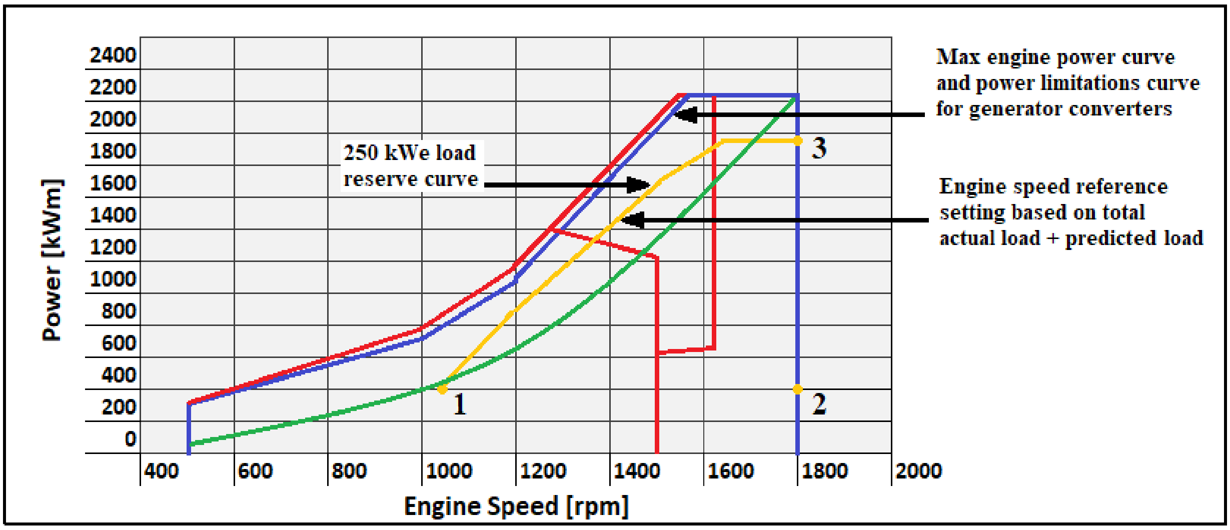

Fig. 2. Example of Engine load curve

CONCLUSION

To be able to analyze the propulsion system and its effect on EEOI, we need to know its parts and their effect on the energy index. In navigation mode, the efficiency of the propeller mainly depends on the interaction of each component of the propulsion in converting energy.Here will the main mechanical engine be stopped and clutched out, propeller will be powered from the electric motor only, and electric motor will be powered from power source within the SAVe CUBE. Electric motor will be in speed control and propeller power/speed be given from propulsion control to electric motor. Here the mechanical engine and the electric motor is connected via clutches together and they will, in combination, power the propeller. When calculating the EEOI energy index and fuel consumption ton-miles, it can be seen that they are closely related to the weight of the cargo (passengers). When the speed decreases, the energy efficiency increases during normal operation of the passenger ship. When analyzing longer periods, periods of downtime and repair work on board the ship should also be noted.

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ВЛИЯНИЕ НА ЕЛЕМЕНТИТЕ НА КОРАБНИЯ ПРОПУЛЛИВЕН КОМПЛЕКС ВЪРХУ EEOI (ЕКСПЛОАТАЦИОНЕН ИНДЕКС НА ЕНЕРГИЙНА ЕФЕКТИВНОСТ) НА ПЪТНИЧЕСКИ КОРАБ ТИП IB

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Ключови думи: *Оперативен индекс на енергийната ефективност; Хибридна енергийна система; Комплекс кораб-двигател-витло; Енергийна ефективност на кораба.*

Резюме: *Задвижващата система на новите хибридни кораби играе важна роля за постигане на все по-високи изисквания на международните разпоредби относно емисиите на парникови газове. В съответствието с регламента, оперативният индекс на енергийната ефективност (EEOI) използван за изчисляване на емисиите на CO2 на кораба, е от съществено значение и съответствието между кораба, двигателя и витлото. В тази статия се извършва цялостен анализ, за да се получи връзката между EEOI и параметрите за съвпадение на системата, като скорост на кораба, ефективна мощност и диаметър на витлото, отразявайки тенденцията и степента на EEOI, когато тези три параметъра се променят. По отношение на EEOI, колкото по-ниски са стойностите, толкова по-добра е ефективността на кораба, тъй като EEOI взема предвид превозваните пътници, колкото повече пътници, толкова по-добър е индекса EEOI.*