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ENGINE POWER LIMITATION (EPL) TO COMPLY WITH EEXI REQUIREMENTS. STUDY ON AN LPG TANKER

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ABSTRACT

The study analyses the Energy Efficiency Existing Ship Index (EEXI), a regulation introduced by the International Maritime Organization (IMO) to enhance energy efficiency in maritime transport and reduce greenhouse gas emissions. Focusing on a semi-refrigerated LPG tanker, the research explores compliance strategies, including engine power limitation (EPL). The reduction of engine power by 24% resulted in a decrease in ship speed, meeting EEXI requirements with minimal impact on performance. Additionally, ship manoeuvrability was assessed through turning circle simulations before and after EPL. The findings confirmed that the vessel's manoeuvrability remains within IMO standards, ensuring both efficiency and operational safety.

Keywords: EEXI, LPG tanker, engine power limitation, ship resistance, manoeuvrability

1. INTRODUCTION

EEXI stands for the Energy Efficiency Existing Ship Index. It is a measure introduced by the International Maritime Organization (IMO) to improve energy efficiency for existing ships. This measure is part of the implications of the IMO aimed at reducing greenhouse gas emissions from international maritime transport [1].

The index is expressed in grams per ton-mile and is calculated based on the ship's engine power, capacity, and operational speed. A "required EEXI" value has been estimated based on the type of ship, capacity, and fuel. This represents the maximum value the index can achieve, which will be compared to the result of an efficiency calculation performed using a formula mandated by regulations. The latter must be less than or equal to the required limit for the ship to be considered compliant with EEXI measures [2].

Ships are obligated to comply with EEXI regulations by assessing their energy efficiency and implementing measures to improve it if the condition is not met. There are several options available to enhance a ship's energy efficiency. These options vary in terms of the costs associated with implementing changes and the improvement quality they will subsequently provide. Among these improvement options, we can mention reducing the main engine power, implementing fuel optimization devices, and lubricating the hull of the ship.

To improve efficiency and comply with EEXI regulations, reducing the main engine power is the most commonly used method by shipowners due to its simplicity in installation and use, high-cost efficiency for installation and maintenance, and minimal impact on the ship's performance, even while the vessel is docked in the shipyard [1].

2. SHIP DESCRIPTION

Fig. 1 LPG Tanker from the series of Gaschem ships

The study was conducted on a semi-refrigerated LPG (Liquefied petroleum gas) Tanker with a 6500 cbm capacity. There is a series containing a couple of similar ships, having minor differences within their main dimensions. These ships were built in Severnav SA shipyard in Turnu Severin, Romania, several years ago [5].

Our study ship was built under the classification society of Germanischer Lloyd (now DNV-GL), having the class notation for a liquefied Gas tanker.

Table 1 Ship main dimensions [1]

Length overall	114.89 m
Length between perpendiculars	109.511
Breadth	16.8 m
Depth	11.825 m
Draught	8.1 m
Deadweight	7340 tdw
Speed	16 nots

Regarding the ship's capacity, we can mention that there are fuel tanks, IFO (Intermediate fuel oil) and MGO (Marine gas oil), ballast tanks with a total capacity of 1362 m^3, and freshwater tanks having 262 m^3. Speaking of cargo capacity, we can find 2 specially arranged tanks for carrying LPG gas with a total capacity of 6461 m^3 on a 100% load [5].

3. SHIP FORWARD RESISTANCE. TOTAL FORWARD RESISTANCE

Resistance, or drag, is a force acting against the motion of a vessel.

Naval architects link ship resistance or, better, total resistance RT with three distinct conditions:

- Total resistance is the horizontal force acting on the hull. The effects of the propeller are deliberately excluded;
- The ship is moving with constant speed on a straight course;
- The water is calm, i.e. without a current and without wind or wind-generated waves. In addition, we assume the water is deep enough so that the sea bottom does not affect the waves generated by a moving vessel.

The total resistance R_T of a hull may be measured as a towing force [6].

3.1 TOWING TANK TESTS

The towing tank tests for our ship were completed under full load conditions and the following results were obtained:

Table 2 Results for total resistance under towing tank tests [1]

Speed [knots]	Speed [m/s]	Pe[kW]	RT[kN]
14	7.2016	1824	253.27
15	7.716	2496	323.48

16	8.2304	3360	408.24
17	8.7448	4800	548.89
18	9.2592	6200	669.60

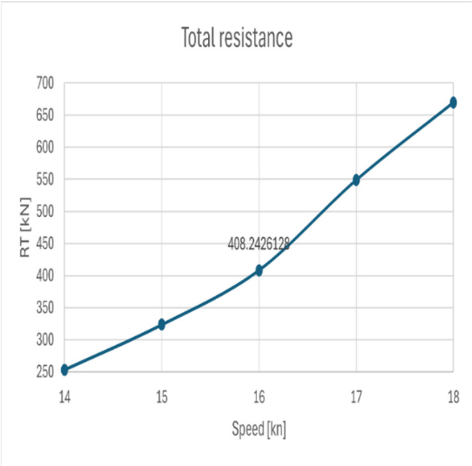

Fig. 2 Generated chart showing results for ship total resistance [1]

3.2 HOLTROP-MENNEN METHOD

Holtrop and Mennen's method is arguably the most popular method to estimate the total resistance and powering of ships. It is based on the regression analysis of a vast range of model tests and trial data which give it a wide applicability. It is – to the best of the author's knowledge – the only method that adopted the use of the ITTC (International Towing Tank Conference) form factor *k*. Resistance is calculated as a dimensional force. The method also provides formulas to estimate the hull–propeller interaction parameters thrust deduction, full-scale wake fraction, and relative rotative efficiency [7].

The basics of the used method depend on the following parameters [7]:

$R_T=R_F(1+k1)+R_{APP}+R_W+R_B+R_{TR}+R_A$,

where:

- R_T is Total resistance;
- R_F is Frictional resistance;
- R_{APP} is Appendage resistance;
- R_W is Wave resistance;
- R_B is Resistance due to bulbous at the bow;
- R_{TR} is the resistance due to immerse transom;
- R_A is resistance due to correlation between model and ship.

Using a calculation manual based on this method, the following results were obtained:

Table 3 Results for total resistance under towing tank tests [1]

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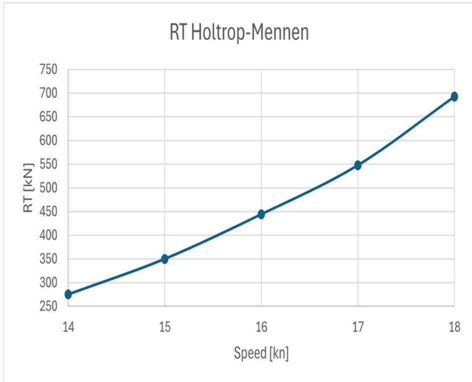

Fig. 3 Generated chart showing results for ship total resistance using H-M method [1]

4 EEXI CALCULATIONS

EEXI requirements shall apply to all ships of 400 GT (gross tonnage), and above which are engaged in international voyages regardless of the ship's delivery date, except the following ships as with the case of EEDI (Energy efficiency design index) [3].

- Ships not propelled by mechanical means;
- Platforms including FPSOs (floating production storage and off-loading) and FSUs

(floating storage unit) and Drilling rigs, regardless of their propulsion;

- Category A ships as defined in the Polar code;
- Vessels that employ alternative propulsion mechanisms, including diesel-electric, turbine, or hybrid propulsion systems (except liquefied natural gas carriers and cruise passenger vessels).

4.1 Required EEXI

Required EEXI represents the maximum value of carbon emissions accepted by the EEXI regulations. It is specified for each ship type and size [8].

In our case, for a gas carrier with a 7340 deadweight, by following the specified calculations, we obtain a 16.748 g/ton-mile value.

4.2 Attained EEXI

Attained EEXI is calculated by an individual ship.

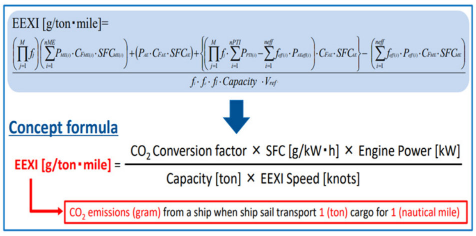

Fig. 4 EEXI formula

The value obtained using the EEXI formula (Attained EEXI) shown in Fig.3.1., should not be higher than the value obtained for the Required EEXI for a ship to comply with EEXI regulations. In case that this condition is not fulfilled, it is imperative that the owner should implement a method for compliance.

4.2.1 Attained EEXI obtained using ship's preliminary data

To determine the achieved Energy Efficiency Existing Ship Index (EEXI) the formula delineated in Fig. 3.1. is used and the parameters stipulated within the Energy Efficiency Design Index (EEDI) Calculation Guidelines are applied, except where explicitly stated to the contrary. In referencing these guidelines, the term "EEDI" should be interpreted as "EEXI." [8].

In this case, the following parameters were used [1][9]:

- P_{ME} (The total power of the main engines expressed in kilowatts) = 3375 kW;
- In instances where a modifiable Shaft / Engine Power Limitation is implemented according to the 2021 Guidelines pertaining to the shaft / engine power limit to fulfill the EEXI stipulations and the utilization of a power reserve (resolution MEPC.335(76)), the value of PME(i) is defined as 83% of the constrained installed power (MCRlim) or 75% of the originally installed power (MCR), whichever value is lesser, for each primary engine.
- P_{AE} (Power of auxiliary engines) = 225 kW;
- In cases where ships have the total installed power on board for the engines less than 10000 kW, the power for auxiliary engines should be considered in the EEXI formula as 0.05 × MCR.
- C_{FME} and C_{FAE} (Conversion coefficient relating fuel utilization to carbon dioxide emissions) = 3.114 (t CO2 / t fuel);
- For engines lacking a test report within the NOx Technical File and for which the manufacturer has not specified the Specific Fuel Consumption (SFC), the corresponding Conversion Factor (CF) for SFCapp should be delineated as follows.: $C_F = 3.114\ [t \cdot CO_2/t \cdot Fuel]$ for diesel propelled ships (which also include heavy fuel oil use in practice) [1].
- SFC_{ME} and SFC_{AE} (Certified specific fuel consumption for the main engine) = 175.5 g/kWh for the main engine and 220 g/kWh for auxiliary engines [1].
- Both parameters are delineated in the assessment documentation contained within the NOx technical dossier pertinent to each engine. The specific fuel consumption for the

main engine is obtained for a 75% load, while the SFC for auxiliary engines is for a 50% load.

- V_{ref} (Ship speed) = 14.5 knots [1];
- The ship speed for the EEXI calculation should be considered for 75% of the main engine power.
- Capacity = 7340 tdw [9];
- For tankers, deadweight should be used as capacity.
- Correction factors fj, f_w, f_i, f_l = 1 [14];
- Correction factor f_c = 0.934 [7];
- In the context of gas carriers, the correction factor for cubic capacity ought to be ascertained utilizing the equation R-0.56, where R signifies the capacity ratio calculated by dividing the vessel's deadweight by the overall cubic volume of its cargo tanks.. Using the mentioned parameters for the formula, we will obtain EEXI = 20.10 g / ton-mile [1].

4.2.2 Attained EEXI calculation using towing tank tests results

For a more precise EEXI calculation, values resulting from the towing tank tests can be used. In this case, the only parameter that changed, compared to the previous chapter where the ship's preliminary data was used, is the ship's speed, which resulted in 15.9 knots during the towing tank tests. In conclusion, it results that EEXI in this case is EEXI = 18.33 g / ton-mile [1].

4.3 Engine power limitation

Engine power limitation (EPL) is a system to improve a ship's energy efficiency by limiting the ship's engine power within the optimum engine setting. As a result, the ship speed will be limited [2].

EPL consists of a simple device that can easily limit the maximum engine power by adjusting a fuel index limiter on the engine control system without retrofitting a complicated system within the current regulatory framework [4].

EPL can be easily installed in a short time during a port without updating the EIAPP (Engine International Air Pollution Prevention) certificate and the NOx technical file [4].

EPL can be released in adverse weather conditions. Therefore, the limited engine power does not have to meet the minimum power requirement [3].

$$\text{EEXI after EPL [g/ton}\cdot\text{mile]} = \frac{\text{Conversion Factor} \times \text{SFC} \times \text{Engine Power (83\% MCR}_{lim})}{\text{Capacity} \times \text{Ship Speed at 83\%MCR}_{lim}}$$

Fig. 5 EEXI formula after engine power limitation

In essence, the EEXI formula shown in Figure 5 can be calculated in this case almost the same, the only difference being that the engine power and the ship's speed are now used for the 83% load of the already limited engine power (MCR_{lim}) [8].

In our case, the MCR_{lim} is 3451.5 kW (2950 kW at 83% load) and the ship speed is 15.4 knots [1].

Applying the parameters in the EEXI formula, we obtain the new EEXI value, that is 16.727 g/ton-mile [1].

In this case, we can conclude that this new result is less than Required EEXI, so our ship is now in compliance with EEXI regulations [1].

5 SHIP MANEUVERABILITY

The subject of ship manoeuvrability is characterized by its complexity and intricacy, necessitating an examination of motion equations that encompass all six degrees of freedom. The analysis of these motion equations facilitates the forecasting of a vessel's manoeuvrability. Nevertheless, a multitude of assumptions is inherent in this process, thus necessitating model testing to substantiate the analytical findings. Upon construction, the manoeuvring attributes of a vessel are systematically assessed during its Sea Trials. [10].

Manoeuvring a ship consists of [10]:

- Course maintenance (this pertains solely to the orientation of the vessel's longitudinal axis);

- Course alteration;

- Track maintenance (crucial in confined waters);

- Velocity alteration (notably halting).

Manoeuvring specifications constitute an integral component of the agreement between the shipyard and the vessel owner. The International Maritime Organization (IMO) regulations delineate baseline requirements applicable to all vessels; however, vessel owners may impose supplementary or more stringent criteria for particular vessel categories, such as tugs, ferries, dredgers, and exploration vessels [11].

The manoeuvrability of a ship is articulated through the following principal attributes [11]:

- Initial turning capability: the capacity to commence a turn (relatively swiftly);
- Sustained turning capability: the capacity for prolonged (relatively high) turning velocity;
- Yaw correction capability: the capacity to cease turning motion (relatively swiftly);
- Stopping capability: the capacity to halt (within a relatively short distance and time frame);
- Yaw stability: the capacity to proceed in a straight line in the absence of external perturbations (e.g., wind) at a singular rudder angle (termed as the neutral rudder angle).

5.1 Turning circle

A turning circle manoeuvre is to be conducted to both the starboard and portside utilizing a rudder angle of 35° or the maximum allowable rudder angle as stipulated by the design parameters at the specified test velocity. The execution of the rudder angle is carried out subsequent to a consistent approach characterized by a yaw rate of zero. The essential information to be obtained from this manoeuvre is tactical diameter, advance, and transfer [10].

• Turning circle: When a vessel alters her course under the helm through 360° degrees, she moves on a roughly circular path called a turning circle. The circle will be a path traced out by the pivot point. Some refer to it as the path traced out by the centre of gravity.

• Advance: The advance is the distance travelled by the centre of gravity along the original course.

• Transfer: The transfer is the distance travelled by the centre of gravity from the original track measured in the direction 90° to the original heading.

• Tactical diameter: It is the transfer for 180°.

• The drift angle: It is the angle between the ship's fore and aft line and the tangent to the turning circle at any instant.

• Pivot point: It is the angle about which the vessel pivots i.e. the bow swings inwards and the stern swings outwards. It is approximately one-third of the vessel's length from forward when going ahead. While going astern, the vessel pivots about a point, approximately one-quarter of length from the astern.

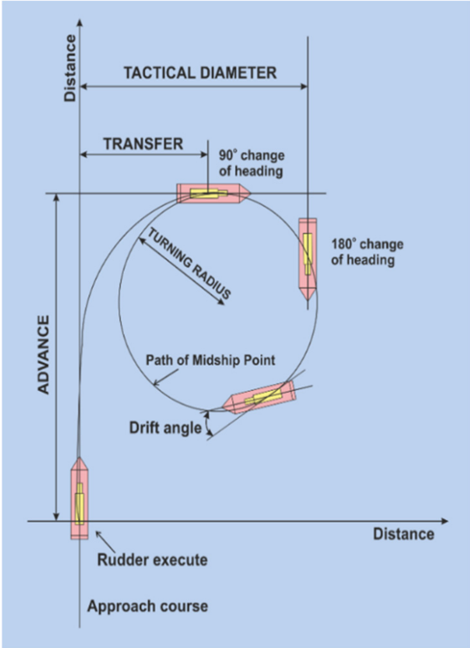

Fig. 6 Turning circle maneuver

5.1.1 Turning circle ability for maximum load of the main engine

In the first case, using a manoeuvrability specialized software, the turning circle ability was simulated to starboard with a 35° rudder angle, at the maximum load of the main engine (4500 kW) and a speed of 16.7 knots, the following results were obtained [1]:

Table 4 Turning circle using the maximum load of main engine [1]

	Ship speed	Rudder angle	Advance	Tactical diameter	STD
Specialized software	16.7 knots	35	331.82m	369.05m	263.92m
MPP	16.7 knots	35	382.79m	462.43m	384m

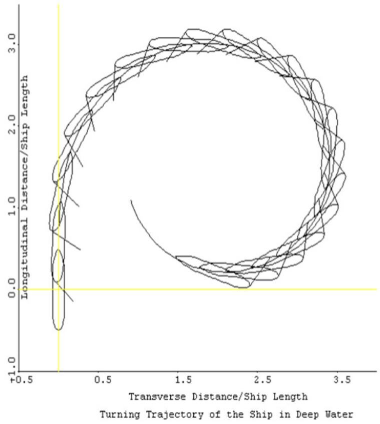

Fig. 7 Turning circle maneuver. Turning trajectory of the ship using maximum load of the main engine [1]

5.1.2 Turning circle ability after the engine power limitation

Using the before mentioned software, the turning circle manoeuvre was simulated after the engine power limitation was installed and the following results were obtained:

Table 5 Turning circle after the engine power limitation [1]

	Ship speed	Rudder angle	Advance	Tactical diameter	STD
Specialized software	15.9 knots	35	347.15m	387.67m	265m
MPP	15.9 knots	35	381.79m	460.49m	384m

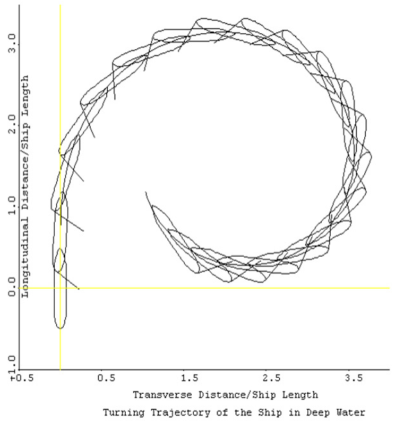

Fig. 8 Turning circle maneuver. Turning trajectory of the ship after the engine power limitation [1]

5.1.3 Turning circle ability at Sea Trials

The turning circle manoeuvre was also analysed at Sea trials, on calm water, without any waves or wind, and the following results were obtained [1]:

Table 6 Results of the turning circle maneuver

Rudder angle	35°
Draught	4.3 m
Main engine power	3709 kW
Ship speed	14.4 knots
Advance	390.33 m (3.56 m/L_{wl})
Tactical diameter	285.66 m (2.6 m/L_{wl})
Steady turning diameter	279.66 (2.55 m/L_{wl})

6 CONCLUSIONS

Engine power limitation is the most used method by shipowners to comply with EEXI regulations. To ensure that the vessel meets the regulations, the power of the main engine must be reduced so that the resulting energy efficiency index, calculated by the specified formula, is lower than the required EEXI. Through calculations, a new (limited) power of the main engine of 3451.5 kW has been determined, down from the initial (maximum) power of 4500 kW. In this context, the new value of the ship's energy efficiency index is 16.727 g/ton-mile [1].

- After reducing the main engine power by 24%, the ship's speed decreases from 16.7 knots (the ship speed at the maximum power of 4500 kW according to power-speed diagram at full load) to 15.9 knots (the new ship speed at the limited power of 3451.5 kW according to power-speed diagram at full load). This 0.8 knot decrease highlights that the engine power limitation to comply with EEXI regulations has a minimal impact on the ship's performance [1].
- To analyse the influence of engine power limitation on the manoeuvrability of the vessel, the turning circle manoeuvre was simulated using a software called MPP and another specialized software. The results from sea trials were used as a comparison. These trials were conducted in calm water, without wind or waves. While using the software, the manoeuvre was simulated in both studied scenarios (before and after the engine power limitation), at speeds of 16.7 and 15.9 knots [1].

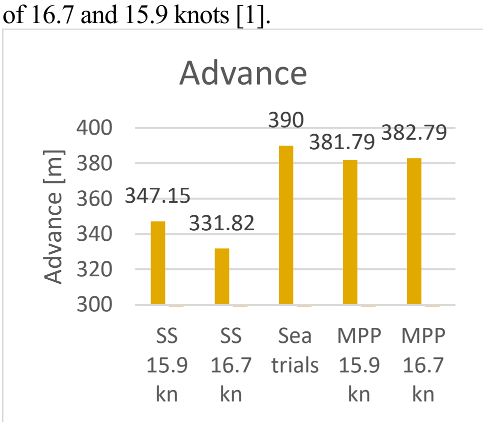

Fig. 9 Turning circle maneuver. Chart representing the ship's advance distance [1]

For this analysis, the results for the ship's advance, tactical diameter, and steady turning diameter were necessary. The best result for the ship's advance was obtained using MPP software, as it closely matched the results from the sea trials, as represented in Figure 9 above.

However, for the tactical diameter and steady turning diameter, better results were obtained using the other specialized software, as shown in Fig.5.2.

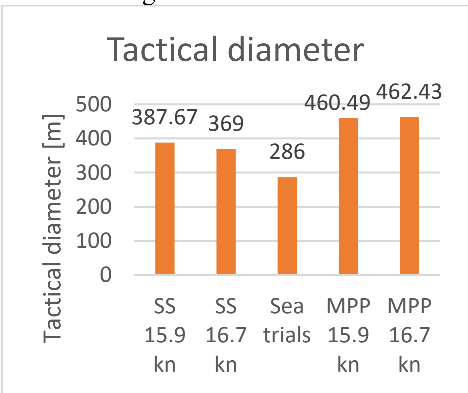

Fig. 10 Turning circle maneuver**.** Chart representing the ship's tactical diameter [1]

It is noteworthy that the value obtained for the steady turning diameter is the same for both speeds, indicating that this distance does not change along speed.

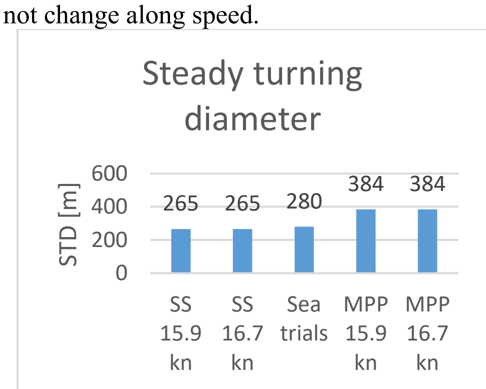

Fig. 11 Turning circle maneuver Chart representing steady turning diameter [1]

After limiting the engine power, the values obtained for the advance and tactical diameter, during the turning circle manoeuvre simulation, meet the criteria set by the IMO regarding manoeuvrability, thus the results are considered satisfactory [1].

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