ESTIMATION OF MAIN ENGINE POWER OF SEAGOING SHIP AT PRELIMINARY DESIGN STAGE

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Abstract

Permanent growth of the container shipbuilding has led to the need of research – developing activities with references to design and ship building process. The requirements for the container vessels have been modified and changed compared with the ships built in the eighties of the past century. The ships capacity have been increased up to and even above 10 000 twenty feet containers (TEU) with the service speed above 25 knots. For such a giant sea going vessels with the overall length above 300 meters and draught above 10 meters the ship hull resistance characteristics have been modified. Those conditions bring to the situation where the propulsion power for the seagoing ships reached 80 MW.

The estimation of the main engine power relation in the preliminary design stage is the main aim of the paper. The problem is such important as in that stage the most important design decisions with relatively low investment costs are determined. Moreover, the preliminary design stage distinguishes that the designer possesses just a few design parameters given by the ship owner of the future vessel. That is why the correct choice of the main engine power is difficult to determine. Determination of the main propulsion power impacts the electric and heat energy amount and the production way of both energy forms. The main engine equation has been determined based on the container ship's parameters for the entire range of container vessels load capacity (TEU). The values of the design parameters have came from author's data base for the contemporary container vessels.

Keywords: *seagoing ships, container vessels, preliminary design stage, ship's propulsion, main engine power*

1. Introduction

One of the fundamental tasks of the design of a seagoing ships is identification of the value of the engine's maximum continuous rating of the vessel's propulsion. The decisions concerning determination of the sea vessel's main engine power are already made at the very beginning of the ship's design process; namely, at the preliminary design stage.

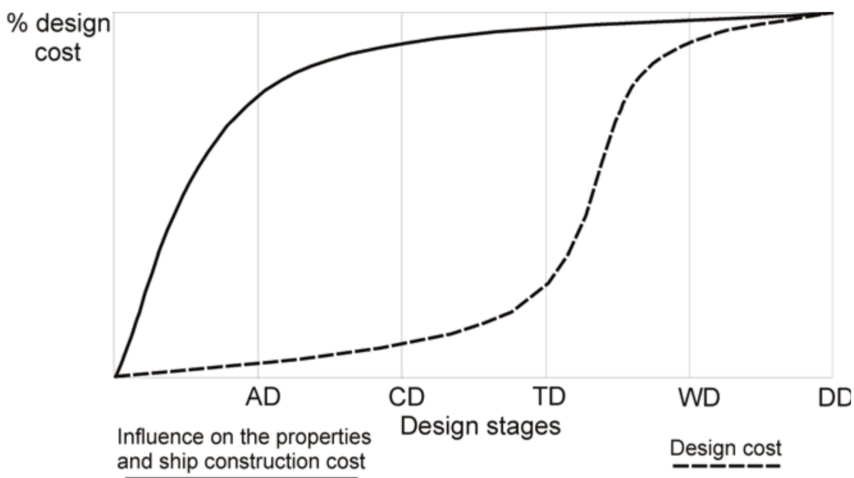

Fig. 1. Design phase expenses and their influence on the technical description and total expenses of the ship [3]

2. Characteristics of container vessels' main propulsion

The main propulsion of container vessels constitute diesel piston engines. With the additional knowledge that the dominating type of ships are vessels with one two-stroke, low speed, crosshead engines with high-power and a fixed pitch propeller (Fig. 2). In a few solutions, the main engine also powers a shaft generator. Most commonly, the container vessels are equipped with engines from manufacturers such as MAN Diesel SE.

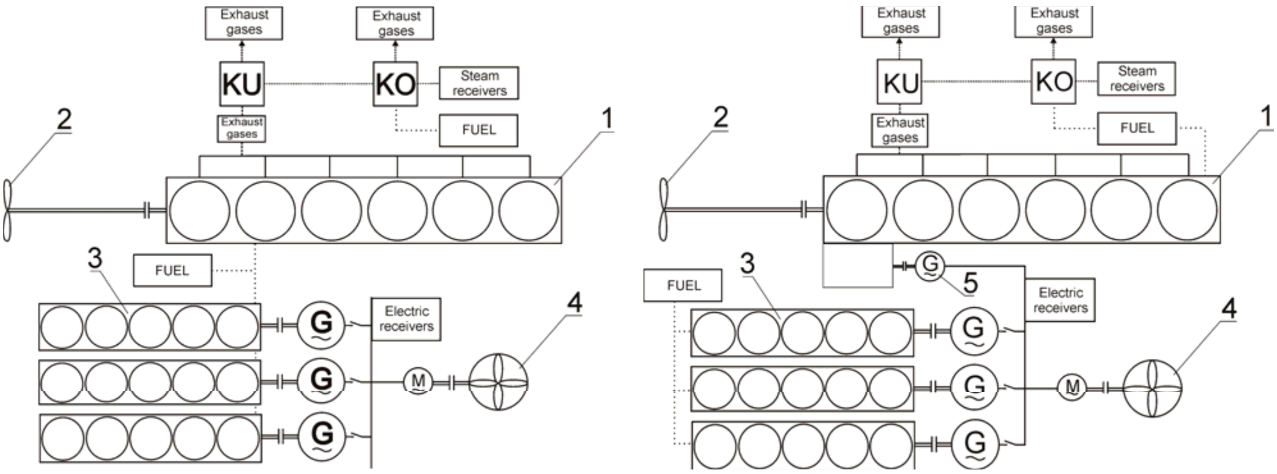

Fig. 2. Marine engine room with fixed pitch propeller driven by two stroke low-speed main engine: 1 – main engine, 2 – propeller, 3 – exhaust gas diesel generators, 4 – bow thruster, 5 – shaft generator, G – generator, M – motor, KU – Exhaust gas boiler, KO – auxiliary fired boiler

The advantage of applying low speed engines to the main propulsion is their low specific fuel oil consumption (SFOC), as compared with other solutions using power transmission systems.

Owing to the limited height of marine engine rooms on feeder vessels with smaller transportation capacity (TEU), there are power systems used that have medium speed propelling engines constituting the main propulsion with a gear and a controllable pitch propeller (Fig. 3). In these solutions, the dominating diesel engines are from two manufacturers: MaK and Caterpillar.

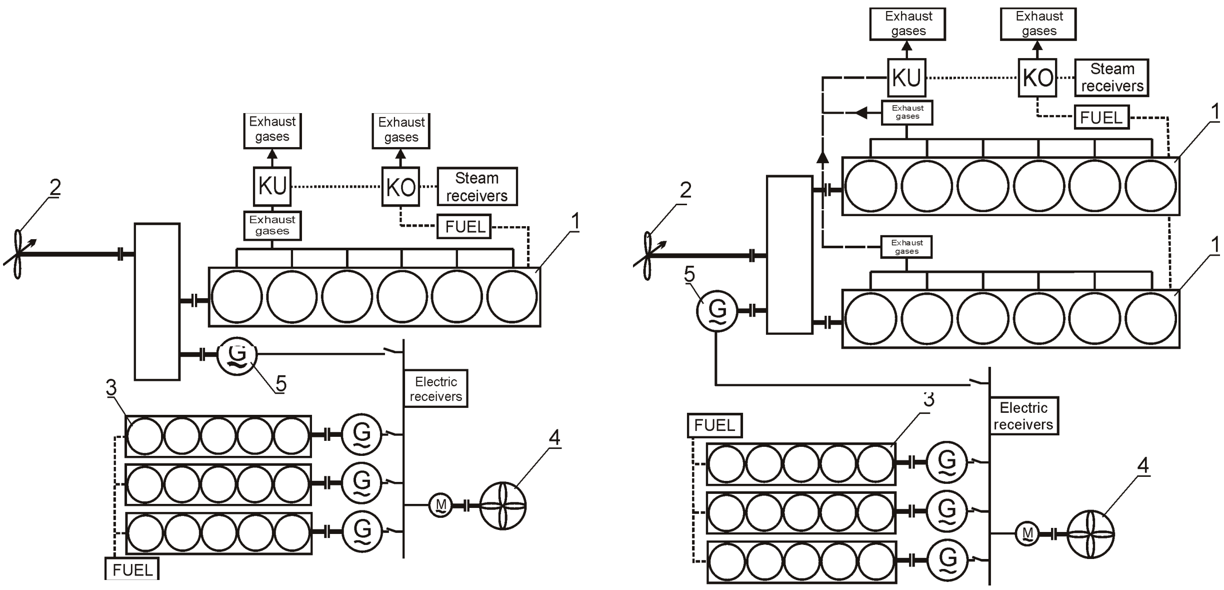

Fig. 3. Marine engine room with shaft generator and controllable pitch propeller driven by medium speed main engine: 1 – main engine, 2 – propeller, 3 – exhaust gas diesel generators, 4 – bow thruster, 5 – shaft generator, G – generator, M – motor, KU – Exhaust gas boiler, KO – auxiliary fired boiler

Depending on the vessel's transportation capacity, the feeder vessels are built for various numbers of main propulsion engines to propel a variable pitch propeller, and a shaft generator via a mechanical gear.

To improve the manoeuvering capabilities and shorten the time needed for manoeuvers, the container vessels are equipped with thrusters, powered by a separate high-powered electrical engine. For electric power generation, one uses independent power units, where generators are powered by combustion piston engines.

The presented diagrams in Fig. 2 and 3 show power systems that constitute the most common solutions for contemporary marine vessels. It does not change the fact that there are other solutions for the number of main propulsion engines, power units, the way to propel a shaft generator, and other factors.

3. Container vessels data base

Proper selection of a main engine, taking into account the operational issues, encourages to an increasingly broader use of the real data concerning ships. Creating the information base on the already constructed ships, and treating the vessel's engine room as a multi-parameter unit, it may turn out that this is a proper method, leading to rationalization for the preliminary design stage.

The data base built on the basis of [2, 4, 5, 9-11], consists of container vessels in the whole range of their load capacity. The data base has been devised so as not to contain the vessels with non-standard solutions and the units for transportation of specialized loads. In the event a shipyard builds more than ten of the same vessels, the base contains only one type of unit, representative for the whole series.

The number share of container vessels in the created data base with breakdown into classes according to [7, 8] has been presented in Fig. 4. The base structure contains both ships with medium speed engines as well as these, where the vessel's propulsion constitute low speed diesel engines.

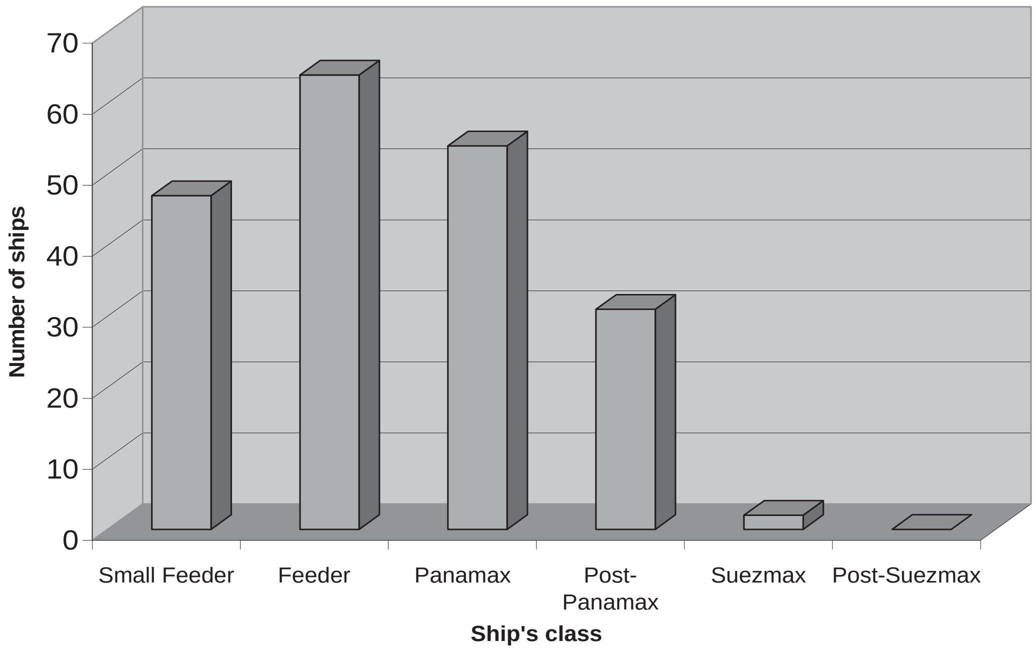

Fig. 4. Data base structure with container carrier's classification

The greatest share in the data base is made up of small and medium container vessels. For the ships with smaller carrying capacity, the technological limitations of shipyards and subcontractors, as well as of the floating docks of the ship being built, practically do not exist. Therefore, it is justified that the greatest share in the data base on container vessels belongs to those ships.

4. Methodology and test results

To determine the maximum continuous power (SMCR) of the marine vessel's main propulsion engine, one has considered two parameters, namely displacement D and speed of vessel υ using relation (1).

$$SMCR = a \cdot D^m \cdot \upsilon^n, \tag{1}$$

where:
a - regression coefficient

Exponents m, n in relation (1) have been determined on the basis of the values for various types of seagoing vessels, proposed in study [1]. Initially, it has been determined that the three values of exponent *m* consist of 1/3, 1/2, 2/3. For various values of exponent n between 2-5, there has been carried out an analysis of the product of the vessel's displacement *D* and service speed υ of the vessel in the form of three relationships (2), (3), (4). For small changes of the correlation coefficient, the value of exponent *n* was analyzed down to 0.1.

$$A = D^{1/3} \cdot \upsilon^n, \tag{2}$$

$$A = D^{1/2} \cdot \upsilon^n, \tag{3}$$

$$A = D^{2/3} \cdot \upsilon^n. \tag{4}$$

The obtained relations were analysed in such a way so as to find the highest value of the correlation coefficient (R) in relation A with respect to the value of maximum continuous rating (SMCR), as specified in the vessels' specifications.

The calculation cycle was terminating when the correlation coefficient, for two subsequent cases, assumed the decreasing values, what has been presented in Tab. 1-3.

Tab. 1. Analysis results of relation A for exponent m = 1/3 with significance level

Index at *D*	Function of the vessel's design parameters	Correlation coefficient	Regression constant	Regression coefficient	Significance of function p<0.05
1/3	$D^{1/3} \cdot \upsilon^{2}$	0.964062513	-13161.77254	9.039140301	5.36761E-64
	$D^{1/3} \cdot \upsilon^{2.5}$	0.968152064	-9184.792205	2.382034587	8.78158E-67
	$D^{1/3} \cdot \upsilon^{2.7}$	0.969421245	-7826.412492	1.400646893	1.01021E-67
	$D^{1/3} \cdot \upsilon^{3}$	0.970978422	-5987.569105	0.63286903	6.25937E-69
	$D^{1/3} \cdot \upsilon^{3.2}$	0.971803537	-4876.204001	0.373107602	1.34759E-69
	$D^{1/3} \cdot \upsilon^{3.4}$	0.972471196	-3844.541672	0.220152887	3.76021E-70
	$D^{1/3} \cdot \upsilon^{3.5}$	0.972749154	-3355.879611	0.169159232	2.18977E-70
	$D^{1/3} \cdot \upsilon^{3.7}$	0.973199241	-2428.135801	0.099923666	9.01518E-71
	$D^{1/3} \cdot \upsilon^{3.8}$	0.973373605	-1987.351481	0.076817753	6.36642E-71
	$D^{1/3} \cdot \upsilon^{4}$	0.973626266	-1148.134675	0.04541963	3.8299E-71
	$D^{1/3} \cdot \upsilon^{4.2}$	0.973757472	-360.8739723	0.026869797	2.93581E-71
	$D^{1/3} \cdot \upsilon^{4.3}$	0.973779893	14.80169709	0.020670781	2.80504E-71
	$D^{1/3} \cdot \upsilon^{4.4}$	0.973774727	379.2455258	0.015903785	2.83465E-71
	$D^{1/3} \cdot \upsilon^{4.5}$	0.973742836	732.967912	0.012237499	3.02438E-71

The conducted analysis for relation $A = D^{1/3} \cdot \upsilon^n$, suggests that the highest value of correlation coefficient exists for exponent $n = 4.3$. For $A = D^{1/2} \cdot \upsilon^n$ the highest correlation coefficient was reached for $n = 3.7$. On the other hand, for the third relation $A = D^{2/3} \cdot \upsilon^n$ the highest value of correlation coefficient was achieved for $n = 3.2$.

Tab. 2. Analysis results of relation A for exponent m = 1/2 with significant level

Index at D	Function of the vessel's design parameters	Correlation coefficient	Regression constant	Regression coefficient	Significance of function p<0.05
1/2	$D^{1/2} \cdot \upsilon^{2}$	0.971398077	-6227.335074	1.217185098	2.88235E-69
	$D^{1/2} \cdot \upsilon^{2.5}$	0.974210324	-3565.676477	0.325580197	1.1606E-71
	$D^{1/2} \cdot \upsilon^{2.7}$	0.974987701	-2625.782445	0.19236488	2.26877E-72
	$D^{1/2} \cdot \upsilon^{3}$	0.975833164	-1328.092261	0.087462137	3.62271E-73
	$D^{1/2} \cdot \upsilon^{3.2}$	0.976203056	-529.5707449	0.051749739	1.59051E-73
	$D^{1/2} \cdot \upsilon^{3.4}$	0.976432026	221.3017638	0.030634031	9.49318E-74
	$D^{1/2} \cdot \upsilon^{3.5}$	0.976497053	580.1978063	0.023573496	8.19141E-74
	$D^{1/2} \cdot \upsilon^{3.7}$	0.976534394	1267.29465	0.013963566	7.52482E-74
	$D^{1/2} \cdot \upsilon^{3.8}$	0.976509015	1596.367244	0.010748424	7.97179E-74
	$D^{1/2} \cdot \upsilon^{4}$	0.976375539	2227.55761	0.006370255	1.07872E-73

Tab. 3. Analysis results of relation A for exponent m = 2/3 with significant level

Index at D	Function of the vessel's design parameters	Correlation coefficient	Regression constant	Regression coefficient	Significance of function p<0.05
2/3	$D^{2/3} \cdot \upsilon^{2}$	0.970522139	-1048.721345	0.1654397	1.43598E-68
	$D^{2/3} \cdot \upsilon^{2.5}$	0.972304187	826.261811	0.044657496	5.18974E-70
	$D^{2/3} \cdot \upsilon^{2.7}$	0.97271146	1503.342177	0.026465724	2.35713E-70
	$D^{2/3} \cdot \upsilon^{3}$	0.973041576	2451.087075	0.01208187	1.23234E-70
	$D^{2/3} \cdot \upsilon^{3.2}$	0.973092652	3041.72758	0.007165749	1.11388E-70
	$D^{2/3} \cdot \upsilon^{3.4}$	0.973021385	3602.305125	0.004251139	1.2825E-70
	$D^{2/3} \cdot \upsilon^{3.5}$	0.972942968	3872.018453	0.003274672	1.49702E-70

Taking into account the highest value of correlation coefficient, for further discussion, relation (3) has been adopted for $n = 3.7$.

The values of exponents m and n, determined statistically for the level of significance p<0.05, have given grounds for determination of the exponent relationship of the marine ships' maximum continuous rating *SMCR* in function *A*.

The correlation coefficient for the relationship presented in Fig. 5 assumes value $R = 0.985$.

Finally, the relationship for the maximum continuous rating of the main propulsion engine for marine ships in the whole range of their load capacities has been expressed with equation (5):

$$SMCR = 0.18 \cdot D^{0.41} \cdot \upsilon^{3.05}, \tag{5}$$

By using the computer application Matlab [6, 12] in a 3D system of Cartesian coordinates, the results are displayed in Fig. 6. This presents the plane generated by equation (5).

For a qualitative evaluation of the relationship of the maximum continuous rating of the vessel's main propulsion engine, Tab. 4 presents the values of standard deviation of the vessel's main propulsion power from the database and the power determined on the basis of the set out relationship (5).

The value of the standard deviation has been presented in [kW] and as a percentage ratio as compared to the engine's maximum continuous rating. The container vessels have been divided into TEU classes, with growth every 1000 of TEU, determining appropriate value of power of the vessel's propulsion to each range of TEU.

The values of calculation errors of the main engine power for the whole range of load capacity TEU were in the range of up to 4%, and for the selected range of the vessels' container capacity of roughly 1%.

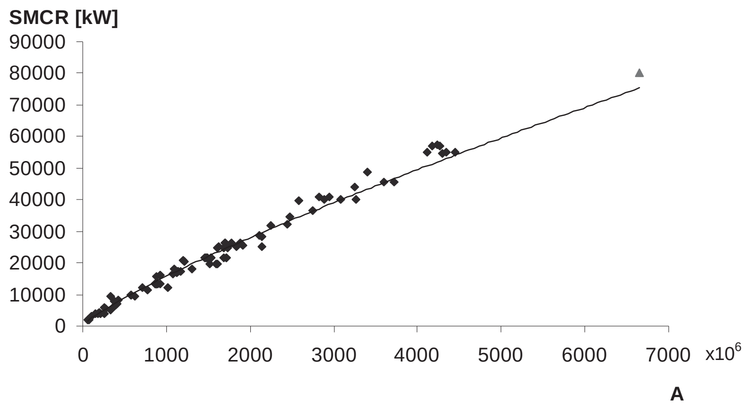

Fig. 5. Specified Maximum Continuous Rating and function A exponent relation

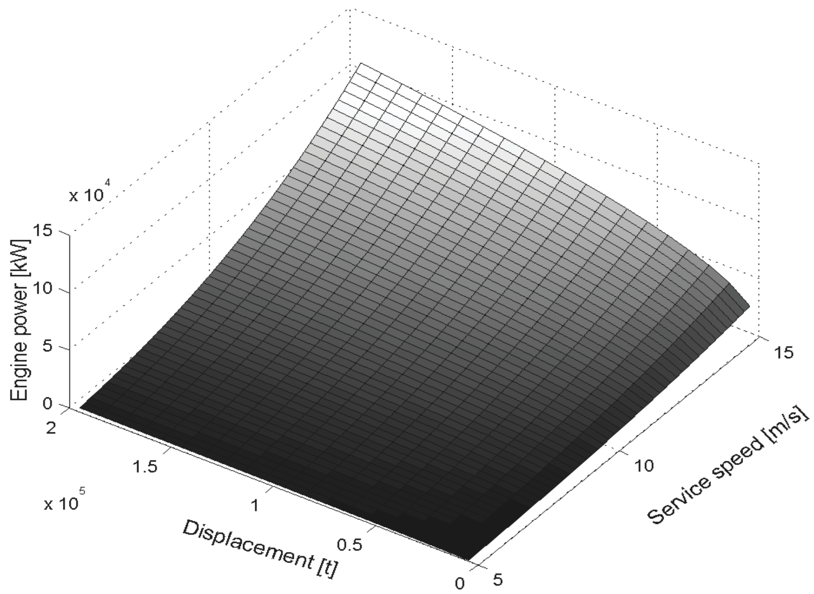

Fig. 6. Relation between Specified Maximum Continuous Rating, displacement and speed of the sea going ship

Tab. 4. Standard deviation values

TEU	Power	σ- stand. dev.	σ/Power
[-]	[kW]	[kW]	[%]
1000	8905	314	3.53
2000	17153	627	3.66
3000	25400	1011	3.98
4000	33647	321	0.95
5000	41894	802	1.92
6000	50142	560	1.12
7000	58389	1085	1.86

5. Conclusions

At the preliminary design stage of the sea vessel, when the knowledge about the ship is being collected, the main engine's power may be determined on the basis of displacement (*D*) and design speed (υ) for the designated values of exponents and regression coefficient a. To determine the power value of the vessel's propulsion engine, one has applied the design data of container vessels in the whole scope of their load capacity.

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