ESTIMATION OF SEAGOING SHIP'S ENGINE POWER BASED ON DISTINGUISHING QUANTITY PARAMETER

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Abstract

The power of main engine must be determined in such a way to let the seagoing ship reaches the predicted, in the agreement with the ship owner, service speed. Significant influence on the main engine power, apart from the ship's speed, has a geometry shape and the dimensions of the ship's hull. Begins from the general form of Admiralition's equation, it is essential to establish the specific quantity parameter for the estimation of main engine power. That parameter can be described by the displacement, DWT, LBT, TEU number, the 14 tons TEU number etc. depends on the type of the seagoing vessel.

The estimation of the specified maximum continuous rating SMCR based on the quantity parameter can be practicable in the preliminary design stage because of the small number of the known design data and the importance of the design decisions made at that level. The characteristic quantity parameter to establish the main engine power of the seagoing ship has been determined using the data of the contemporary container ships in operation. The research has been done in the whole range of the container capacity in TEU, where the combustion, reciprocation engines are used to propel the seagoing vessels. The statistical and regression tools have been utilized in the data analysis process to determine the quantity parameter.

Keywords: *container vessels, TEU, main engine power, quantity parameter, displacement*

1. Introduction

At the preliminary design stage, selection of the vessel's main propulsion power is a complex and time-consuming issue owing to there being little available design data and also to the importance of the design decisions taken at this stage.

Many design parameters of the seagoing ships have an impact on the value of the main engine's power such as the vessel's service speed, assumed by the shipowner, displacement (D), load capacity (DWT), the quotient of basic vessel's main dimensions (LBT), the number of containers (TEU), the number of containers with weight 14 tons (14TEU) and other parameters.

2. Ship's design process

The decisions concerning determination of the sea vessel's main engine power are taken at the very beginning of the ship's design process, namely at the preliminary design stage.

Comparing the cost of different stages of design with their effect on characteristics and the general cost of the vessel, in accordance with Fig. 1, it turns out that the most important decisions are made at the preliminary design stage (AD), before signing the contract (CD). At the same time, this results in very low design costs. The importance of determinations in the initial (acquisition) design stage (AD) has great impact on the characteristics of the designed ship. For this reason, already at this stage, one should very thoroughly estimate the seagoing vessel's engine power. The cost of later stages of the vessel's construction, particularly at the technical design (TD) and working design (WD), are disproportionately high, compared with the preliminary stage.

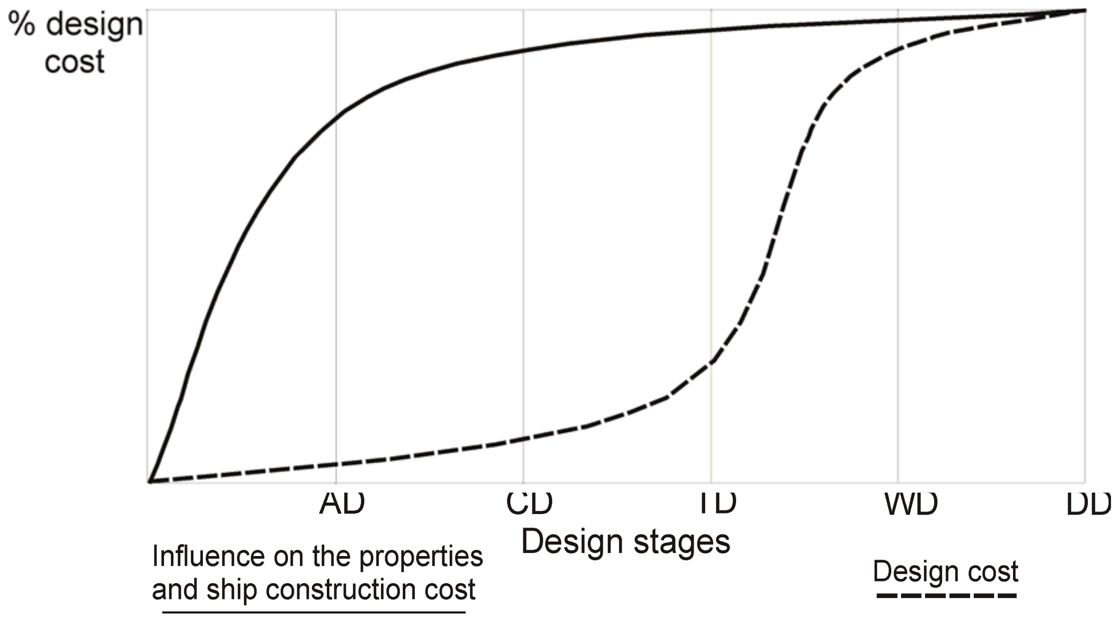

Fig. 1. Design phase expenses and their influence on the technical description and total expenses of the ship [3]

The effects of the decisions made in the initial stage of the design have cardinal importance for the ship, not only in terms of its characteristics, but also in terms of the costs of manufacturing and, what is more important for the shipowner, the costs of its operation.

3. Continer vessels' database

Proper selection of the main engine, taking into account operational issues, results in increasingly broader use of real ships' data.

Creating the information based on already constructed seagoing ships, treating the vessel's engine room as a multi-parameter unit, it may turn out that this is a proper procedure, leading to rationalization at the preliminary design stage.

An important stage in the process of evaluation of the characteristic design based on the sea vessel's engine power is creation of database about the operational values of container vessels. This data results from the design assumptions during the sea vessel's construction.

To preserve a statistically high value of the level of significance, received depending on the examined design sizes of values, as well as a small number of deviating values, the database must be constructed in such a way so as not to contain the ships with non-standard solutions and the vessel for transportation of specialized loads. In the event of a shipyard building over ten of the same ship, the database contains only one representative of the whole series.

The ratio of container vessels in the created database with breakdown into classes according to [7] has been presented in Fig. 2. The database structure contains the ships propelled by diesel engines.

The database built on the basis of [2, 4, 5, 8-10], consists of container vessels in the whole range of their load capacity.

The greatest share in the database constitute small and medium container vessels. For the ships with a smaller load capacity, there are practically no technological limitations upon the vessel's construction and en route region. Therefore, it is justified that the greatest share in the database on container vessels belongs to ships with a smaller capacity i.e.up to 2800 TEU for the Kiel Channel and St. Lawrence sea route, as well as up to 5000 TEU for the Panama Canal, making the database more objective.

In New Panamax class, namely from 10000 up to 14500, there is one vessel, which may accommodate up to 11000 twenty feet containers (TEU).

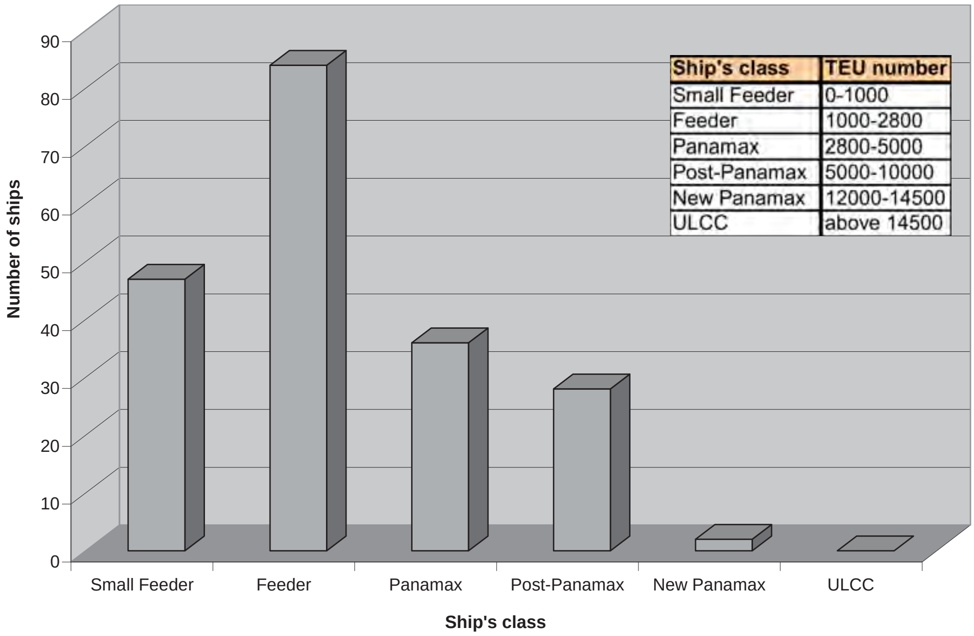

Fig. 2. Database structure with container carriers' classification

4. Methodology and test results

The effective power of the vessel's main propulsion, defined as the specified maximum continuous rating (SMCR), can be determined on the basis of relation (1), which constitutes the generalized form of the Admiralty formula.

In studies [1, 14], one has suggested a modification of the Admiralty formula to replace the characteristic parameter of the vessel, which is displacement, with other values i.e. length, width, draught and load capacity.

$$SMCR = \frac{X^m \cdot \upsilon^n}{C}, \quad (1)$$

where:

X - design parameter of the vessel,

υ - service speed of the vessel according to design assumptions,

C - proportionality coefficient dependent on the shape of the hull and Froude number, defined on the basis of the parameters of similar ships [11],

m, n - values of exponents being searched.

Using the container vessels data gathered in the database, in the first place, one made an attempt to define the value of adequate proportionality coefficient (C). Knowing the value of the vessel's speed (υ) and the maximum value of continuous rating of the main engine (SMCR), one has determined proportionality coefficient (C) for the known value of the examined design value (X). The coefficient C assumed various values depending on the watercraft class and on the vessel's design data (X). As the design data, one has taken into account a product of LBT, load capacity (DWT), number of twenty feet containers (TEU), displacement (∇) and a number of twenty feet containers with the adopted mass of 14 tons (14TEU). Based on this, one has created two scopes of the examined design value (X) that define the way to determine proportionality coefficient value (C). The first scope has been specified with equations of linear, logarithmic or exponent regression. The second, designated as the arithmetic average of the examined design value (X), results from dispersion of the value in the adopted scope and lack of monotonicity defining the functional interpretation of changes in direction. For all examined cases, the value of Pearson correlation coefficient (R) in accordance with relation (2) was above 0.90.

$$R_{EF} = \frac{\text{cov}(E, F)}{\sigma E \sigma F}, \quad (2)$$

where:
cov (E,F) - covariance of the selected variables E, F,
σEσF - standard deviation of variables E, F.

Figure 3 presents the values of proportionality coefficient (C), depending on the vessel's displacement (∇) adopted as a design value in equation (1).

For displacement up to 60 000 tons, the proportionality coefficient (C_∇) was determined from logarithmic regression equation $C_\nabla = 16{,}59 \ln \nabla - 101{,}01$.

In Tab. 1, based on this equation, one has made statements of proportionality coefficient values (C_∇) for the selected range of the vessels' container capacity.

Tab. 1. Tabulation of displacement up to 60 000 tons and proportionality factor depends on container number (TEU)

TEU	∇	C_∇
[-]	[t]	[-]
up to 500	up to 9363	50.7
501–1000	9363-16893	60.5
1001–2000	16893-31953	71.1
2001–3000	31953-47013	77.5
3001–3862	47013-60000	81.5

Proportionality coefficient values (C_∇) presented in Tab. 1 shall be understood as the highest for the maximum scopes of the vessels' displacement (∇).

Using the relation of the vessel's displacement (∇) in the function of the number of twenty feet containers (TEU), represented in Fig. 4, for individual ranges of the number of 20-feet containers, one has assigned relevant displacement values (∇) and further (C_∇).

In Tab. 2 for the vessel's displacement above 60 000 tons, the proportionality coefficient (C_∇) has been defined as an arithmetic average with the value of 79.5, owing to lack of possibilty of determination of the character of changes.

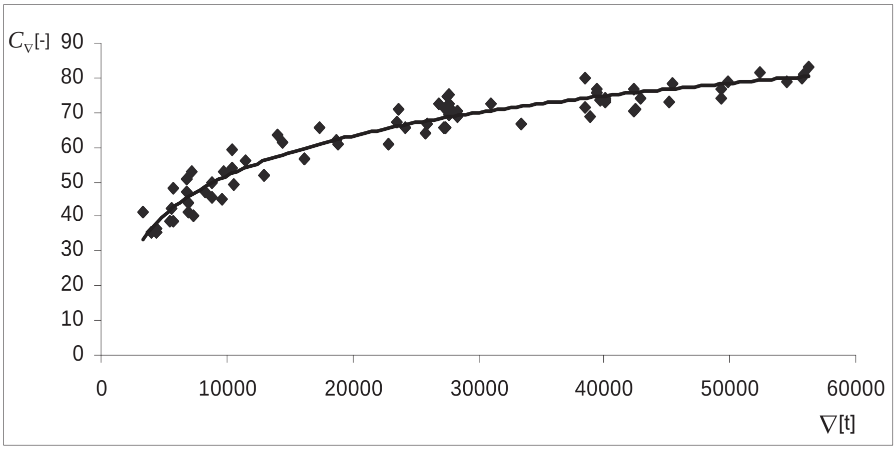

Fig. 3. Determination of proportionality factor (C) for ship's displacement in first range

Knowing the values of proportionality coefficient for the examined design values ∇, DWT, LBT, TEU, 14TEU, one has determined the estimated value of the maximum continuous rating of the vessels' main engine (SMCR).

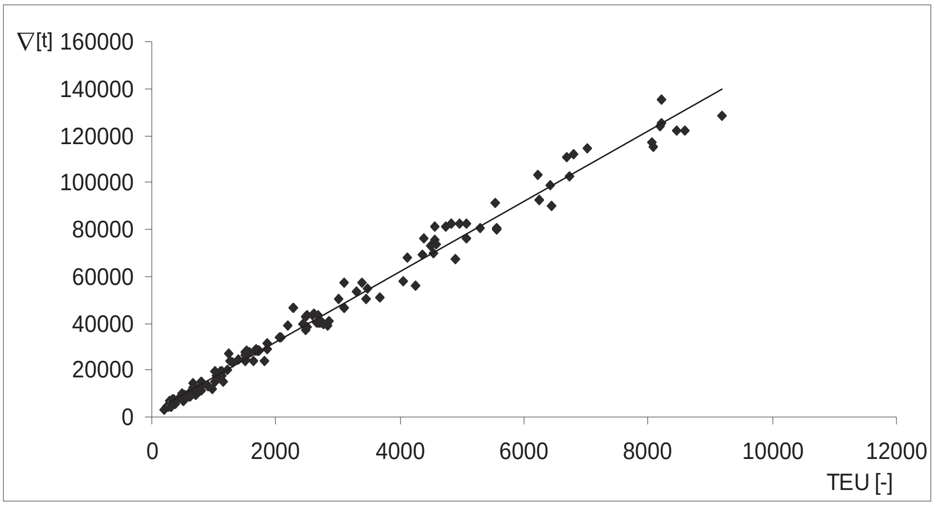

Fig. 4. Linear relation between container vessels displacement and container number (TEU)

On the basis of the specified maximum continuous rating (SMCR) of the main engines as specified in the vessel's specification (database) and the power values specified indirectly from the vessel's design parameters i.e.: ∇, DWT, LBT, TEU, 14TEU one has determined a characteristic design parameter (X) of the seagoing vessel.

Tab. 2. Tabulation of displacement above 60000 tons and proportionality factor depends on container number (TEU)

TEU	∇	C_∇
[-]	[t]	[-]
3863	60009	81.5
3001-4000	62073	82.1
4001-5000	77133	77.0
5001-6000	92193	82.0
6001-7000	107253	77.5
8000-10000	152433	77.1
	AVERAGE	79.5

The criterion that has enabled selection of the most beneficial value parameter of the vessel was standard deviation σ [6], [12], [13] presented in Tab. 3. Deviation σ described with relation (3) determines the value by which all ships of the given set of container vessels differ on average from the arithmetic average of the examined design variable

$$\sigma = \sqrt{s^2}, \tag{3}$$

Based on this, for further calculations, one has assumed displacement (∇) as a distinguishing quantity parameter.

The vessel's specified maximum continuous rating (SMCR) in accordance with relation (1) and Tab. 3 should be specified on the basis of the vessel's service speed (υ), proportionality coefficient (C_∇) and in the function of the vessel's displacement (∇) (4).

$$SMCR=f(\nabla, \upsilon, C_{\nabla}) \quad (4)$$

Tab. 3. Presentation of design data and statistical parameters for all container carrier classes

Design parameter X	Unit	Symbol	Variance s^2	Standard deviation σ
∇	t	$SMCR_D$	42679704	2035
LBT	m^3	$SMCR_{LBT}$	15652615	3956
TEU	item	$SMCR_{TEU}$	63100920	7944
14TEU	item	$SMCR_{14TEU}$	14512933	3810
DWT	t	$SMCR_{DWT}$	23016172	4798

5. Conclusions

At the preliminary design stage of the seagoing vessel, when the knowledge about future ship is being collected, the main engine's power may be determined on the basis of displacement (∇) and design speed (υ). The proposed methodology of selection of a distinguishing quantity parameter for determination of the value of power of the vessel's propulsion engine is so innovative that it was established on the basis of the design data of the presently operated container vessels in the whole range of their load capacity.

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