IMPROVEMENT IN PRELIMINARY DETERMINATION OF ENERGY DEMAND FOR MAIN PROPULSION, ELECTRIC POWER AND AUXILIARY BOILER CAPACITY BY MEANS OF STATISTICS AS AN EXAMPLE OF MODERN RO-RO VESSELS

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Abstract

The paper presents the method of estimated main propulsion power, electrical power and auxiliary steam delivery of the modern ro-ro vessels by using statistical method of calculations. The statistical researches were executed to determine dependencies among the main propulsion power, electric power and heating power as a function of selected basic ship parameters. The reference list of the modern ro-ro vessels was used in the analysis. The chosen ships were selected mainly from the studies of The Royal Institution of Naval Architects elaborated by the most eminent authors of the world shipping enterprise running their articles in a years issue SIGNIFICANT SHIPS OF YEAR. The chosen as the independent variables are the ship parameters being in a logical connection with the main propulsion power, electrical power and steam production of the vessel. Regression analyses were executed by means of the least squares method. Each determined formula was subjected to the statistical verification and the correlation coefficient between the obtained formula and analysed input data was determined.

Keywords: *ro-ro vessel, main propulsion power, electrical power, auxiliary steam delivery, statistics*

1. Introduction

On Ro-Ro ships cargo is rolled on and rolled off by lorries or trailers. The great advantage of this system is that no cargo handling equipment is required. The loaded vehicles are driven aboard by means of ramps through special stern and bow doors and properly secured for the passage. Upon arrival in the port of discharge, the vehicles are released and driven ashore to their destinations. Part of a Ro-Ro vessel's cargo may be loaded/discharged by gantry cranes, for example containers to/from the weather deck.

Various types of Ro-Ro vessels include ferries, cruiseferries, cargo ships, and barges. A true Ro-Ro's ramps can serve all of the vessel's decks; otherwise it is a hybrid type. New automobiles that are transported by ship around the world are often moved on a large type of Ro-Ro called a Pure Car Carrier (PCC) or Pure Car Truck Carrier (PCTC).

The acronym RoPax describes a Ro-Ro vessel equipped with cabins to accomodate passengers (fig. 1).

Sto-Ro (stowable Ro-Ro) is a modification of the ro-ro transport method where cargo is stowed directly into the ship's hold and the rolltrailer used for stowage does not accompany the cargo to the port of discharge. The sto-ro method is especially suitable for shipment of cargo such as paper reels.

Provisional analysis shows that:

- usually, the main propulsion of these vessels is multiengine type (mainly 4 engines), which drive two propellers trough gearbox,

- power plants are usually created by main engine-driven alternators and by three diesel-driven alternators,
- auxiliary steam is generated by main engines exhaust gas boilers (the amount of exhaust gas boilers is equal to the amount of engines) and by at least one oil fired auxiliary boiler.

Fig. 1. RoPax vessel at sea

The paper presents the method of estimated main propulsion power, electrical power and auxiliary steam delivery of the modern Ro-Ro vessels by using statistical method of calculations.

2. Method for the determination of energy demand for main propulsion, electric power production and boiler capacities for Ro-Ro ship.

Presently a number of methods are in use, which allow the approximate determination of demand for mechanical energy, electric power and auxiliary boiler capacity for seagoing vessels. For example the provisional determination of the ship main propulsion energy can be obtained by means of Papmiel, Guldhammer-Harvald, Hansen, Holtrop or Series 60 methods. These methods are based on arduous calculations and need the determination of the big number of coefficients and their further corrections without satisfactory accuracy in the final results. That is why there is an expectation for the method or ready given formulas, which can allow the estimation of energy demand for seagoing vessel during the preliminary designs in a quick and simple manner and with acceptable accuracy.

The target of research work was to obtain ready formulas by means of mathematical statistics. For this purpose “the list of similar vessels” (reference list) was prepared, in which the basic data of 61 modern Ro-Ro vessels built in last years or actually under construction are listed. Among the parameters the ones that are logically and functionally connected with energy demand for main propulsion, electric power and steam production are listed. The vessels placed in the reference list come from *The Royal Institution of Naval Architects*, where the most significant world representatives of the marine industry are published. Their works and designs are annually issued in the *SIGNIFICANT SHIPS OF YEAR.*

2.1. Determination of power for ship main propulsion

In the considered number of Ro-Ro vessels the power of main propulsion N_w was assumed as:

$$N_w = N_e - N_{pw} \ [kW] \tag{1}$$

where:

N_e [kW] – main engine shaft power,
N_{pw} [kW] – shaft generator power consumption.

The analysis of power demand for main propulsion of the vessel N_w was executed by means of Admiralty Formula, in which the main propulsion power depends on ship deadweight *D*, ship speed *v* and Admiralty Coefficient c_x regarding the geometric similarity of the hull:

$$N_w = \frac{D^{\frac{2}{3}} \cdot v^3}{c_x} \tag{2}$$

Using the formula (2) for *i=57* vessels from the reference list the c_x coefficient was calculated and next used for calculation of main propulsion power at nine selected ship speeds *v=30, 28, 26, 24, 22, 20, 18, 16* and *14 knots*. Next the relationship between main propulsion power and deadweight $N_w = f(D)$ was determined for the whole vessel population at each a.m. speed. It was stated that for given speed the main propulsion power N_{wv} has a linear dependency on displacement:

$$N_{wv} = a_o + a_1 D \tag{3}$$

The calculations of coefficients a_{oi} and a_{1i} for each given speed were executed by linear regression based on the least squares method. The following dependencies were obtained:

$$\text{for:} \quad \left.\begin{array}{ll} v = 30\ w & Nw_{30} = 40234 + 1{,}04993\ D \\ v = 28\ w & Nw_{28} = 32712 + 0{,}85363\ D \\ v = 26\ w & Nw_{26} = 26191 + 0{,}68346\ D \\ v = 24\ w & Nw_{24} = 20600 + 0{,}53756\ D \\ v = 22\ w & Nw_{22} = 15857 + 0{,}41406\ D \\ v = 20\ w & Nw_{20} = 11921 + 0{,}31109\ D \\ v = 18\ w & Nw_{18} = 8691 + 0{,}22678\ D \\ v = 16\ w & Nw_{16} = 6104 + 0{,}15928\ D \\ v = 14\ w & Nw_{14} = 4089 + 0{,}10670\ D \end{array}\right\} \begin{array}{l} r^2 = 0{,}2632 \\ r = 0{,}5130 \end{array} \tag{4}$$

with the coefficient of determination $r^2 = 0{,}2632$, which confirms the linear nature of dependency $N_w = f(D)$.

Figure 2 presents the result of calculation for a speed of 22 *knots*.

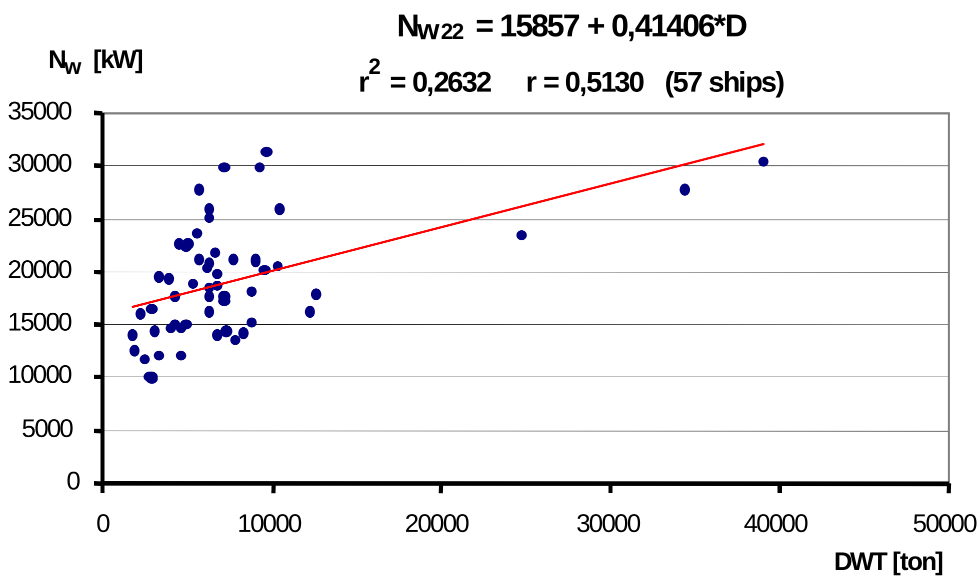

Fig. 2. Linear regression of dependency N_w =f(D) for the speed 22 knots

The coefficients a_{oi} and a_{1i} in formulas (4) are functions of the vessel speed i.e.:

$$a_o = f(v)$$

$$a_1 = f(v) \qquad (5)$$

The determination of coefficients a_o and a_1 depending on ship speed was executed by means of power curve regression [2] of the function described as:

$$y = b\,x^{d} \qquad (6)$$

In this case coefficients of functions (4) are described as:

$$a_o = b_o\,v^{do}$$

$$a_1 = b_1\,v^{d1}$$

After the coefficients of regression b_i and d_i were calculated the functions (5) are:

$$a_0 = f(v) = 1{,}5886 * v^3$$

$$a_1 = f(v) = 0{,}00003488 * v^3$$

After the substitution of the above formulas into formula (3) the final form of main propulsion power equation was obtained. It is as follows:

$$\boldsymbol{Nw = (1{,}49042 + 0{,}00003888 * D) * v^3} \; [kW] \qquad (7)$$

where:

D [tons] – vessel deadweight,
v [knots] – vessel speed.

The correlation between the value of main propulsion power taken from the reference list and obtained according to the formula (7) is presented in figure 3. The linear regression of points location at the correlation area results as the straight line with the coefficient of the determination $r^2 = 0{,}8141$. However the Pearson linear regression coefficient of formula (7) with reference to the data from vessels reference list is $r = 0{,}9023$, which confirms the correctness of the above assumptions and calculations.

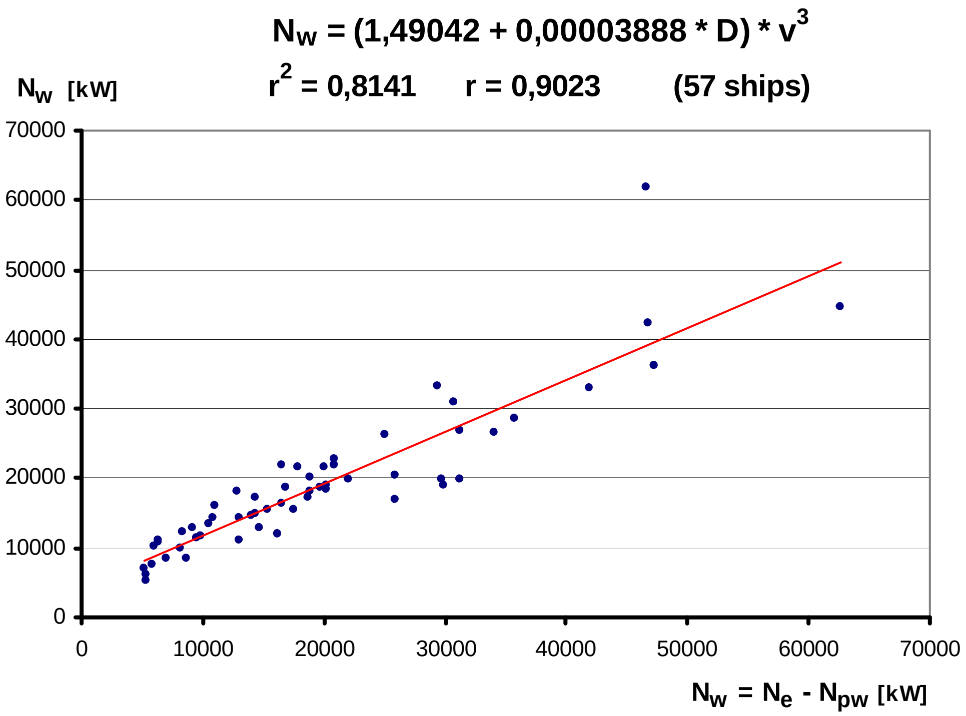

Fig. 3. Correlation area between main propulsion power obtained acc. to formula (7) and taken from reference list

2.2. Determination of total electric power demand

The accurate determination of electric power plant is not possible during the vessel preliminary design works due to lack of the final electric energy balance. Existing formulas [6, 9] regard to the vessels of older design and don't take into consideration new circumstances, which came as a result of ship construction development. It brought the necessity of modernising the existing formulas taking into consideration the new design trends according to the reference list of vessels.

During the determination of the electric power demand for the modern Ro-Ro vessels the principle that the total electric power ΣN_{el} *is* the function of main propulsion power N_w [6]. In that case linear dependence was assumed.

To show this relationship the linear regression was used with regarding to the least squares method. Total number of 56 vessels from the reference list was taken into consideration. As a result the following formula was obtained:

$$\Sigma N_{el} = 2432 + 0{,}14944\, N_w \quad [kW] \tag{8}$$

where: N_w *[kW]* – main propulsion power,

with the coefficient of determination $r^2 = 0{,}6387$. The graphical picture of formula (8) determination shows figure 4. Obtained Pearson linear regression coefficient of correlation between the values from formula (8) and values taken from the vessels reference list is $r = 0{,}7992$, which confirms the usefulness of formula in the preliminary calculations.

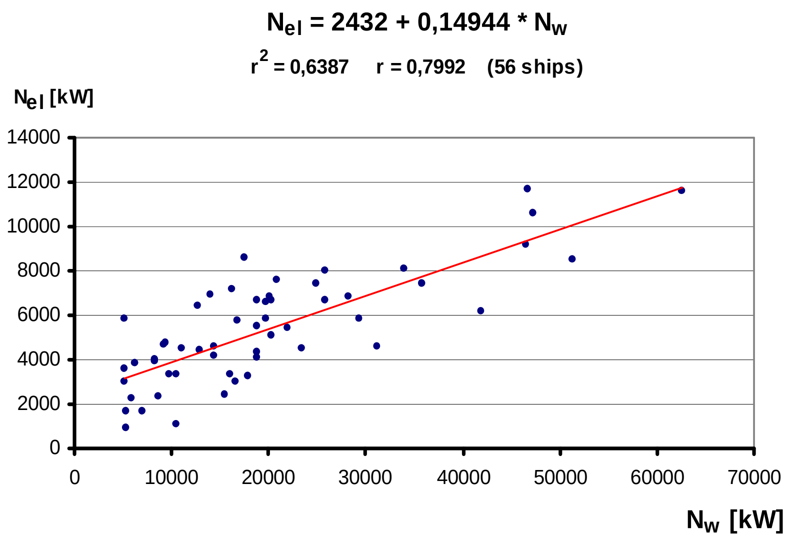

Fig. 4. Linear regression for determination of total electric power as the function of the main propulsion power

2.3. Determination of auxiliary boiler capacity

Similarly to the electric power the accurate determination of auxiliary boiler capacity is not possible during the vessel preliminary design works due to lack of the final heat energy balance.

During the determination of auxiliary boiler capacity for the modern Ro-Ro ships the principle that the auxiliary boiler capacity D_{blr} *is* the function of main propulsion power N_w [6] and that it is a linear dependence was assumed.

In this case the linear regression was also used with regarding to the least squares method.

Total number of 41 vessels from the reference list was taken into consideration. The following formula was obtained:

$$\boldsymbol{D_{blr} = 1382 + 0{,}15265\ N_w \quad [kg/h]} \tag{9}$$

where: N_w *[kW]* – main propulsion power,
with the coefficient of determination $r^2 = 0{,}5885$. The graphical picture of formula (9) determination shows figure 5. Obtained Pearson linear regression coefficient of correlation between the values from formula (9) and values taken from the vessels reference list is $r = 0{,}7671$.

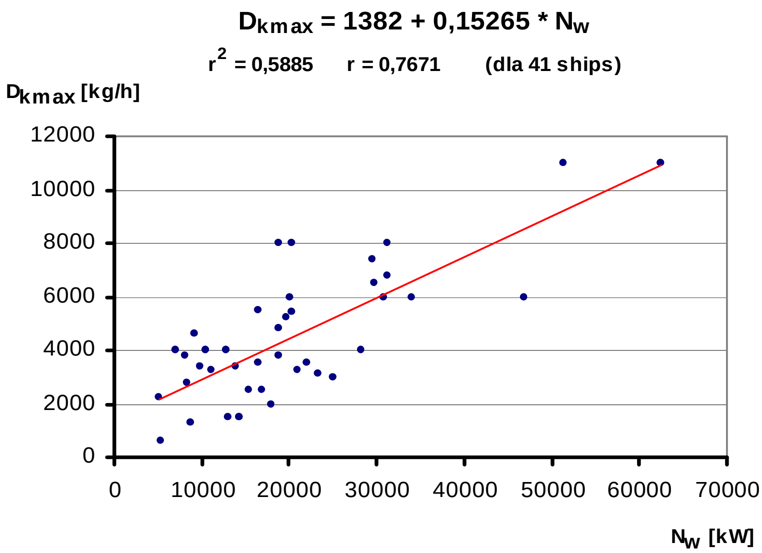

Fig.5. Graphical representation of formula (9) determination

3. Conclusion

The above discussion proves that statistic is very useful means for determination of energy demand for main propulsion, electric power and auxiliary boiler capacity in ship design preliminary calculations.

Authors of presented paper are concerned in this way of design calculations improvement. The method is to be used also in case of another types of sea going vessels. For example, for modern container vessels obtained formulas are as follows [2]:

$$N_w = (0{,}9179 + 0{,}00003412\ D)\ v^3 \quad [kW]$$

$$\Sigma N_{el} = 1077 + 0{,}1580\ N_w \quad [kW]$$

References

[1] Draper, N.R. and Smith, H., *An application of linear regression*, Warszawa (1973).

[2] Giernalczyk, M., Górski, Z., *Method for determination of energy demand for main propulsion, electric power production and heating purposes for modern container vessels by means of statistics,* Marine Technology Transactions, Marine Technology Commity of the Polish Academy of Sciences, Gdańsk 2004

[3] Giernalczyk, M., Górski, Z., *Improvement in the preliminary determination of energy demands for main propulsion, electric power and auxiliary boiler capacity by means of statistic: an example based on modern bulk carriers,* 9th BALTIC REGION SEMINAR ON ENGINEERING EDUCATION, Gdynia Maritime University 17-20 June 2005 pp 49-51

[4] Giernalczyk, M., Górski, Z., *A Statistics-based Method for the Determination of energy demands for main propulsion, electric power and auxiliary boiler capacity for modern crude oil and products tankers.Explo-ship 2006,* Szczecin Maritime University pp 183-192

[5] Hewlett Packard: *HP-65 Stat Pac 1.* Cupertino, California, (1976).

[6] Michalski, R., *Ship propulsion plants. Preliminary calculations,* Szczecin Technical University, Szczecin (1997).

[7] *Report – Energetic assessment of recent ship propulsion plants and means for theirimprovement. Research project no 9 T12D 033 17 of Government Research Comity Polish under management of Prof. Romuald Cwilewicz,* Gdynia Maritime University, Gdynia (2002).

[8] *Standardisation of calculation methods of motor ship engine room systems designing,* Study of Ship Techniques Centre (CTO), Gdańsk 1974

[9] *Unification of ship engine room. Part V. Ship power plant,* Study of Ship Techniques Centre (CTO), Gdańsk 1978.

[10] Zieliński, R., *Statistics Tables*. Scientific and Technical Publications (WNT), Warszawa 1978.