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ESTIMATION METHOD OF SHIP MAIN PROPULSION POWER, ONBOARD POWER STATION ELECTRIC POWER AND BOILERS CAPACITY BY MEANS OF STATISTICS

Mariusz Giernalczyk, Zygmunt Górski, Bartłomiej Kowalczyk

Marine Power Plants Department
Gdynia Maritime University, 83 Morska Street, 81-225 Gdynia, Poland
Tel.:+48 58 6901307,
e-mail: magier@am.gdynia.pl

Abstract

This paper describes an estimation method of ship propulsion power, onboard power station electric power and boilers capacity for the number of ship types by means of statistics. A wide population of being in operation and new built container ships, ferries, ro-ro vessels, passenger cruisers, tankers, LNG carriers and bulk carriers was taken into consideration on the base of similar ships list. The list of similar ships was prepared mainly on data given in works of THE ROYAL INSTITUTION OF NAVAL ARCHITECTS published in famous year's issue the *SIGNIFICANT SHIPS OF YEAR. As a result of analysis formulas for calculations of ship propulsion power, onboard power station electric power and boilers capacity for considered types of ships were obtained. Formulas elaborated by means of described method are characterised by good representation of described values as they have high coefficients of correlation and regression determination.*

Keywords*: ship main propulsion power, onboard power station electric power, ship boilers capacity*

1. Introduction

There are number of methods making possible the estimation of propulsion energy, electric power and heating energy for seagoing ship. For example the main propulsion power may be determined by means of Papmiel, Guldhammer-Harvald, Hansen, Holtrop or Series 60 methods. These methods are based on arduous calculations and on determination of big number of coefficients which should be farther corrected and finally results of calculations are not satisfied in accuracy. Thus a necessity to elaborate such a method or ready made formulas which can make possible to determine energy needed for new designed ship in simple and quick manner.

The paper introduces ready made formulas making possible estimation of ship main propulsion power, onboard power station electric power and steam boilers capacity for different types of seagoing ships by means of statistic methods.

To apply statistic methods a “reference list of similar ships” was elaborated. The reference list includes basic technical particulars of ships built in recent years and being under construction. Technical particulars logically and functionally connected with main propulsion energy, electric power and boilers capacity were analysed.

Ships placed in reference list come mainly from *The Royal Institution of Naval Architects* publications, where the most outstanding representatives of marine industry and management present their works in year's issue *SIGNIFICANT SHIPS OF YEAR*. It guarantees rational and objective selection of reference list ships and ensures that this list includes representative selection of ships.

2. Determination of ship main propulsion power

A following was considered as a main propulsion power N_w:

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

where:

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

To analyse ship main propulsion power of the ship N_w The Admiralty Formula was used where the propulsion power depends on ship deadweight or displacement D, ship speed v and Admiralty Coefficient c_x regarding a hull geometric similarity:

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

Using formula (2) the coefficient c_x was calculated for each ship from reference list. Next it was used for calculation of main propulsion power N_{wi} for a number of ship speed $v = v_1 \div v_n$ for each ship from reference list. Calculations were executed for a number of ships from reference list. For each given ship speed a cumulative diagram of dependency $N_w = f(D)$ for all population was elaborated. The linear dependency between main propulsion power in given ship speed N_{wv} and ship deadweight or displacement was affirmed:

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

Calculations of a_{oi} and a_{1i} coefficients for each chosen ship speed were based on linear regression by means of least squares method. Coefficients a_{oi} and a_{1i} in formula (3) depend on ship speed:

$$a_o = f(v),$$
$$a_1 = f(v), \tag{4}$$

To determine a_o and a_1 coefficients value in dependence on ship speed the approximation by power function was used:

$$y = b\, x^d , \tag{5}$$

In this case the following was assumed:

$$a_o = b_o\, v^{do} \text{ and } a_1 = b_1\, v^{d1}.$$

Coefficients b_i and d_i were calculated by means of least square method an it was assumed that formula (5) is third power function of ship speed:

$$a_o = f(v) = b_o \cdot v^3,$$
$$a_1 = f(v) = b_1 \cdot v^3. \tag{6}$$

The dependency (5) was applied to formula (3) and as a result a final formula for ship main propulsion power was obtained:

$$N_w = (a_o + a_1 \cdot D)\, v^3 \; [kW], \tag{7}$$

where:

D *[tons]* – ship deadweight or displacement,
v *[knots]* – ship speed,
a_o, a_1 – coefficients depending on ship type.

Example of calculation of tankers main propulsion power [4]

A number $i=63$ ships was analyzed. Using formula (1) coefficient c_x was calculated for each ship from reference list and next it was used for calculation of each tanker main propulsion power N_{wi} for seven chosen speeds v: *12, 13,14, 15,16, 17* i *18 knots*. For each speed the cumulative diagram of dependency $N_w=f(D)$ for whole population was elaborated. An example of linear regression for $v=15$ *knots* is shown on figure 1.

Calculation of formula (2) a_o and a_1 coefficients was executed by means of least square method for each ship speed. The following dependencies were obtained:

$$\text{for:} \quad \left.\begin{array}{ll} v = 18\ w & N_{w18} = 12955 + 0{,}10030\ D \\ v = 17\ w & N_{w17} = 10914 + 0{,}08449\ D \\ v = 16\ w & N_{w16} = 9099 + 0{,}07044\ D \\ v = 15\ w & N_{w15} = 7497 + 0{,}05804\ D \\ v = 14\ w & N_{w14} = 6096 + 0{,}04719\ D \\ v = 13\ w & N_{w13} = 4881 + 0{,}03778\ D \\ v = 12\ w & N_{w12} = 3839 + 0{,}02972\ D \end{array}\right\} \; r^2 = 0{,}8066,\; r = 0{,}8981 \tag{8}$$

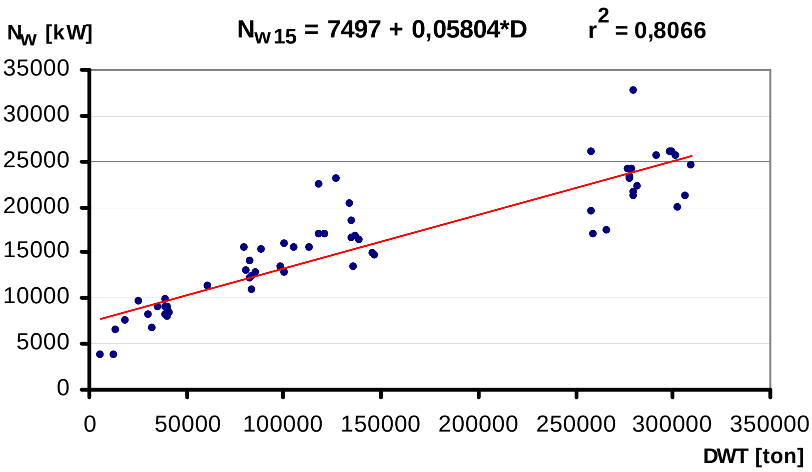

Fig. 1. An example of linear regression describing dependence $N_w=f(D)$ for ship speed $v=15$ knots

As coefficients a_o and a_1 of dependencies (7) are power functions of ship speed type $y=ax^b$ in this case was assumed:

$$a_o = b_o\, v^{do}, \quad a_1 = b_1\, v^{d1}, \tag{9}$$

After regression coefficients b_i and d_i are calculated by means of least square methods formulas (9) are as follows:

$$a_o = f(v) = 2{,}2215 * v^3,$$
$$a_1 = f(v) = 0{,}0000172 * v^3, \qquad (10)$$

Applying (9) to formula (2) the final form of formula for main propulsion power is:

$$\mathbf{N_w = (2{,}2215 + 0{,}0000172 * D) * v^3\ [kW]}\ , \qquad (11)$$

where:

D[tons] - DWT ship deadweight
v[knots] - ship speed.

For formula (11) the coefficient of regression determination is $r^2 = 0{,}8420$ and correlation coefficient is $r = 0{,}9176$. It proves high compatibility of calculation results obtained from formula (11) with real parameters and confirms the correctness of previous assumptions. The correlation between power calculated according to formula (10) and power appointed in reference list is shown on figure 2.

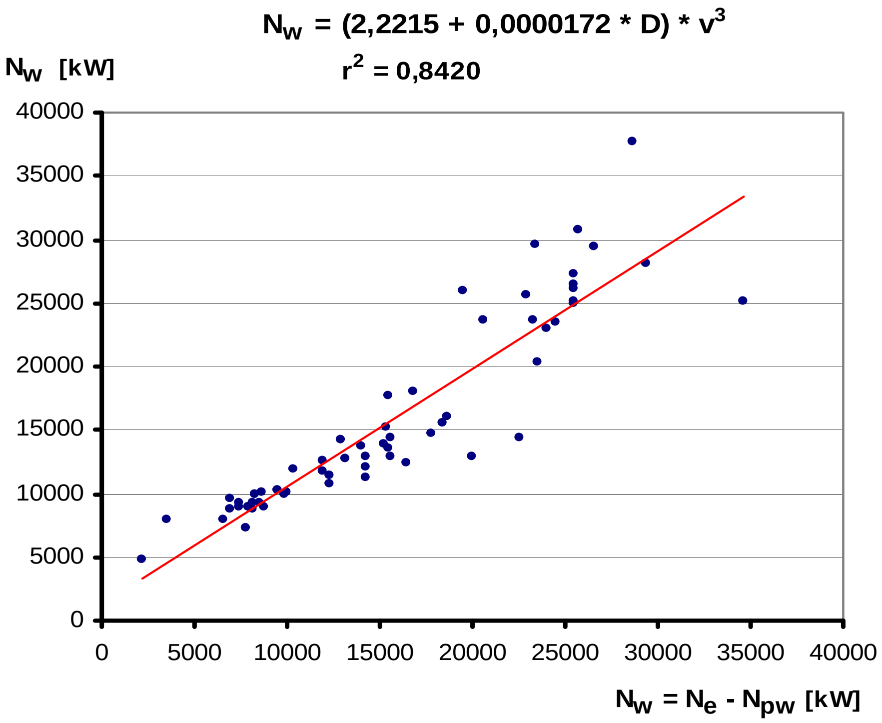

Fig. 2. Correlation between shaft power calculated according to formula (10) and shaft power of ship main propulsion from similar ship list

3. Determination of total electric power

At preliminary estimation of ship engine room working parameters it is not possible to determine exactly total electric power of onboard power station is the electric power balance of ship is not yet elaborated. Thus, to obtain forecast of total electric power it is necessary to use reference list or empirical formulas. However existing formulas concern ships of older construction and do not regard many aspects concerning new ships construction. The necessity to elaborate new formulas is obvious at the moment. A number of ship types was statistically analysed with assumption that the total electric power of onboard power station depends on main propulsion power. The statistic analysis showed that with satisfactory accuracy the linear regression could be used giving the following formula:

$$\Sigma N_{el} = a + b \cdot N_w , \tag{12}$$

where:
ΣN_{el} – total electric power of ship power station,
N_w – main propulsion shaft power.

Example of calculation of tankers total electric power [4]

Thirty three tankers (26 crude oil carriers and 7 product carriers) were taken into statistic analysis. Only tankers with steam turbine driven cargo pumps were taken into consideration because tankers with hydraulically or electrically driven cargo pumps are characterized by higher electric power consumption due to higher energy demand of such driven pumps.

To estimate total electric power of onboard power station the linear regression with least square method was used. Concerning tankers, the formula (12) is as follows:

$$\Sigma N_{el} = 1225 + 0{,}07443 * N_w \ [kW], \tag{13}$$

where:
ΣN_{el} [kW] – total electric power,
N_w [kW] – main propulsion shaft power.
Coefficient of regression determination is $r^2 = 0{,}6311$, correlation coefficient $r = 0{,}7944$.

The dependence between total electric power obtained from formula (12) and main propulsion shaft power from similar ships reference list is shown in figure 3.

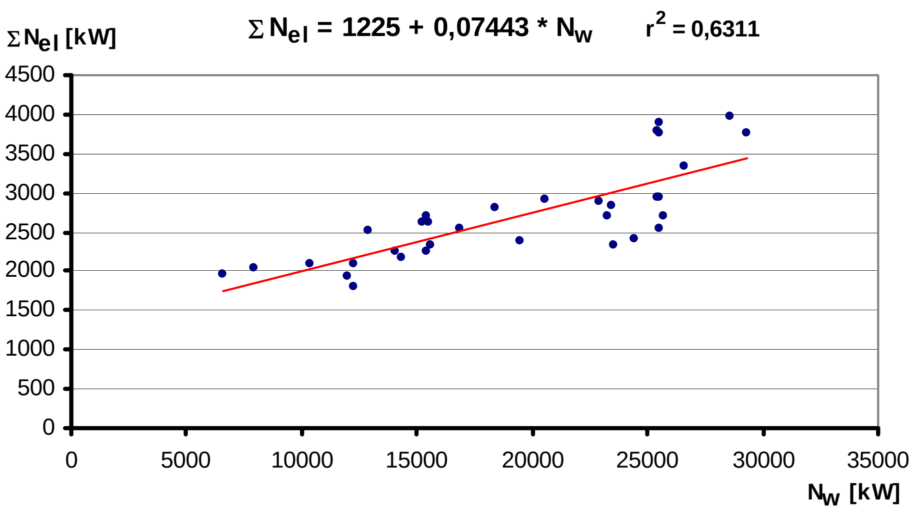

Fig. 3. Dependence between total electric power obtained from formula (12) and shaft power of main ship propulsion from similar ships list

4. Determination of total boilers capacity

To estimate total boilers capacity without exact steam consumption balance the problem is similar to the estimation of total electric power. It is impossible to determine exactly boilers capacity during preliminary estimations.

Similarly to electric power estimation the linear dependency between total boilers capacity and main propulsion shaft power was assumed. To estimate total boilers capacity as a function of main propulsion shaft power the linear regression with least square method was used. As a result of calculations the following formula was obtained:

$$D_{kmax} = c + d \cdot N_W \ [kg/h] , \qquad (14)$$

where:

D_{kmax} [kg/h] – total boilers capacity,

N_w [kW] – main propulsion shaft power.

Example of calculation of tankers total boilers capacity [4]

Comparing other types of ships steam systems and boilers configuration are much developed. Usually there are two main fuel fired boilers of high capacity and one auxiliary boiler heated by main engine exhaust gases. The steam from main boilers is among other proposes used for steam turbine driven cargo pumps. That is why it is necessary to analyze steam production of such ships. The population of 39 tankers was analyzed (32 crude oil carriers and 7 product carriers). Only tankers with steam turbine driven cargo pumps were on the list because tankers equipped with hydraulically driven cargo pumps have much lower steam consumption.

Similarly to electric power case it was assumed that total steam boilers capacity is linear function of main propulsion power. To determine total boilers capacity the linear regression pattern with least square method. As a result of calculations the following formula for total boilers capacity was obtained:

$$D_{kmax} = 24981 + 2{,}4289 \cdot N_W \ [kg/h], \qquad (15)$$

where:

D_{kmax} [kg/h] – total boilers capacity,

N_w [kW] – main propulsion shaft power.

Coefficient of regression determination $r^2=0{,}6819$, correlation coefficient $r = 0{,}8258$.

The dependence between total boilers capacity obtained from formula (14) and main propulsion shaft power from similar ships reference list is shown in figure 4.

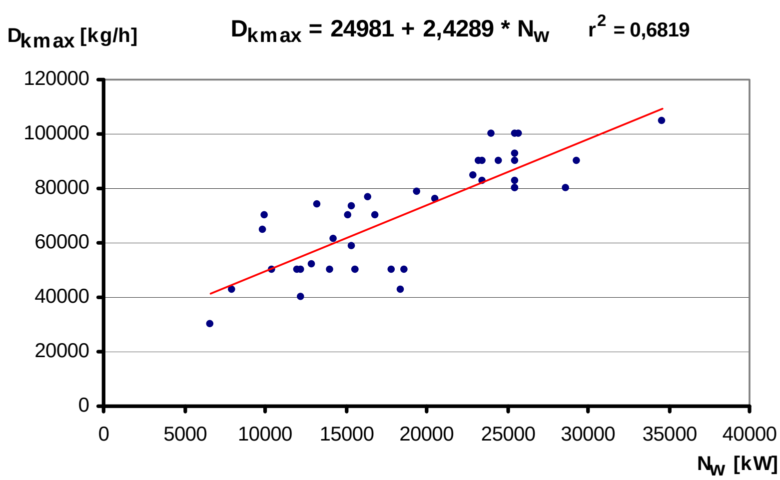

Fig. 4. Dependence between total capacity of boilers obtained from formula (14) and shaft power of main ship propulsion from similar ships list

5. Ready made formulas for calculations of main propulsion shaft power, total electric power and boilers capacity for different types of seagoing ships

5.1. Container ships

$$N_w = (0{,}9179 + 0{,}00003412 \cdot D) \cdot v^3 \; [kW], \tag{16}$$

where:

D[tons] - ship displacement,
v[knots] - ship speed.

$$\Sigma N_{el} = 1077 + 0{,}1580 \cdot N_w \; [kW], \tag{17}$$

where:

N_w [kW] - main propulsion shaft power,

$$D_{kmax} = 2537 + 0{,}0657 \cdot N_w \; [kg/h], \tag{18}$$

where:

N_w [kW] - main propulsion shaft power.

5.2. Ferries and ro-ro ships

$$Nw = (1{,}49042 + 0{,}00003888 \cdot D_n) \cdot v^3 \; [kW], \tag{19}$$

where:

D_n [tons] - DWT ship deadweight,
v[knots] - ship speed,

$$\Sigma N_{el} = 2432 + 0{,}14944 \cdot N_w \; [kW], \tag{20}$$

where:

N_w *[kW]* - main propulsion shaft power,

$$D_{kmax} = 1382 + 0{,}15265 \cdot N_w \; [kg/h], \tag{21}$$

where:

N_w [kW] - main propulsion shaft power,

5.3. Passenger cruisers

$$N_w = (1{,}1896 + 0{,}00002051 \cdot D) \cdot v^3 \; [kW], \tag{22}$$

where:

D[tons] - ship displacement,
v[knots] - ship speed,

$$\Sigma N_{el} = 3044 + 0{,}24048 \cdot D \ [kW], \tag{23}$$

where:

D[tons] - ship displacement,

$$D_{kmax} = -4763 + 1{,}15191 \cdot N_w \ [kg/h], \tag{24}$$

where:

for N_w>5000 [kW] - main propulsion shaft power,

5.4. Tankers

$$N_w = (2{,}2215 + 0{,}0000172 \cdot D_n) \cdot v^3 \ [kW], \tag{25}$$

where:

D_n [tons] - DWT ship deadweight,
v[knots] - ship speed,

$$\Sigma N_{el} = 1225 + 0{,}07443 \cdot N_w \ [kW], \tag{26}$$

where:

N_w [kW] - main propulsion shaft power,

$$D_{kmax} = 24981 + 2{,}4289 \cdot N_w \ [kg/h], \tag{27}$$

where:

N_w [kW] - main propulsion shaft power,

5.5. LNG carriers

$$N_w = (1{,}34571 + 0{,}00003091 \cdot D_n) \cdot v^3 \ [kW], \tag{28}$$

where:

D_n [tons] - DWT ship deadweight,
v[knots] - ship speed,

$$\Sigma N_{el} = -1126 + 0{,}4401 \cdot N_w \ [kW], \tag{29}$$

where:
for N_w>5000 [kW] - main propulsion shaft power,

$$D_{kmax} = -1010 + 0,4761 \cdot N_w \ [kg/h], \tag{30}$$

where:
for N_w>5000 [kW] - main propulsion shaft power,

5.6. Bulk carriers

$$N_w = (1,535 + 0,0000197 \cdot D_n) \cdot v^3 \ [kW], \tag{31}$$

where:
D_n [tons] - DWT ship deadweight,
v[knots] - ship speed,

$$\Sigma N_{el} = 812,7 + 0,08912 \cdot N_w \ [kW],$$
(321)

where:
N_w [kW] - main propulsion shaft power,

$$D_{kmax} = 656,6 + 0,09145 \cdot N_w \ [kg/h], \tag{33}$$

where:
N_w [kW] - main propulsion shaft power.

6. Conclusions

Ready made formulas presented in the paper make possible quick and simple calculations of energy demand for ships being on preliminary state of design [2, 3, 4, 5, 6, 8]. Formulas may be useful for designers or students in project calculations especially in preliminary estimations while modeling simulations of hull resistance, electric energy balance and steam consumption balance are not yet executed.

During statistic analysis high correlation coefficients were obtained in formulas for ship main propulsion power, total electric power and total boilers capacity (in the most cases r>0,9). It shows a strong relation between analyzed parameters. High correlation coefficients make possible to apply the method with high expectation that obtained preliminary results will be in high approximation of precise real results obtained in exact technical project of the ship.

It can be stated that the farther statistic analysis are necessary to improve presented formulas regarding new built ships and trends in ship industry. The paper does not deal with some types of ships for example having dynamic positioning, characterized by high electric energy consumption and usually propelled by diesel-electric systems.

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