MAIN PROPULSION OF MODERN CRUISE LINERS AND MAIN PROPULSION POWER ESTIMATION

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Abstract

This paper describes development trends of modern cruise liners and their main propulsion plants as well. The growing size of such vessels and growing power of propulsion plants is observed in the population. Diesel-electric propulsion plants, combined propulsions plants CODAG type (diesel and gas turbines) and COGES type (gas turbines and steam turbines) are mostly used on this class ships. In this types of propulsion diesel engines, gas turbines and steam turbines drive generators thus creating central electric power station to supply electric power to main propulsion electric motors and to ship electric network as well. Medium speed diesel gear type main propulsions are used on older cruise liners only.

The paper presents the method of preliminary estimation of ship energetic system parameters i.e. main propulsion power, onboard electric power station power and auxiliary boilers capacity. The method is based on statistic analysis of cruise liners being in service and under construction. Statistic methods are elaborated in Department of Marine Propulsion Plants of Gdynia Maritime University. These methods make possible in simple and quick way to estimate parameters of ship energetic system. The estimation is carried out with good correlation coefficient and high coefficient of regression determination. Statistic methods make also possible to forecast energetic systems parameters for ships to be built in the future.

***Keywords**: cruise liner, main propulsion*

1. Introduction

Passenger liners at the turn of the XIX and XX centuries were the basic means for transport of people and goods between continents and islands. Mostly it was regular line trade. Nowadays due to air transport development passenger lines vanished except some lines kept for prestige purposes for example Cunard Line. It executes monthly voyage connecting Southampton (Great Britain) and New York (USA) executed by Queen Mary 2 one of the biggest passenger cruisers in the world. The voyage lasts in 6 days. Today the basic task of passenger ships is to operate as holiday cruise liners. During the year millions of passengers are transported on big cruise liners having gross register tonnage above 100000 BRT and length above 350 m. A new philosophy of such a sea trading is to give a pleasure of sea voyage, opportunity to spend holidays at sea and a good time. The destination port is not important. An airport in vicinity of anchorage place is very convenient to exchange passengers. The construction of modern passenger cruisers depends on kind of sea trade, which can be:

- regular passenger liner trading,
- holiday cruise trading,
- ferry service.

In case of two first kinds of sea trading ships are not different and frequently execute both liner and cruise trading. They are named cruise liners.

The biggest cruise liner is now Oasis of the Seas (Fig. 1), built in 2009 in Turku (Finland) for the owner Royal Caribbean International operating the biggest cruise liners in the world. Oasis of

Fig. 1. Cruise liner Oasis of the Seas

the Seas has above 360 m in length, 47 m breadth and 71 m of height above sea level. The ship is carrying 6296 passengers and 2165 crewmembers. The main propulsion is diesel-electric type consisting 3 diesel engines Wartsila16V46D 18480 kW power each and 3 diesel engines Wartsila12V46D 13860 kW each driving main alternators. The ship is equipped with 3 azipod thrusters ABB Azipod 20 MW power each. The speed of ship is 22.6 knots.

Statistic analysis were carried out on representative population above 30 cruise liners. The results of preliminary analysis are:

- the main propulsion of ships is mostly diesel-electric type (24 cruise liners including Oasis of the Seas), two ships have COGES type main propulsion (Radiance of the Seas and Millennium) and one CODAG type main propulsion (Queen Mary2). Some older ships are equipped with medium speed diesel engines driving propellers via reduction gears. The steaming speed of cruise liners is about 20-27 knots. Configuration of cruse liners main propulsion plants is shown in Fig. 2.
- onboard electric power plant of cruise liners mostly consists of high power diesel-alternators sets as these ships are equipped with many energy-consuming machines for example bow and stern thrusters (2-4 sets); in case of azipod thrusters two tasks are simultaneously executed i.e. main propulsion and steering,
- other characteristic feature of passenger cruise liners are developed steam systems; they consist of high capacity boilers and usually consist of two fuel fired boilers and heat recovery boilers the same in number same as diesel engines.

2. Determination of ship main propulsion power

To determine ship main propulsion power N_w the Admiralty Formula was used where the main propulsion power depends on ship displacement D, ship speed v and Admiralty Coefficient c_x which takes into consideration geometric similarities of ship hull:

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

Reference list of 31 ships were taken into consideration during statistic analysis. Using formula (1) for each ship from reference list the Admiralty Coefficient c_x was calculated. Next c_x coefficient was used for calculation of each ship main propulsion power N_{wi} in nine chosen ship speeds 19, 20, 21, 22, 23, 24, 25, 26 and 27 knots. For each one of nine speed the diagram of dependency N_w=f(D) was established. Calculated main propulsion power N_{wi} is described by linear formula:

$$Nw = ao + a1 * D. \tag{2}$$

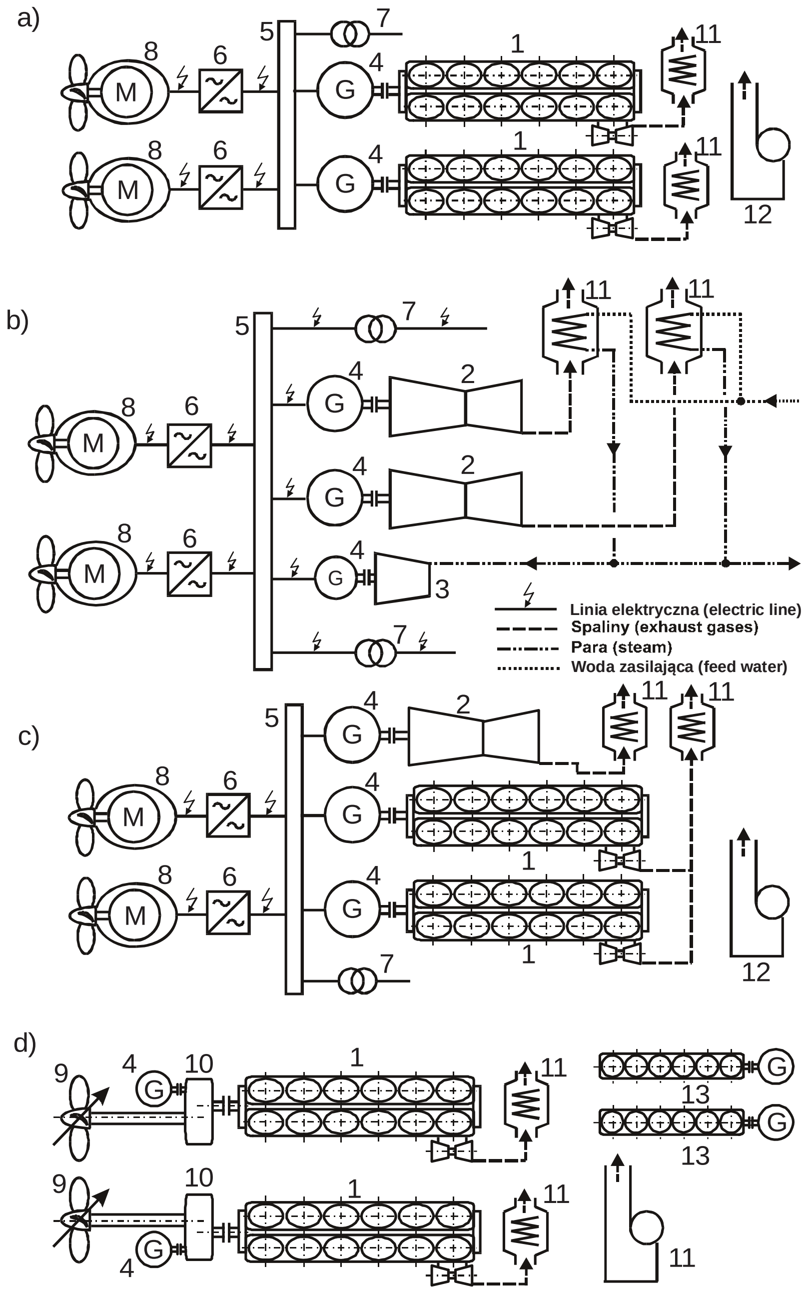
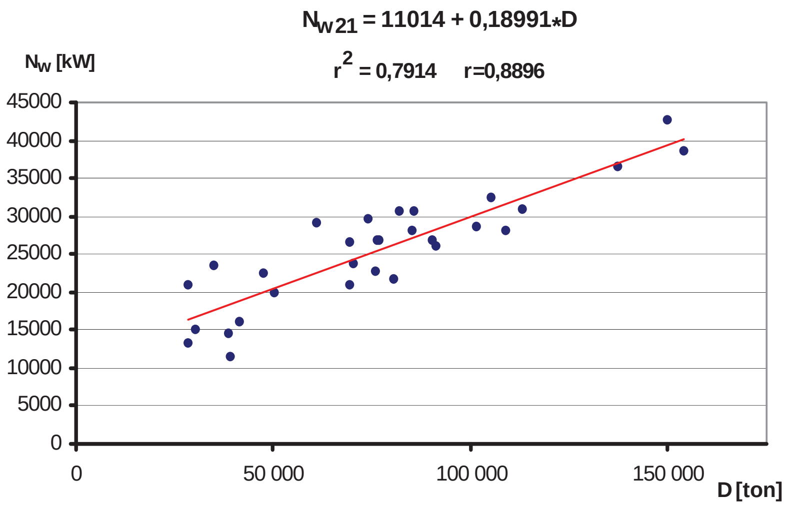


Fig. 2. Cruise liners Propulsion plants a) diesel-electric type, b) COGES type, c) CODAG type, d) gear type; 1 - medium speed diesel engine, 2 - gas turbine, 3 - steam turbine, 4 - generator, 5 - main switchboard, 6 - frequency converter, 7 - transformer, 8 - azipod thruster, 9 - controllable pitch propeller, 10 - reduction gear, 11 - exhaust gas heat recovery boiler, 12 - oil fired boiler, 13 - diesel-generator

Calculations of a_{oi} and a_{1i} coefficients values were executed for each chosen ship speed by means of linear regression based on the least square root method. [1,7]. The following was obtained:

$$\left.\begin{array}{ll} \text{for:}\quad v = 27w & Nw_{27} = 23410 + 0.40362\,D \\ v = 26\,w & Nw_{26} = 20904 + 0.36041\,D \\ v = 25\,w & Nw_{25} = 18583 + 0.32041\,D \\ v = 24\,w & Nw_{24} = 16441 + 0.28348\,D \quad r^2 = 0.7914 \\ v = 23\,w & Nw_{23} = 14471 + 0.24950\,D \quad r = 0.8896 \\ v = 22\,w & Nw_{22} = 12664 + 0.21835\,D \\ v = 21\,w & Nw_{21} = 11014 + 0.18991\,D \\ v = 20\,w & Nw_{20} = 9515 + 0.16405\,D \\ v = 19\,w & Nw_{19} = 8158 + 0.14065\,D \end{array}\right\} \qquad (3)$$

An example of linear regression for v = 21 knots is shown in Fig. 3.



[tons]

Fig. 3. An example of linear regression determining dependence $N_w=f(D)$ for ship speed v=21 knots

Coefficients a_{oi} and a_{1i} of dependency (3), are functions of ship speed:

$$a_o = f(v)$$

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

The determination of coefficients ao and a1 depending on ship speed was executed by means of power curve regression of the function described as:

$$y = a * x\ b. \tag{5}$$

In this case the functions (4) are described as:

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

$$_1 = b_1{}^* v^{d1}.$$

After the coefficients of regression b_i and d_i were calculated the functions (4) are:

$$a_o = f(v) = 1.1896\ ^* v^3,$$

$$a_1 = f(v) = 0.00002051\ ^* v^3.$$

After the substitution of the above formulas into formula (2) the final form of main propulsion power equation was obtained. It is as follows:

$$Nw = (1.1896 + 0.00002051 * D) * v3\ [kW], \tag{6}$$

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

Correlation coefficient of such determined formula in comparison to data from ships reference list is r = 0.9664. It proves high compatibility of results obtained from formula (6) to real data and proves correctness of analysis assumptions. Correlation between propulsion power obtained from formula (6) and propulsion power from ship reference list is shown in Fig. 4.

3. Determination of onboard electric power station

During preliminary project of ship the exactly determination of onboard electric power station is not possible because electric balance of ship is not yet carried out. It creates necessity to use ship reference list or to apply empiric formulas.

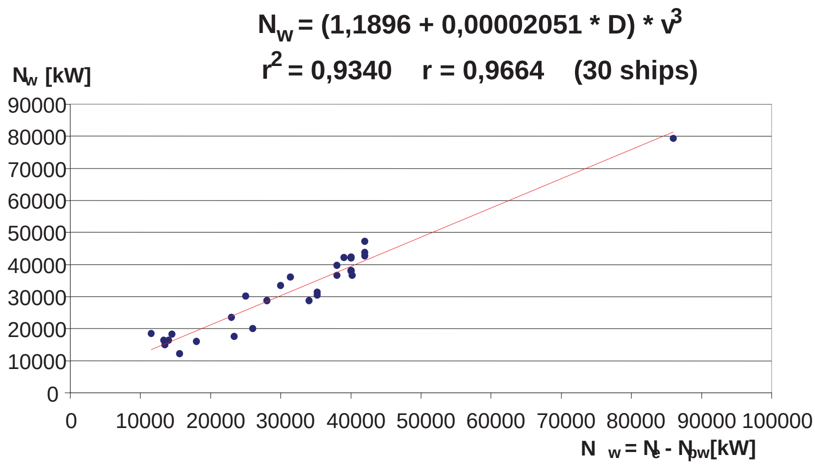


Fig. 4. Correlation between shaft power obtained from formula (6) and shaft power from ships reference list

Passenger cruise liners due to high and diversified electric energy demand in different sailing conditions mainly are equipped with diesel-electric propulsion (e.g. Oasis of the Seas), COGES propulsion (Radiance of the Seas, Millennium) or CODAG propulsion system (Queen Mary2).

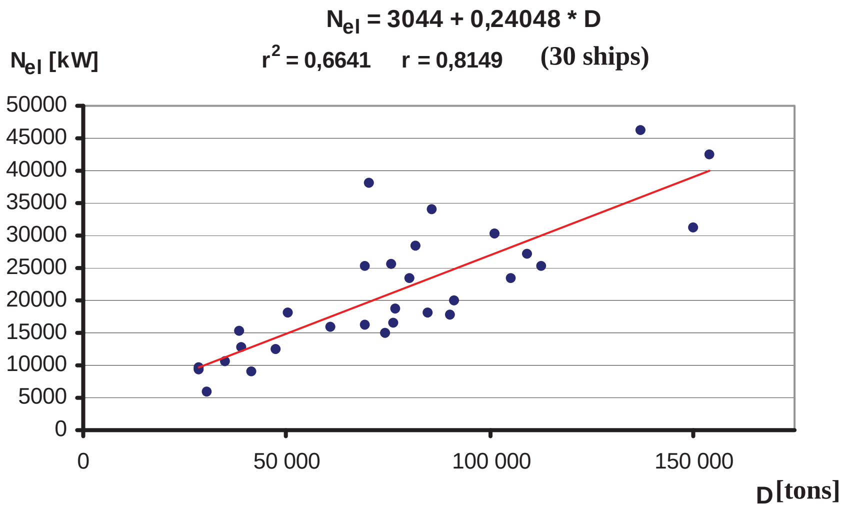


Fig. 5. Dependence between total electric power obtained from formula (7) and gross tonnage of the ship given in reference list

Ones of the biggest receivers of electric energy are bow thrusters, which power depends on ship size. Determining ship electric power demand it was accepted that the total power of onboard power station strongly depends on ship displacement and has linear character. Linear regression based on the least square root method was applied. As a result the following formula was obtained:

$$\Sigma N_{el} = 3044 + 0,24048 * D \ [kW], \tag{7}$$

where *D[tons]* - ship displacement.

Dependency between total power of onboard power station according to formula (7) and ship displacement from reference list is shown in Fig. 5. Correlation coefficient of this dependency is r=0.8149.

4. Determination of steam boilers capacity

During calculations of heating steam demand the same problems took place as during calculations of electric energy demand. At preliminary project of ship exactly determination of boilers capacity is not possible because heating steam balance is not accessible.

Passenger cruise liners have developed systems of high capacity steam boilers in comparison to other types of ships. Usually there are two high capacity main boilers and auxiliary boilers heated by diesel engines exhaust gases. High capacity of boilers is a result of ship service to large number of passengers and crew (accommodation, sanitary services, laundries etc.). The number of people on board achieves 6000 passengers and 2000 crewmembers.

Because a big number of boilers are heat recovery boilers heated by diesel engine exhaust gases it was assumed that total capacity of boilers depends on total power of ship main propulsion and has linear character. By means of linear egression based on the least square root method the following formula was obtained:

$$Dkmax = - 4763 + 1.15191 * NW\ [kg/h], \tag{8}$$

where N_w *[kW]* - main propulsion power.

The negative value of free term in the formula (8) is a result of minimal main propulsion power assumed as 10 000 kW. The dependency between total boilers capacity and main propulsion power described by formula (8) is shown in Fig. 6. Correlation coefficient of this formula r = 0.8672.

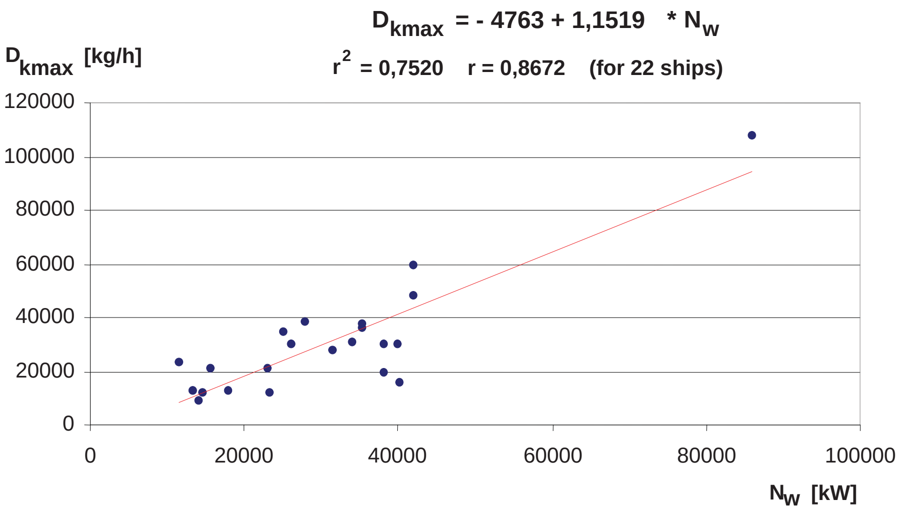


Fig. 6. Dependence between total boilers capacity obtained from formula (8) and main propulsion shaft power given in reference list

5. Conclusion

The review of modern cruise liners and analysis of their propulsion plants executed in the paper makes possible to notice development trends in construction. Passenger cruise liners still are getting larger and the same concerns their propulsion plants power.

Presented in the paper analysis methods make possible quickly determination, with acceptable accuracy energy demand during ship preliminary projects. It can be useful for design offices and students during preliminary calculations when the results of hull model testing as well as electric power balance and heating steam balance are not available.

Attention to be paid to high correlation coefficient in formula for main propulsion power determination ($r > 0,9$) and not much less values of correlation coefficients for determination of total power of onboard power station and total boilers capacity on cruise liners. It expresses strong relations between analysed values. High correlation coefficients allow applying described methods with high probability that the results will be very close to exact results being obtained in technical project.

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