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ENERGETIC PLANTS OF CONTAINER SHIPS AND THEIR DEVELOPMENT TRENDS

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Abstract

The paper deals with problem of energy demand for main propulsion as a function of deadweight and speed for container vessels. Changes in power of main propulsion and trends observed in the matter are appointed. In the same way analysis of electric power and boilers capacity are carried out. Summary conclusions and prognosis concern energetic plants of container vessels are expressed.

Keywords: *cargo ship, container ship, main propulsion power, electrical power, auxiliary steam delivery, statistics*

1. Introduction

Container ships are ships especially equipped with cell guides assigned for container transport with vertical load on and load off. The first ship assigned for container transport was *Ideal-X*, reconstructed tanker in 1956. Today the biggest container ships carry above 10000 TEU witch hardly can pass Panama Channel. They are named Panamax Class. Number of container ships are bigger than Panamax and are operated on routes by-passing Panama Channel for example China-USA West Coasts. Now the biggest container ship is m/s EMMA MAERSK with cargo capacity 14500 TEU (fig.1).

Rys.1.

m/s EMMA MAERSK sailing at sea

To assure world wide and fast transport of containers as well to reduce the cost of trade large container vessels are operated. They call a several large ports between continents named *hubs*. Containers from smaller ports are delivered to hubs by small container vessels named *feeders* (capacity 500-2000 TEU). Some container vessels (below 3000 TEU) are equipped with cargo cranes thus can call ports not equipped with container handling facilities. Larger container vessels are not equipped with cargo cranes and become entirely dependent on port facilities. Due to dimensions of this ships and weight of containers special container gantry cranes are used. Classification of container vessels according to the size and cargo capacity is shown in table 1.

Table 1. Container Ships Size Categories

Category name	*Container capacity (TEU)*	*Example*
Post-Suezmax ULCV (Ultra Large Container Vessel)	14501 and higher	*m/v Emma Maersk* capacity 14500 TEU, L=397m, B=56m, T=15,5m,
Suezmax (New Panamax)	10001÷14500	*m/v COSCO Guangzhou* capacity 9500 TEU, beam 43 m to big to fit through Panama Canal's old locks, but could fit through the new built expansion
Post-Panamax	5101÷10000	
Panamax	3001÷5000	*m/v Providence Bay* capacity 4224 TEU L=292,15m, B=32,2m, upper dimension limit of the Panamax class, can pass through the Panama Canal
Feedermax	2001 – 3000	*m/v TransAtlantic* capacity 384 TEU Container ships under 3000 TEU are called feeders, many of them are equipped with cargo cranes
Feeder	1001 – 2000	
Small feeder	up to 1000	

Large container vessels are the fastest merchant ships achieving speed 24÷26 knots. Only small feeder class container vessels with the capacity below 1000 TEU sail with speed 14÷18 knots. The preliminary analysis shows trends in construction of container vessels energetic plants as follows:

- **small feeders with capacity up to 2000 TEU:**
  - main propulsion is executed by medium speed diesel engines (sometimes two engines) and controllable pitch propellers driven via reduction gear; slow speed diesel engines are rarely used,
  - during sea passage electric power is mainly produced by shaft generators; shaft generators rated power is 500÷2000 kW; in addition there are installed two or three diesel generators with rated power 200÷700 kW each,
  - usually feeders are equipped with two steam boilers, one fuel oil fired and one heated by main engine exhaust gases (waste heat recovery boiler), rated capacity 1000÷2000

kg/h each; a number of feeders are equipped with thermooil heaters fuel oil fired and waste heat heated with heat capacity 600÷1500 kW each,

- **large container vessels with capacity 3000÷15000 TEU:**
  - main propulsion is executed by slow speed diesel engines of high rated power due to high sea passage speed; these are the biggest diesel engines achieving rated power 80000 kW, and even bigger for example 14 RT-flex 96C 80080 kW,
  - onboard electric power stations of big container vessels are very big achieving total power 3000÷20000 kW due to delivering electricity to bow thrusters (1000÷3000 kW) and to 300÷1000 refrigerated containers (up to 8000 kW); usually there are 4÷5 diesel generators 1000÷4000 kW each; sometimes shaft generators and rarely steam turbo generators are used,
  - steam generating stations consist of two boilers one fuel oil fired and one waste heat boiler with average capacity 2000÷3000 kg/h each, boiler capacity on bigger container vessels (6000 TEU and higher) are much higher (5000÷6000 kg/h); sometimes also thermooil instead steam is used.

The aim of this paper is the analysis of development trends and elaboration of formulas describing main propulsion power, electric power and boilers capacity of modern container vessels by means of statistics. To apply statistic methods a “reference list of similar ships” was elaborated. The reference list includes basic technical particulars of container vessels built in 1993÷2010. Technical particulars logically and functionally connected with main propulsion energy, electric power and boilers capacity were analysed.

2. Determination of ship main propulsion power

These days container fleet is characterised by operation of growing number of large ships Post-Suezmax ULCV, Suezmax and Post Panamax class. Analysis of these ships main propulsion brought the necessity to change the range of analysis. Types and rated performance of propulsion plants on small and large container vessels are different. It was decided to split analysed population into two groups above and below 15000 DWT.

Propulsion plants of 92 container ships were analysed in the first group. It was considered that similarly to many previous analysis e.g. [1] the propulsion power N_w depends on ship deadweight D and ship speed v according to The Admiralty Formula:

$$N_w = \frac{D^{\frac{2}{3}} \cdot v^3}{c_x} \quad (1)$$

where:

$N_w = N_e - N_{pw}$ $[kW]$ – ship propulsion power,
N_e $[kW]$ – main engine shaft power,
N_{pw} $[kW]$ – shaft generator power,
D $[tons]$ – ship deadweight,
v $[knots]$ – ship speed,
c_x $[-]$ – Admiralty Coefficient regarding hull geometric similarity.

Using formula (1) the coefficient c_x was calculated for each 92 in number ships from reference list. Next it was used for calculation of main propulsion power N_{wi} for a number of ship speed $v = 14, 16, 18, 20, 22, 24$ and 26 *knots*. 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 was affirmed as:

$$N_{wv} = a_o + a_1 D \,. \tag{2}$$

Calculations of a_{oi} and a_{1i} coefficients for each chosen ship speed were based on linear regression by means of least squares method. The following dependencies were obtained:

$$\begin{array}{lll} \text{for:} & v=26\ w & N_{w26} = 20068 + 0{,}5200\, D \\ & v=24\ w & N_{w24} = 15784 + 0{,}4090\, D \\ & v=22\ w & N_{w22} = 12158 + 0{,}3150\, D \\ & v=20\ w & N_{w20} = 9134 + 0{,}2367\, D \\ & v=18\ w & N_{w18} = 6659 + 0{,}1725\, D \\ & v=16\ w & N_{w16} = 4677 + 0{,}1212\, D \\ & v=14\ w & N_{w14} = 3133 + 0{,}0812\, D \end{array} \tag{3}$$

Obtained regression determination coefficient was $r^2 = 0{,}9194$, and correlation coefficient was $r = 0{,}9588$, which confirms linear dependency between main propulsion power in given ship speed and ship deadweight. An example of linear regression for *v=20 knots* is shown on figure 2.

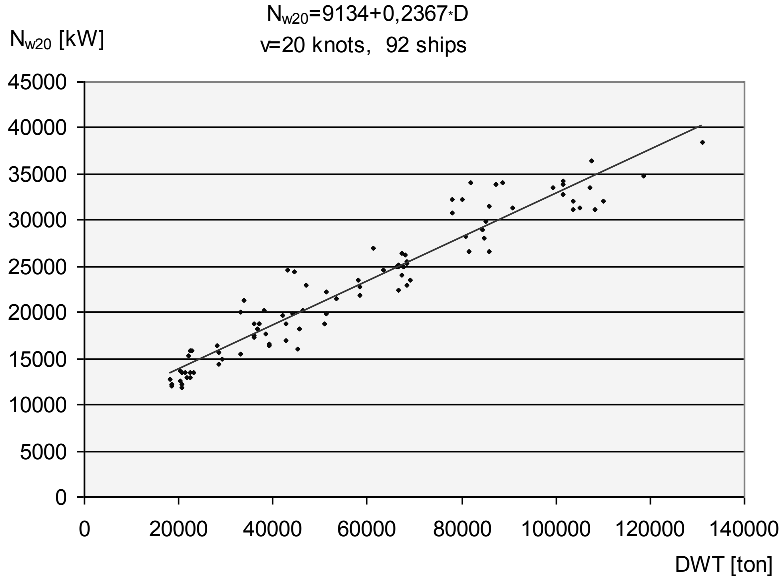

Fig. 2.
Linear regression of dependence $N_w = f(D)$ for ship speed 20 knots

Coefficients a_{oi} and a_{1i} in formula (2) depend on ship speed:

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

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 described case it was assumed as; $a_o = b_o\, v^{do}$ and $a_1 = b_1\, v^{d1}$. Regression coefficients b_i and d_i calculated by means of least square methods are as follows:

$$a_o = f(v) = 1{,}14184\, v^3; \quad a_1 = f(v) = 0{,}00002961\, v^3 \tag{6}$$

Applying (6) to formula (2) the final form of formula for main propulsion power is:

$$\mathbf{N_w = (1{,}1418 + 0{,}00002961 * D) * v^{3}} \tag{7}$$

where:

- D *[tons]* – ship deadweight above 15000 DWT,
- v *[knots]* – ship speed.

For formula (7) the coefficient of regression determination is $r^2 = 0{,}9729$ and correlation coefficient is $r = 0{,}9864$. It proves high compatibility of calculation results obtained from formula (7) with real parameters and confirms the correctness of previous assumptions. The correlation between power calculated according to formula (7) and power appointed in reference list is shown on figure 3.

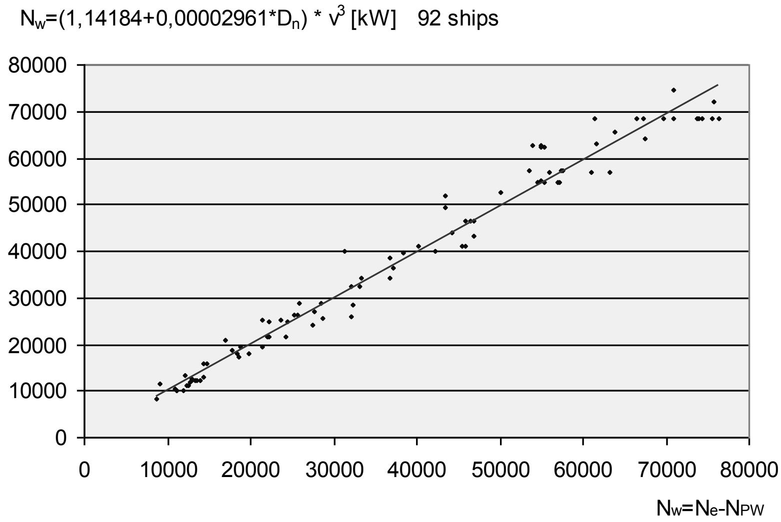

Fig. 3.
Correlation between shaft power calculated according to formula (7) and shaft power of ship main propulsion from similar ship list

Similarly elaborated formula for main propulsion power of container vessels below 15000 DWT is as follows:

$$N_w = (0{,}2631 + 0{,}00007581 * D) * v^3 \qquad (8)$$

where:

D [tons] – ship deadweight below 15000 DWT,
v [knots] – ship speed.

Correctness of this formula can be undermined by small population of investigated ships (7 vessels only). However only such number of reliable data were obtained from reference list. Even so, coefficients of regression determination ($r^2 = 0{,}9919$) and Pearson linear correlation ($r = 0{,}9959$) of formula (8) linked to the data from reference list lean towards acceptation of this formula.

3. Determination of total electric power

To determine total electric power of modern container vessels onboard power station the principle of linear dependency of electric power on main propulsion power was used [2, 4].

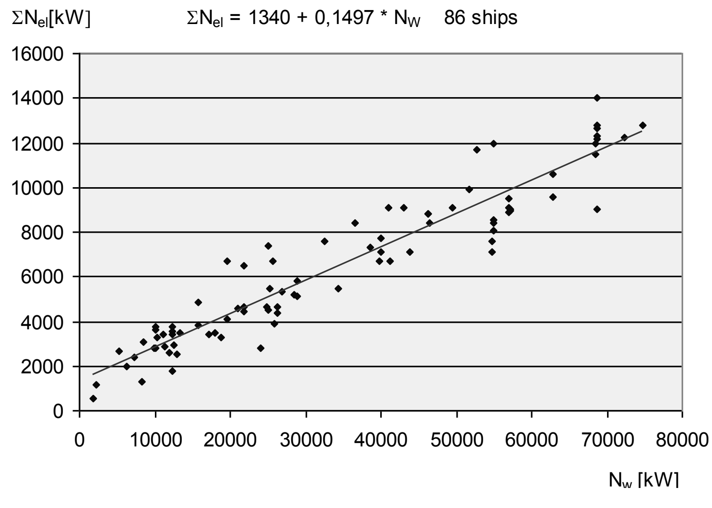

Fig. 4.
Linear regression of total electric power as a function of main propulsion power for container vessels

To estimate total electric power of onboard power station the linear regression with least square method was used. During analysis onboard power stations 86 ships from reference list were taken into consideration. As a result the following formula for total electric power ΣN_{el} was obtained:

$$\Sigma N_{el} = 1340 + 0{,}1497\ N_w \quad [kW] \tag{9}$$

where:

N_w *[kW]* – ship main propulsion power.

Graphical estimation of formula (9) is shown in figure 4. Coefficient of regression determination $r^2 = 0{,}8973$. Coefficient of linear correlation of values taken from formula (9) and data from reference list $r = 0{,}9473$. It confirms the correctness of analysis.

4. Determination of total boilers capacity

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. 46 ships from reference list were taken into consideration. As a result of calculations the following formula for total boiler capacity D_k was obtained:

$$D_k = 2238 + 0{,}1192 * N_w \quad [kg/h] \tag{10}$$

where:

N_w *[kW]* – ship main propulsion power.

Graphical estimation of formula (10) is shown in figure 5. Coefficient of regression determination $r^2=0{,}7903$ and correlation coefficient $r=0{,}8890$ confirm good accuracy of presented method.

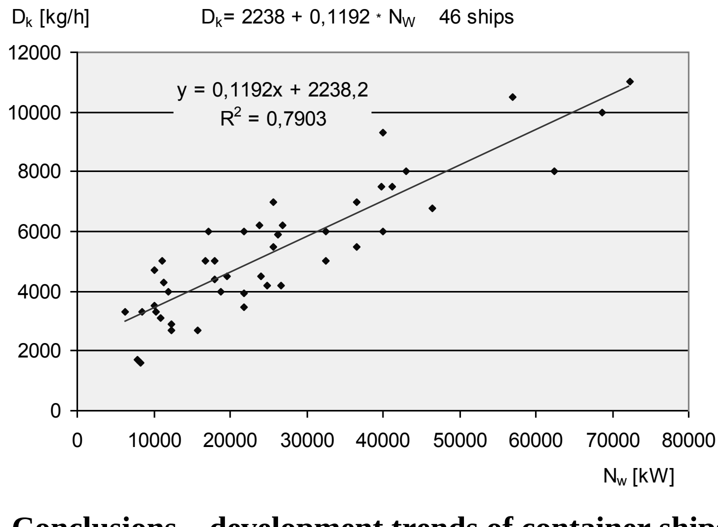

Fig. 5.
Total boilers capacity on container ships as a function of main propulsion power

5. Conclusions – development trends of container ships

Modern large container vessels belong to population of ships with the biggest energetic systems i.e. main propulsion, onboard electric power station and boilers capacity. As an example of such a ship can be recognized m/s EMMA MAERSK (fig. 1), capacity 14500 TEU, service speed 25 knots, built in 2006. The main propulsion engine of this ship is huge slow speed diesel engine Wartsila Sulzer 14RT-flex 96C performing rated shaft power *80080* *kW*. Onboard electric power station consists of five diesel generators total power 20700 kW and one steam turbo generator *8500 kW* driven by steam from waste heat boiler. Due to high waste heat utilization the ship achieves high efficiency of engine room during sea passage above 70%. Economic analysis show that there is requirement for even larger such type container ships. However there are limits in rated power of these ships propulsion engines. The main engine of m/s EMMA MAERSK is the biggest diesel engine offered today on the market. The only alternative is propulsion with two engines similarly to propulsion of modern largest LNG carriers. Construction of container vessels with capacity 18000 TEU and two main MAN engines rated shaft power *43000 HP* each and specific fuel consumption 168 g/kWh is planned by MAERSK LINES one of the biggest container ships operators in the world. The list of new ordered series of container ships was announced by MAERSK in February 2011. First ship is to be put into service in 2014. Series is named „Triple E” ("*Economy of scale, Energy efficient and Environmentally improved*"). It means economical low resistance optimal hull shape, high energetic efficiency due to waste heat utilization and environment protection. In addition minimizing of fuel consumption is to be achieved by reducing of ship speed to 19 knots.

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