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ANALIYSIS OF PROPULSION FOR VARIOUS TYPES OF SHIPS IN ASPECTS OF POWER REQUIRED AND FUEL CONSUMPTION DURING EXPLOITATION

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Abstract

The paper presents comparative analysis of energetic possibilities of different ships with close parameters of displacement and operational ailing range, for selected type of main engine. Analysis is related to three types of ships, i.e. bulk carrier, tanker and container ship, with assumed displacement at level of 120 000DWT and typical for that ships sailing speed. The analysis concerns shipping route from Gdynia to Shanghai.

First step of conducted analysis was based on elaboration of the list of contemporary similar ships for every class, their general dimensions, dimensional coefficients, and subsequently evaluation of hulls resistances using Holtrop – Mennen Method necessary for calculation of propulsive power, main engines' selection, most convenient for every type of ship and calculation of trips durations and fuel consumptions.

All calculations were done assuming typical cruising speed for considered types of ships, it means 25 knots for container ships and 15 knots for tankers and bulkers. Results of carried out calculations lets come to the conclusion that total time of trip duration of container ship is 1.5 times shorter and fuel consumption is 2.5 times higher comparing with tankers and bulk carriers going on the same trip. Taking under consideration constantly growing prices of heavy oil, that situation is inconvenient from economical point of view. Above facts explains general trend to reduce speed of container ships presented by almost all shipping companies. The way of speed's reduction is decreasing of continuous power rate of main engine, what is related to necessity of blinding or dismounting some numbers of turbochargers. Hypothetic example of such operation and its impact at operational properties were analysed, and results showed, that exploitation parameters of the container ship begun closer to bulk carriers and tankers but could not achieve proper level of efficacy due to not optimal hull shape and engine characteristic.

Keywords: *shipbuilding, calculation of propulsive marine power, hulls resistances of ship, diesel engines*

Introduction

Design assumptions of ship's propulsion includes cargo load capacity in TEU (twenty feet equivalent unit) for container ships or DWT (load weight in tons) for other classes of cargo ships, and sailing speed. That values have crucial impact at necessary propulsion power. In order to conduct comparable analysis of different class ships, unified volumetric capacity was taken, and the value was 120000 m^3. It corresponds to 8500 TEU container ship and 100000 DWT bulk carrier and tanker. Container ship speed was taken at level of 25 knots and for bulk carrier and tanker15 knots was assumed [8]. Above values were taken in accordance with statistical analysis of contemporary ships presenting similar constructions. Design assumptions were the basis for creating of knowledge data base about considered classes of ships being in exploitation.

Taking under consideration that general dimensions of ship's hull are in mutual correlation, seems to be important to undertake proper selection of their proportions. It is very important because of necessity of ensuring safety properties of a ship, like stability, hull's strength, free board height, and simultaneously to cope with condition of ship drag minimizing. Below, most important dimensional relations were presented.

- Lpp\B – length between perpendiculars to moulded beam,
- Loa\H – length over all to hull's height,
- B\T – moulded beam to draft,

- B\H – moulded beam to hull's height,
- $\frac{L_{pp}}{\sqrt[3]{D}}$ – shape coefficient,
- $C_B = \frac{D}{L_{PP} \cdot B \cdot T}$- block coefficient,
- C_m – midship section coefficient,

where:
D – displacement [m³],
ρ – sea water density (1025 kg/m³),
L_{pp} – length between perpendiculars [m],
$Fn = \frac{v}{\sqrt{g \cdot L_{pp}}}$ – Froude number.

1. Determination of ship's main dimensions

The very first step' before beginning of main engine's selection is determination of general dimensions of the ship. The procedure is based on the list of significant ships, similar to our object.

Amongst data included in the similar ships list, for initial calculation are taken two basic ones i.e.: Froude number F_n and block coefficient C_B.

When main dimensions are calculated, especially the length, values of Froude numbers from the range which gives local maxima of wave friction mast be avoided. Mentioned maxima occurs in the range of Froude number 0.22-0.23; 0.32; and global maximum of that coefficient ours always when Froude number is F_n=0.5 [2].

It is particularly important for fast ships like container ships, for which typical Froude number is close to first local maximum of wave resistance coefficient. For typical transportation vessels like bulk carriers or tankers, Froude number takes values below 0.2, thus problem of wave resistance minimisation does not occur.

Basing on the list of around 50 similar ships of considered classes[8], ranges of implementation of main dimensional relations were determined, and subsequently, for hypothetic ships some coefficients and relations of dimensions necessary for resistance's calculations were determined.

Table 1 contains presentation of calculated dimensional proportions ant Tab. 2. presents characteristic coefficients for hypothetic ship with assumed displacement.

Tab. 1. Range of implementation of characteristic coefficients of similar ships

	Lpp\B	Loa\H	B\T	B\H	$\frac{L_{pp}}{\sqrt[3]{D}}$	C_B	Fn
Container ship	6.6-7.8	12-13	2.3-3.6	1.7-1.9	5.5-6.5	0.6-0.69	0.23-0.24
Bulk carrier	5.5 - 7	11-12	2.3-3.6	1.7-1.9	4.5-5.5	0.7-0.86	0.16
Tanker	5.5-6.5	11-12	2.3-3.6	1.7-1.9	4.5-5.5	0.8-0.90	0.16

Tab. 2.Characteristic coefficients for hypothetic ship with displacement of 120000 m³

	Lpp\B	Loa\H	B\T	B\H	$\frac{L_{pp}}{\sqrt[3]{D}}$	C_B	Fn
Container ship	7.3	13.16	3.28	1.72	6.38	0.63	0.24
Bulk carrier	5.94	11.64	2.78	1.90	4.73	0.86	0.16
Tanker	5.84	11.53	3.03	1.91	4.73	0.88	0.16

Analysis of values of presented coefficients let ones come to the conclusions that they are similar for tankers and bulk carriers but differ significantly from those typical for container ships. It is generally about Froude number, shape coefficient, block coefficient and relation Lpp\B. It is because of higher speed of sailing of container ships, and hulls' shapes fulfilling necessity of drag diminishing.

In Tab. 3 are presented data characterising hulls of selected ships. Calculations of block coefficient and shape coefficient were carried out according to [3-5].

Tab. 3 List of main parameters of ships with volumetric displacement 120000 m^3

	parameter	container ship	bulk carrier	tanker
Length bp	L_{pp}[m]	316.68	237.16	237.16
beam	B [m]	43.38	39.93	40.61
height	H [m]	25.22	21	21.26
draught	T [m]	13.23	14.36	1.4
speed	V [kn]	25	15	15
Froude number	Fn	0.24	0.16	0.16
Reynolds number	R_n	$3.65 \cdot 10^9$	$1.58 \cdot 10^9$	$1.58 \cdot 10^9$
Wetted area	S $[m^2]$	16060	14452	14384
Shape coefficient	k_1	0.327	0.657	0.751
Block coefficient	C_B	0.63	0.86	0.88
Midship section coefficient	C_M	0.979	0.999	0.997
Longitudinal prismatic coefficient	C_p	0.628	0.840	0.861

Presented values of parameters describing hull's shape are necessary for determination of movement resistance using contemporary approximate calculation method basing at results of systematic model research. Holtrop –Mennen method represents such kind of calculation [1,8].

2. Characteristic of elements of ship movement resistance

Total resistance of a ship can be presented by formula [2,6,8]:

$$R_T = R_F \cdot (1 + k_1) + R_{APP} + R_W + + R_A, \qquad (1)$$

where:

R_F – frictional resistance,
k_1 – shape coefficient,
R_{APP} – resistance of protruding elements,
R_W – wave resistance,
R_A – air resistance.

Components of resistance for considered ships were calculated according to Holtrop – Mennen method [8].

After analysis of obtained results one can observe that dominant factor of total resistance is frictional resistance. Frictional resistance contribution is 70 to 80% of total resistance, and others components does not oversteps 30%. The table does not consist values of protruding elements and bow bulb resistance because of its low value in comparison with others and can be omitted.

Tab. 4. Juxtaposition of obtained parameters of ships

		Container ship		*Bulk carrier*		*tanker*	
		value	R_T%	value	R_T%	value	R_T%
speed	V	25kn	-	15kn	-	15kn	-
Frictional resistance	R_F	1932.32kN	53.52	639.10kN	4.91	636.7 kN	42.65
Shape resistance	$k_1 \cdot R_F$	631.51 kN	17.49	419.92kN	30.82	483.32 kN	32.37
Wave resistance	R_W	696.84 kN	19.30	162.80 kN	11.95	233.57 kN	1. 5
Air resistance	R_A	336.84 kN	9.32	135.82 kN	9.97	137.37 kN	9.20
Total resistance	R_T	3610.2 kN	100	1362.3kN	100	1489.96kN	100

3. Power of main engines

Basing on calculated resistance of ships, and taking under consideration configuration of propulsion system, main power of propulsion can be determined. For further analysis, simple straight propulsion system was taken.

In Tab. 5 are presented selected engines for hypothetic ships.

Tab. 5. Main engines selected for hypothetic ships

parameter	Container ship	Bulk carrier	tanker
	14RT-flex96C	6L70ME-C8	7L70ME-C8
Number of cylinders	14	6	7
Cylinder bore [mm]	960	700	700
Stroke [mm]	2500	2360	2360
Power [kW]	84420	19620	22890
Rotational speed rev/min]	92-102	91-108	91-108
Specyfic fuel consumption [g/kWh]	171	172	172
Effective pressure [bar]	19.6	20	20
Mass [t]	2300	506	569

Presented list of engines leads to the conclusion that main engine power of container ship is roughly four times higher than other engines, and mass of the engine for container ship is in the same relation.

4. Analysis of exploitation parameters

For comparison of fuel consumption of analysed ships, was taken a trip from Gdynia to Shanghai. Total distance of the trip was 11000 nautical miles. In the Tab. 6 are presented total amounts of fuel and specific consumption per 1 Nm, consumed by engines running at service rating (SCR) with assumed speed. Table presents also duration of the trip. For comparison reasons was calculated also power necessary for propulsion of container ship when is sailing with the speed typical for tankers and bulk carriers. In that case, resistance were not calculated for optimisation criteria but for previously defined shape of ship for 25 kn.

Tab. 6. Trip duration and fuel consumption

ship	Trip duration [h]	Fuel consumption total [t]	Fuel consumption per Nm [t/NM]
Container v=25 kn	528	6068	O.55
Container v=15 kn	880	3012	0.27
Bulk carrier	880	2237	0.20
tanker	880	2440	0.22

5. Final conclusion

Analysis of obtained results of fuel consumption versus power and ship's speed, leads to the conclusion that fuel consumption of container ship sailing with speed of 25 kn is around 2.5 times higher but service speed only 15 times higher in comparison with bulk carrier and tanker proceeding with speed of 15 kn. For more clear picture of taken results, comparison was extended by attached calculations of the same container ship but sailing with reduced service speed to the level of 15 kn. It is clearly shown that fuel consumption was reduced to half of amount necessary for sailing with higher speed of 25 kn. It let us conclude that increasing of service speed is disproportional to the costs of fuel, and diminishing of service speed to the level of 15 kn reduce fuel consumption more than twice. That conclusion is justify by actual situation at contemporary maritime shipping market, because majority of shipowners ordered speed reduction for minimising of fuel reduction. It is done for example, by dismounting or disengagement of one of tyrbochargers, moreover, new units are designed for sailing with lower service speed.

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