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MEAN LONG-TERM SCREW PROPELLER SERVICE PARAMETERS OF TRANSPORT SHIP SAILING ON A GIVEN SHIPPING ROUTE

Key words

thrust, efficiency and rotational speed of screw propeller, long-term prediction, shipping route, design working point of screw propeller.

Summary

During ship sailing on a given shipping route in real weather conditions all propulsion system performance parameters of the ship change along with changes of instantaneous total resistance and speed of the ship. In this paper, the results of calculations are presented of the distribution function and mean statistical values of screw propeller thrust, rotational speed and efficiency, as well as propulsion engine power output and specific fuel oil consumption occurring on selected shipping routes. On this basis new guidelines for ship propulsion system design, procedures are formulated.

Introduction

A crucial element of the design process of the propulsion system of a transport ship is the selection of its design parameters, i.e. the determination of a speed value for which screw propeller should be designed and a determination of a thrust value that should be developed by this propeller at the assumed speed. Correct selection of the design speed is specially important for ships fitted with fixed pitch propellers (most often applied to transport ships), because only at that design speed the propeller is able to use full engine power output.

The service speed at which the designed ship has to operate in real weather conditions on a given shipping route should be assumed as the design speed.

The means of calculation of the mean long-term service speed and the mean long-term resistance of the ship is presented in [1, 2, 3].

The design working point of a screw propeller is associated with the following design parameters: ship speed and propeller thrust. Selection of this point is very important with a view of the correct operation of the propulsion system. At this point, screw propeller efficiency should reach a value as high as possible. For screw propellers interacting with piston combustion engines, the design point is usually placed half way between the points A and B (Fig. 1). That generally ensures correct operation of the propulsion system in the point B, i.e., in service conditions (real weather conditions).

Instantaneous service speed of the ship and its total resistance depend on instantaneous weather conditions occurring on a given shipping route. Hence, working parameters of the screw propeller designed and applied to propel the ship will be changeable, depending on weather parameters and the assumed criteria of propulsion system control [4]. Knowing statistical data on wind and waves occurring on a given shipping route, as well as the long-term distribution function of ship speed [3] on the route, one can determine the long-term distribution functions of the working parameters of the screw propeller and, hence, the mean statistical location of its working point on a given shipping route.

Therefore, this paper presents calculations performed for designed ships and their propulsion systems together with the long-term service parameters of the screw propeller and the mean service location of its working point and a discussion on how it would influence its design working point.

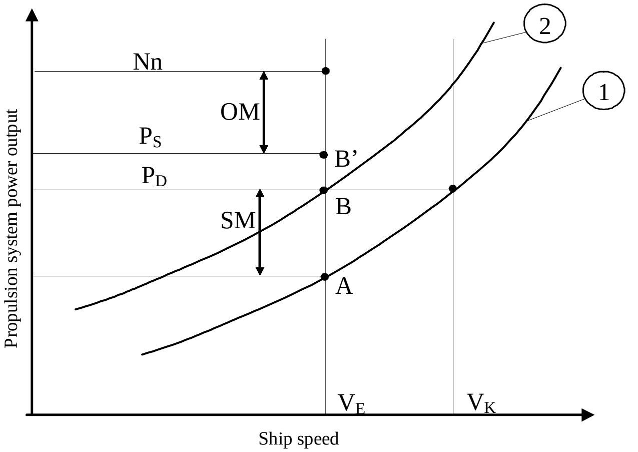


Fig. 1. Predicted service speed of ship: Nn – nominal power output of engine, PS – shaft-line power, PD – power delivered to propeller cone, VK – contractual speed of ship, VE – predicted service speed of ship, 1 – still-water propeller curve for clean ship hull, 2 – predicted propeller curve with service margin, in real conditions, OM – operational margin, SM – service margin

1. Service parameters of a screw propeller

The service parameters of a screw propeller to be calculated for a ship sailing on a given shipping route are the following:

- propeller thrust T,
- propeller rotational speed n_p,
- free-propeller efficiency η_0.

The thrust of the behind-the-hull propeller is expressed as follows:

$$T = \frac{R_C}{1-t} \tag{1}$$

where:

R_C − total resistance of ship to motion in waves
t − thrust deduction.

The free-propeller thrust can be calculated by using the formula as follows:

$$T = K_T \rho_w D_p^4 n_p^{\ 2} \tag{2}$$

where:

D_p − propeller diameter,
n_p − propeller speed,
K_T − thrust ratio which – for typical B-Wageningen screw propellers of given parameters: (P/D) (A_E/A_0), (Z) – is approximated with the use of the expression:

$$K_T = A_0 + A_1 \cdot J + A_2 J^2 + A_3 \cdot J^3 \tag{3}$$

where:

A_0, A_1, A_2, A_3 − coefficients of polynomial approximating propeller thrust characteristic, dependent on (P/D), (AE/A0), (Z),
J − advance ratio:

$$J = \frac{V[1 - w(V)]}{D_p \cdot n_p} \tag{4}$$

where:

w(V) − wake fraction dependent on the ship speed V.

2. Prediction of the mean statistical service speed of the screw propeller of a ship sailing on a given shipping route

2.1. Instantaneous values of propeller service parameters

While sailing in waves, the ship is loaded by additional resistance components due to wind, waves, sea surface currents, and possible rudder-blade deviation [1]. The additional resistance forces make changes in propeller speed and thrust, and new values of propeller speed and thrust are searched for in such a way as to keep the working point of the engine within its working area. Searching for the working point at given criteria, e.g. at maintaining a given ship speed or reaching the maximum one without engine overloading, is performed in the same way as the search for of instantaneous ship speed [2, 3].

On the basis of the solution of the non-linear set of equations presented in [2], at first instantaneous values of propeller speed and ship speed are determined; and, if all criteria are satisfied, then instantaneous values of propeller thrust and efficiency are calculated.

2.2. Mean statistical values of screw propeller service parameters of a ship sailing on a given route

In the case of screw propeller, as in calculating the mean statistical value of ship service speed, its parameters depend on statistical parameters of waves and wind, and the assumed ship course angles and speeds on a given shipping route. Therefore, the probability of ship being in a given situation while sailing in waves on a given shipping route is the following:

$$p_w = f_A \cdot f_S \cdot f_\mu \cdot f_{HT} \cdot f_V \cdot f_\psi \tag{5}$$

where:

- f_A – probability of staying the ship in the sea area A,
- f_S – probability of staying the ship in the sea area A during the season S,
- f_μ – occurrence probability of the wave direction μ in the sea area A during the season S,
- f_{HT} – occurrence probability of wave of the parameters (H_S, T_1), propagating from the direction μ,
- f_V, f_ψ – probability of the event that ship will sail with the speed V and the course angle ψ, respectively.

For each situation for which the probability p_w is calculated, the instantaneous working point of the propeller, determined by the instantaneous ship speed V_i and the instantaneous propeller speed, n_{pi}, is calculated. Different instantaneous values of V_i and npi may yield the same value of the advance ratio J_i acc. (4) and - in consequence - instantaneous values of the thrust T_i and the propeller efficiency η_{0i}.

The total occurrence probability P_T of given values of propeller thrust and efficiency is as follows:

$$P_{TT} = \sum_{A=1}^{n_A} \sum_{S=1}^{n_S} \sum_{\mu=1}^{n_\mu} \sum_{H,T=1}^{n_{HT}} \sum_{V=1}^{n_V} \sum_{\psi=1}^{n\psi} p_{T_i} \left[T_i \left(\Delta R_i \right) \right] \tag{6}$$

where:

P_{TT} – total occurrence probability of a given value of the thrust,

$T_i(\Delta R_i)$ – instantaneous value of the propeller thrust in function of the instantaneous additional resistance,

n_A, n_S, n_μ, n_{HT}, n_V, n_ψ – number of: sea areas crossed by the ship, seasons of the year, values of wave direction, wave parameters and ship course angle, respectively.

All instantaneous values of propeller service parameters are grouped into classes (intervals of a width appropriate to a given parameter and the number of its calculation results).

Calculating the distribution function of occurrence probability of instantaneous propeller thrust, $f(T_i)$, or that of occurrence probability of instantaneous propeller speed, $f(n_{pi})$, or that of occurrence probability of instantaneous propeller efficiency, $f(\eta_{0i})$, one can determine the mean, long-term value of propeller thrust (or – analogously – propeller speed and efficiency) for a given shipping route as follows:

$$\overline{T} = \frac{\sum_{i=1}^{n_T} P_{TT} \cdot T_i\left(\Delta R_i = const\right)}{\sum_{i=1}^{n_T} P_{TT}} \tag{7}$$

where:

n_T – number of intervals containing similar instantaneous values of propeller thrust.

From the expressions similar to (7), the mean, long-term value of propeller speed, $\overline{n}_p$, or that of propeller efficiency, $\overline{\eta}_0$, can be calculated.

The calculations of the mean statistical service parameters of a screw propeller were performed for the ships and shipping routes whose parameters were given in [3].

3. Results of calculations

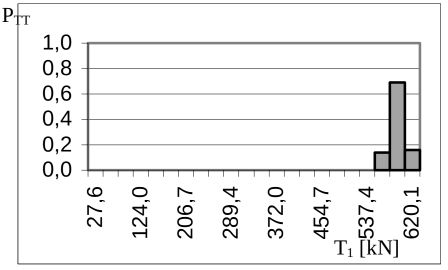
Results of the calculations for the selected ship and shipping routes are presented in the form of the following:

– a histogram of propeller thrust and its mean statistical value (Fig. 2),
– a histogram of propeller speed and its mean statistical value (Fig. 2),
– a histogram of propeller efficiency and its mean statistical value (Fig. 2),
– the mean statistical value of propeller efficiency (Fig. 3),
– the mean statistical propeller working point (Fig. 4).

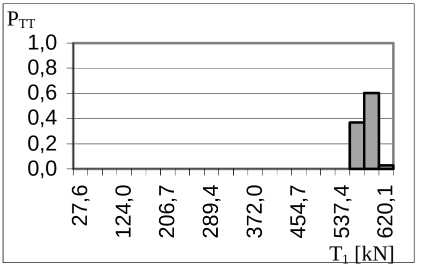
Ship: K1 - assumed service speed = 8.44 [m/s] - probability of maintaining the assumed speed P_{VE}

Thrust histograms

Route no. 2b - P_{VE} = 0.50



Route no. 5b - P_{VE} = 0.83

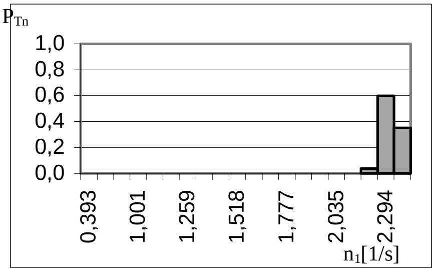


Thrust in still water T = 579 [kN]
Mean thrust T = 593 [kN]

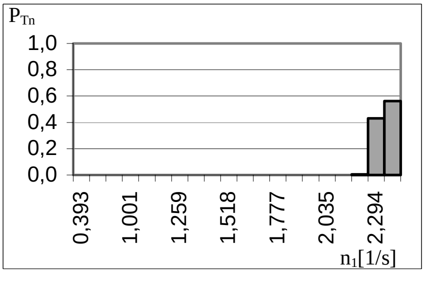
Mean thrust T = 582 [kN]

Propeller speed histograms

Route no. 2b - P_{VE} = 0.50



Route no. 5b - PVE = 0.83

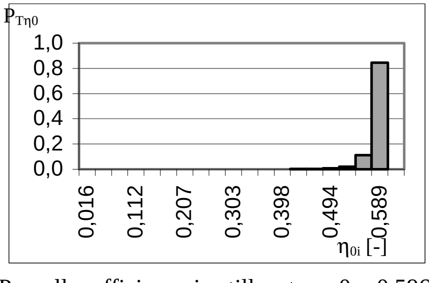


Nominal propeller speed n_n = 2.330 [1/s]
Mean propeller speed $\overline{n}$ 0 = 2.335 [1/s]

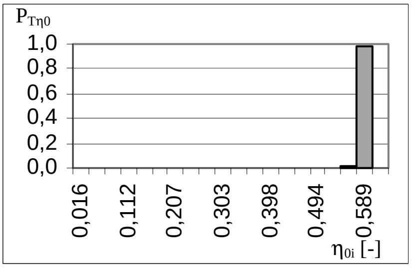
Mean propeller speed n = 2.335 [1/s]

Propeller efficiency histograms

Route no. 2b - P_{VE} = 0.50



Route no. 5b - P_{VE} = 0.83



Propeller efficiency in still water $\eta 0$ = 0.596
Mean propeller efficiency $\overline{n}$ 0 = 0.584

Mean propeller efficiency $\overline{\eta}_0$= 0,593

Fig. 2. Histograms and mean statistical values of thrust, speed and efficiency of propeller for K1 ship sailing on 2 b and 5 b shipping routes

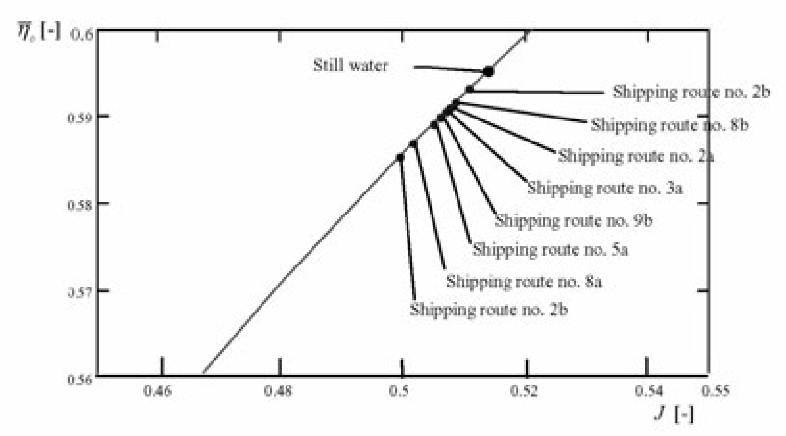


Fig. 3. Influence of shipping route [3] (weather parameters on a given shipping route) on mean statistical value of propeller efficiency for K1 ship

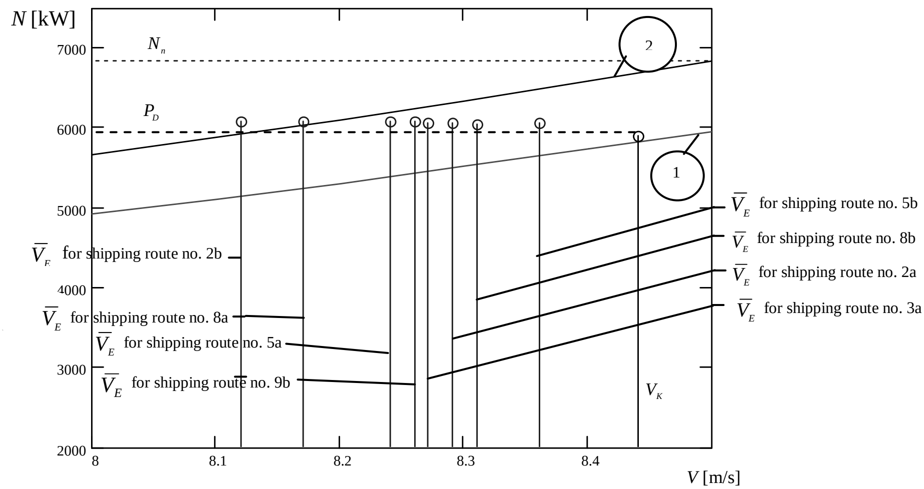


Fig. 4. Mean statistical working point of K1 ship propeller, depending on the mean statistical ship service speed $\overline{V}_E$ on various shipping routes: 1 − still-water propeller curve, 2 − propeller curve containing the service margin SM = 15%, P_D − power delivered to propeller cone at ship's contractual speed in still water conditions, N_n − nominal power output of propulsion engine, V_E − mean statistical long-term value of ship service speed on a given shipping route, V_K − contractual speed of ship

All the calculations were performed under the assumption that the power output of the engine reaches at most 0,9 N_n.

In the below attached figures the calculation results are presented for a K1 containership [3] and the two very different shipping routes: 5b - “easy,” and 2b – “difficult” – in the sense of occurrence of long-term weather parameters.

Conclusions

Presented in Fig. 2, the histograms of propeller thrust, speed and efficiency show that propeller service parameters depend largely on shipping route weather parameters. The most interesting is the distribution of the free-propeller efficiency η_0, the mean statistical value of propeller efficiency on a given route, $\overline{\eta}_0$, and its comparison with that in still water, η_0.

The enlarged fragment of the propeller efficiency characteristic, together with the depicted mean statistical values of propeller efficiency for various shipping routes, makes it possible to determine the values of propeller design parameters for a selected ship sailing on a given route. For a ship that sails on many shipping routes, the appropriate mean efficiency value can be calculated from mean statistical efficiency values for the ship on particular shipping routes.

Based on the calculation results of the mean statistical values of propeller efficiency, the mean statistical working points of the propeller, presented on the power output were calculated – ship speed diagram (Fig. 4). On comparison of Fig.4 and Fig. 1, it can be clearly stated that the design working point is not only located between the points A and B (Fig. 1) but also its location depends on the mean statistical service speed of ship on a given shipping route; hence, it also depends on statistical weather parameters on the shipping route in question These problems are planned to be further investigated so as to make it possible to elaborate design guidelines for the screw propeller of ship sailing on a given shipping route.

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Reviewer:
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Średnie, długoterminowe parametry pracy śruby napędowej statku transportowego na linii żeglugowej

Słowa kluczowe

Napór, sprawność i obroty śruby napędowej, długoterminowa prognoza, linie żeglugowe, projektowy punkt pracy śruby napędowej.

Streszczenie

Podczas pływania statku na danej linii żeglugowej w rzeczywistych warunkach pogodowych, wraz ze zmianami chwilowego całkowitego oporu i chwilowej prędkości eksploatacyjnej zmieniają się parametry pracy układu napędowego. W artykule przedstawiono wyniki obliczeń funkcji rozkładu i średnich statystycznych wartości naporu, obrotów i sprawności śruby oraz mocy i zużycia paliwa silnika napędowego statku na wybranych liniach żeglugowych. Na podstawie wykonanych obliczeń przedstawiono nowe wytyczne do projektowania napędu statku.