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MEAN, LONG-TERM PROPULSION ENGINE SERVICE PARAMETERS OF A 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 a ship's propulsion system design procedure are formulated.

1. Service parameters of propulsion engine operation

The service parameters of propulsion engine operation calculated below for a ship sailing on a given shipping route, are as follows:

- Engine power output N,
- Engine speed (number of engine revolutions per time unit) n, and
- Specific fuel oil consumption (SFOC), g, or hourly fuel oil consumption G.

The first two parameters (N, n) determine the engine's working point (if engine directly drives the propeller without any reduction gear then $n = n_p$). During ship's sailing on a given shipping route in changeable weather conditions the engine working point changes its location. By controlling fuel charge (consequently, the number of revolutions), a new engine's working point is searched with the use of the criterion assumed below, so as to get it placed within the engine layout area. A change of the location of the engine's working point makes fuel oil consumption changing both the specific, g, and hourly, G.

2. Engine performance characteristics and load diagram

The propulsion engine load diagram consists of a few areas limited by appropriate characteristic lines. The working point of the propulsion engine can be located in various areas, but in some of them, only for a determined time of operation. The example load diagram of a Sulzer propulsion engine is shown together with depicted SFOC characteristics in Fig. 1.

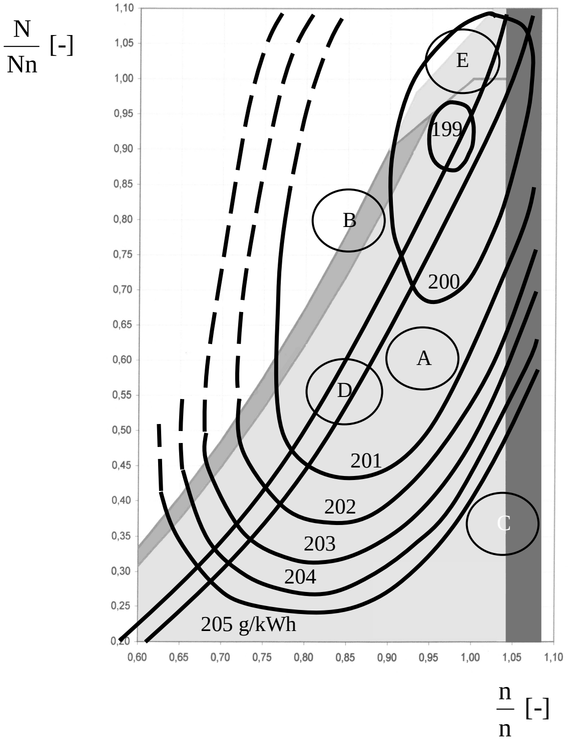


Fig. 1. Load diagram of a Sulzer propulsion engine [8]: M_n − rated torque, A − continuous rating area; B − engine overload area; C − sea trial rating area; D − still-water optimum rating area (...); E − instantaneous rating area

The particular areas are limited by engine the performance characteristics of the following form:

$$N = k_m \cdot n^m \tag{1}$$

where: N − engine power output,
k_m − coefficient for a given characteristic line,
n − engine speed,
m − exponent depending on an engine type and producer; for SULZER RTA 52, RTA 62, RT 72, RTA 84 slow speed diesel engines: m = 0 − for nominal continuous rating or maximum continuous rating, m = 1 − for constant torque characteristics, m = 2.45 − for overload characteristics.

Particular characteristics and the range of engine speed are determined depending on an engine type (producer).

In Fig. 1, on the engine load diagram the SFOC characteristics, g-values are shown. They are provided by engine's producer and valid for a given engine and determined conditions (a given air temperature, etc). There are also more general characteristics published by engine producers in the form of relevant nomograms, e.g. [8], which make it possible to calculate the SFOC depending on an engine type (producers), its nominal parameters (power and speed), instantaneous engine load, and ambient conditions (temperature of air and cooling water). The way of making use of the nomograms to calculate the SFOC of engines is given in [5]. Fuel consumption can be also determined on the basis of measurements carried out with the use of special instruments (flow meters, calibrated tanks) during propulsion engine operation [1].

3. Ship propulsion characteristics – propulsion system's performance in changeable weather conditions

The ship propulsion characteristics are the following: curves of propulsion power, thrust, efficiency and torque at propeller's cone, fuel consumption and ship speed available for a given ship resistance characteristic. The characteristics are usually presented on the propulsion engine load diagram in a function of propeller (engine) speed or ship speed (then the characteristic of the constant number of revolutions is attached). The propulsion characteristics published in the subject-matter literature are usually developed on the basis of the following:

- Model test results of free propellers or behind-the-hull ones,
- The results of measurements carried out onboard the ship [2, 7], and
- The results of measurements carried out onboard the ship with simultaneous use of free-propeller characteristics derived from model tests or numerically determined [3, 4, 5, 6].

For purposes of this work, a numerical method for predicting the ship propulsion characteristics was elaborated (for a designed ship appropriate model tests are not to be performed), in the following form:

- T(V, n) − propeller thrust,
- Q(V, n) − propeller torque,
- η_0(V, n) − propeller efficiency,
- P_D(V, n) − power output at propeller's cone,
- V(P_D, n) − ship speed characteristic.

where: V − ship speed,
n − engine speed (if the engine is of a slow speed then $n = n_p$, where n_p - propeller speed).

The ship propulsion characteristics are presented in [10].

4. Mean, statistical service parameters of the propulsion engine of ship sailing on a given shipping route

Prediction of the mean, statistical service parameters of the propulsion engine is performed in the same way as for a screw propeller [10]. At first the instantaneous parameters which result from an instantaneous increase of ship resistance due to wind, waves, sea surface current and possible lay of the rudder blade are calculated and then the probability of the occurrence of relevant values of propulsion engine's output and speed and the SFOC are calculated.

The total probability of the occurrence of given values of the propulsion engine output and speed, PT, is expressed as follows:

$$P_{Tn} = \sum_{A=1}^{n_A} \sum_{S=1}^{n_S} \sum_{\mu==1}^{n_\mu} \sum_{H,T=1}^{n_{HT}} \sum_{V=1}^{n_V} \sum_{\psi=1}^{n\psi} p_{n_i} \left[n_i \left(\Delta R_i \right) \right] \tag{2}$$

$$P_{TN} = \sum_{A=1}^{n_A} \sum_{S=1}^{n_S} \sum_{\mu==1}^{n_\mu} \sum_{H,T=1}^{n_{HT}} \sum_{V=1}^{n_V} \sum_{\psi=1}^{n\psi} p_{N_i} \left[N_i \left(\Delta R_i \right) \right] \tag{3}$$

where: P_{Tn} − total probability of occurrence of a given value of the engine speed n_i (if the engine directly drives the propeller the occurrence probabilities of a given value of the engine and propeller speeds are the same: $P_{Tn} = P_{Tnp}$),
P_{TN} − total probability of occurrence of a given value of the engine power output N_i,
n_i, N_i − instantaneous values of engine speed and output depending on an instantaneous value of the additional resistance ΔR_i,

p_{ni}, p_{Ni} – instantaneous occurrence probabilities of given values of the engine's speed n_i and output N_i for an instantaneous situation resulting from ship sailing on a given shipping route,

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

By applying the same technique as in the case of a propeller, the mean statistical values of engine speed and output on a given shipping route can be expressed as follows:

$$\overline{n} = \frac{\sum_{i=1}^{n_n} P_{T_n} \cdot n_i \left(\Delta R_i = const\right)}{\sum_{i=1}^{n_n} P_{T_n}} \tag{4}$$

$$\overline{N} = \frac{\sum_{i=1}^{n_n} P_{T_N} \cdot N_i \left(\Delta R_i = const\right)}{\sum_{i=1}^{n_N} P_{T_N}} \tag{5}$$

where: n_n, n_N – number of the intervals containing similar instantaneous values of engine speed and output, respectively.

During sailing on a shipping route in changeable weather conditions, all the ship's service parameters result from its engine's working point, which is to be located within the area of the engine's load diagram (Fig. 1), characterised by engine speed and power output.

Having the occurrence probabilities of given values of engine speed and output, one is able to determine the occurrence probability of a given working point, i.e. of the pairs of values: engine speed – engine output (in the same way as for those of propeller speed – ship speed, Fig. 5 in [10]).

The calculated distribution function of engine speed – engine output makes it possible to calculate the distribution function of SFOC as a determined value of fuel consumption that corresponds with each of engine's working points, Fig. 1. Having the distribution function, one can calculate the mean long-term value of specific fuel oil consumption for a given shipping route, in a similar way as for engine speed and output.

5. Results of calculations

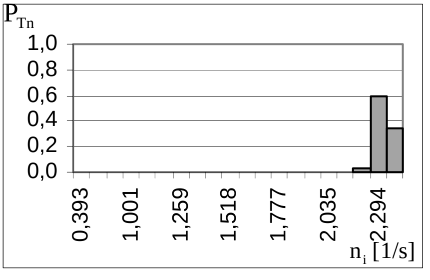
Results of the calculations for the selected ship and shipping route (engine and shipping route parameters were specified in [9]) are presented in the following form:

- Engine speed histogram and mean statistical value,
- Engine power output histogram and mean statistical value, Fig. 2,
- Specific fuel oil consumption (SFOC) distribution function and mean statistical value, Fig. 2,
- Probability distribution function of long-term occurrence of given values of engine speed and output (histogram of engine's working point), Fig. 3, and Mean, long-term working point of propulsion engine, Fig. 4.

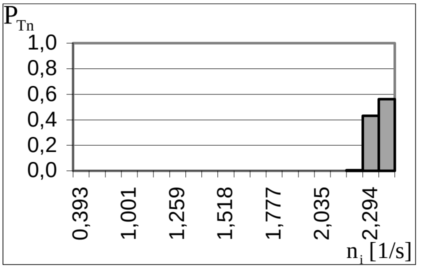
Ship: K1 – assumed service speed = 8.44 [m/s]
– probability of maintaining a given speed, P_{VE}

Engine speed histograms

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



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

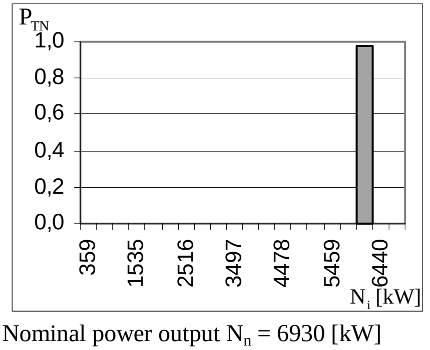


Nominal engine speed n_n = 2.330 [1/s]
Mean engine speed $\overline{n}$ = 2.335 [1/s]

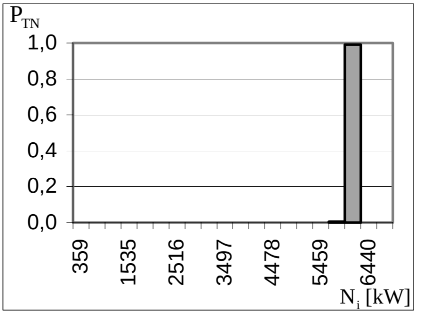
Mean engine speed $\overline{n}$ = 2.335 [1/s]

Power output histograms

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



Route no. 5b - P_{VE} = 0.50



Nominal power output N_n = 6930 [kW]
Mean power output $\overline{N}$ = 6164 [kW]

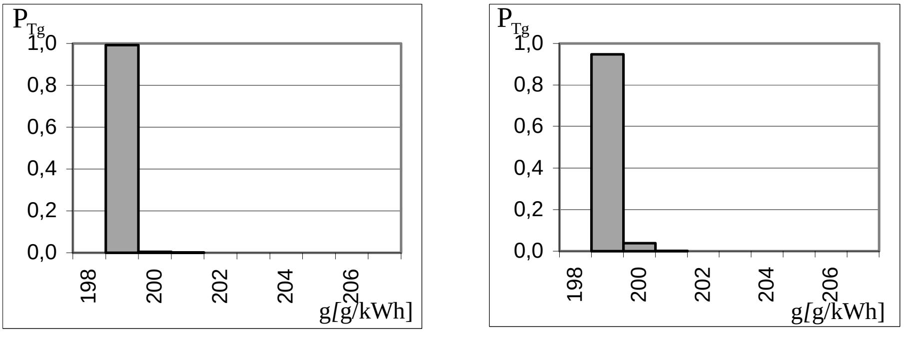
Mean power output $\overline{N}$ = 6156 [kW]

Fig. 2. Histograms and mean statistical values of speed and output of propulsion engine of K1 ship sailing on shipping routes : 2b and 5b

Ship: K1 - assumed service speed = 8.44 [m/s] - mean specific fuel oil consumption (SFOC) in still water, g = 199.00 g/kWh

Shipping route: 5b – „easy”

Shipping route: 2b – “difficult”



Mean SFOC = 199.01 g/kWh

Mean SFOC = 199.05 g/kWh

Fig. 3. Histograms and mean statistical values of specific fuel oil consumption (SFOC) for K1 ship sailing on shipping routes: 2b and 5b

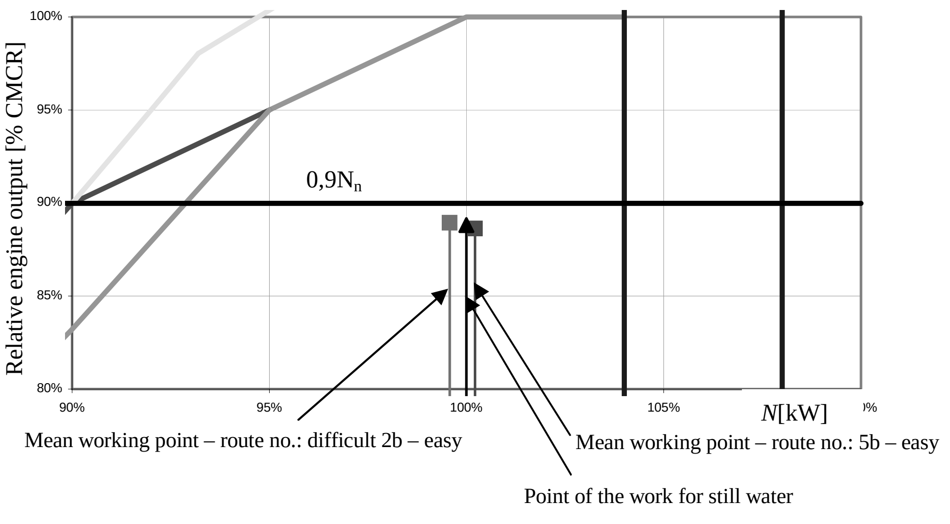


Fig. 4. Mean, long-term working point of propulsion engine of K1 ship sailing on shipping routes: 2b and 5b

In the figures, the calculation results are presented under the assumption that the engine’s output reaches at most 0.9 N_n – for K1 containership [9] and the two very different shipping routes: 5b – “easy,” and 2b – “difficult” – in the sense of the occurrence of long-term weather parameters.

Conclusions

- Conclusions resulting from the calculations of mean statistical service parameters of screw propeller were presented in [10]. Results of the calculations of the mean statistical parameters of the propulsion engine operation (engine speed, output and specific fuel oil consumption – SFOC) in the form of histograms are very similar to those of a screw propeller as the engine in question directly drives the propeller and the calculated power output is used only for propelling the ship (as no other power consumers were taken into consideration, e.g. shaft generators).
- The calculations of SFOC were performed for approximate characteristics under the assumption that the engine is new, air and cooling water parameters are standard, and ship's hull and screw propeller are clean (not fouled). Therefore, the calculation results should be assessed rather qualitatively but not quantitatively.
- The obtained histograms and mean statistical parameters depend, not only on weather conditions on a given shipping route, but also on an assumed criterion of propulsion control. The presented calculations were performed for the criterion of maintaining a constant ship speed, and if it is not possible – for a maximum available speed at the engine power output of 0.9 N_n at most. The assumed criteria of ship's propulsion (engine) control highly influence the service parameters of the propulsion system. This can be observed in the case of the SFOC distribution as well as the occurrence probability of a given working point of the engine on a given shipping route.
- Weather conditions occurring on a shipping route are not the only decisive influences on the fuel consumption level. Therefore, to obtain a possibly low SFOC level, the propulsion control should be optimised by using various criteria, and the ship's course can be changed, which consequently is equivalent to shipping route optimisation.
- The refined and expanded computer software makes it possible to choose different control criteria for the ship's propulsion and to optimise both its service parameters and entire shipping route.
- Calculations of the probability of the occurrence of the propulsion engine's working point (Fig. 4) may be also used for assessing the wear level of the engine or its elements as well as for scheduling overhauls.

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Reviewer:
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Średnie, długoterminowe parametry pracy silnika napędowego statku transportowego na linii żeglugowej

Słowa kluczowe

Napór, obroty i sprawność śruby, przewidywanie długoterminowe, linia żeglugowa, projekt punktu pracy śruby.

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.