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INFLUENCE OF THE SERVICE MARGIN OF SERVICE PARAMETERS OF TRANSPORT SHIP PROPULSION SYSTEM

Part II

Screw propeller service parameters of transport ship sailing on a given shipping route

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Abstract

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 results of calculations are presented of 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 at different service margin values. On this basis new guidelines for ship propulsion system design procedure are formulated.

Keywords*: thrust, efficiency and rotational speed of screw propeller, long-term prediction, shipping route, design working point of screw propeller, service margin*

5. Service parameters of propulsion engine operation

The service parameters of propulsion engine operation, calculated below for a ship sailing on a given shipping route at different service margin are as follows:
- engine power output *P*
- engine speed (number of engine revolutions per time unit) *n*
- specific fuel oil consumption(SFOC), g, or hourly fuel oil consumption *G*.

The first two parameters (*P*, *n*) determine engine working point (if engine directly drives 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 also number of revolutions) a new engine working point is searched with the use of the criterion assumed below, so as to get it placed within engine layout area. Change of location of the engine working point makes fuel oil consumption changing: both the specific, g, and hourly one *G*.

6. Engine performance characteristics and load diagram

The propulsion engine load diagram consists of a few areas limited by appropriate characteristic lines. Working point of propulsion engine can be located in the 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. 7.

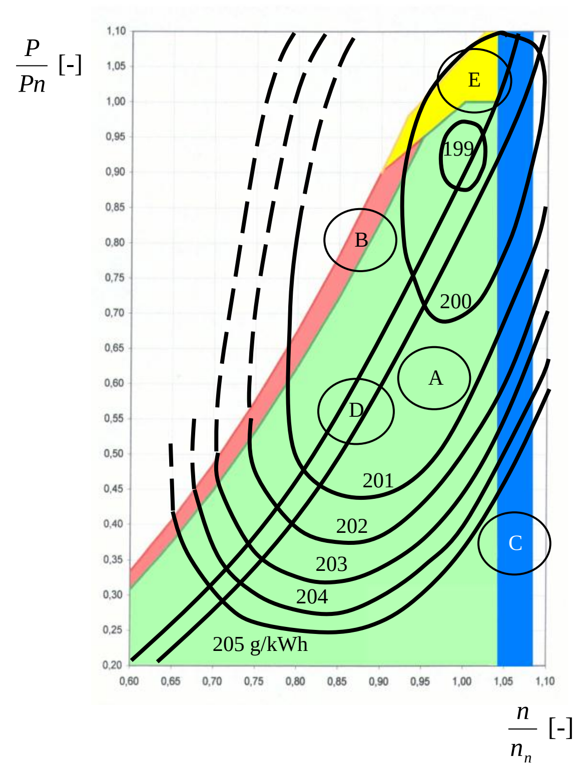


Fig. 7. Load diagram of a propulsion engine [8].

P_n – rated torque, n_n - nominal engine speed, A – continuous rating area (green); B – engine overload area (red); C – sea trial rating area (blue); D – still-water optimum rating area (...); E – instantaneous rating area (yellow)

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

$$P = k_m \cdot n^m \qquad (2)$$

where:

P - 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, RTA 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 range of engine speed are determined depending on an engine type (producer).

In Fig. 7, on the engine load diagram the SFOC characteristics, g, are shown. They are provided by engine 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 as well as 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].

7. 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 function of propeller (engine) speed or ship speed (then characteristic of constant number of revolutions is attached). The propulsion characteristics published in the subject-matter literature are usually elaborated on the basis of:

⇒ model test results of free propellers or behind-the-hull ones
⇒ results of measurements carried out on ship board [2, 7]
⇒ results of measurements carried out on ship board 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
- $\eta_0(V, n)$ - 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 above characteristics together with the criteria for selecting service parameters for a ship in a changeable weather conditions are shown in [10].

8. Results of calculations mean statistical parameters of engine for ship sailing on route

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

⇒ engine speed histogram and mean statistical value

⇒ engine power output histogram and mean statistical value

⇒ specific fuel oil consumption (SFOC) distribution function and mean statistical value

⇒ probability distribution function of long-term occurrence of given values of engine speed and output (histogram of engine's working point)

⇒ mean, long-term working point of propulsion engine.

In the figures the calculation results are presented – under the assumption that engine's output reaches at most 0.9 P_n - for M2 [9] and the two very different shipping routes : 5b - "easy" one and 2b - „difficult" one - in the sense of occurrence of long-term weather parameters.

Ship: M2 - assumed service speed = 7,72 [m/s] SM=15%

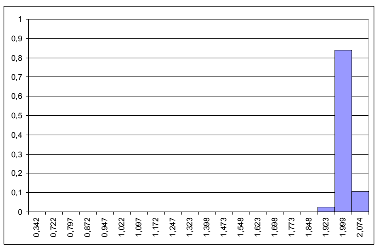
- probability of mantaining a given speed P_{VE}

Route no. 2b - P_{VE} = 0,55

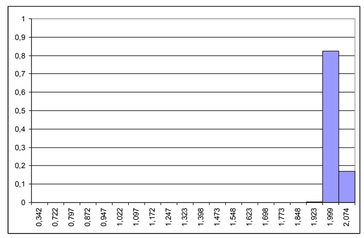
Route no. 5b - P_{VE} = 0,86

Engine speed histograms

P_{Tn}



P_{Tn}



n[1/s]

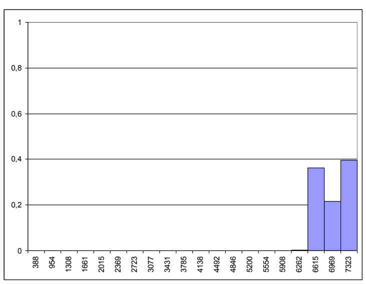
Nominal engine speed n_n = 2,030 [1/s]

Mean engine speed $\bar{n}$ = 2,021 [1/s]

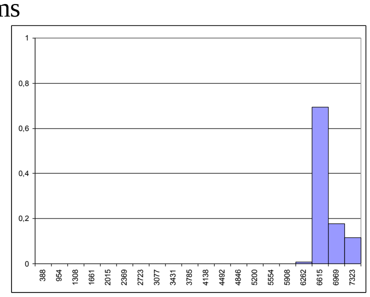
Mean engine speed $\bar{n}$ = 2,031 [1/s]

Power output histograms

P_{TP}



P_{TP}



N[kW]

Nominal power output P_n = 7500 [kW]

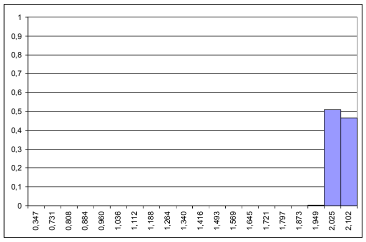
Mean power output $\bar{P}$ = 6970 [kW]

Mean power output $\bar{P}$ = 6724 [kW]

SM=20%

Route no. 2b - P_{VE} = 0,79

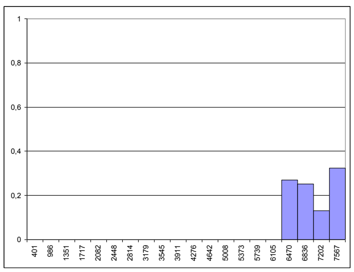
P_{Tn}



Nominal engine speed n_n = 2,057 [1/s]

Mean engine speed $\bar{n}$ = 2,063 [1/s]

P_{TP}



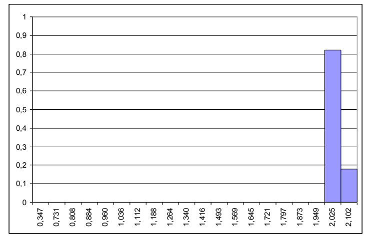
Nominal power output P_n = 7750 [kW]

Mean power output $\bar{P}$ = 7044 [kW]

Route no. 5b - P_{VE} = 0,96

Engine speed histograms

P_{Tn}

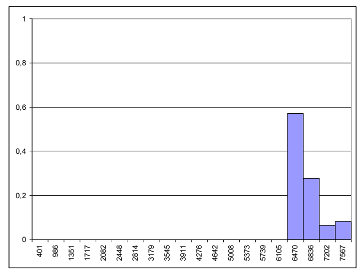


n[1/s]

Mean engine speed $\bar{n}$ = 2,045 [1/s]

Power output histograms

P_{TP}



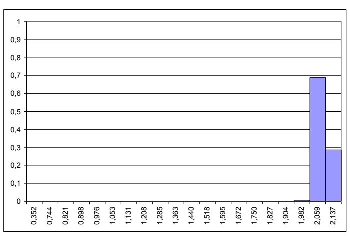
N[kW]

Mean power output $\bar{P}$ = 6740 [kW]

SM=25%

Route no. 2b - P_{VE} = 0,82

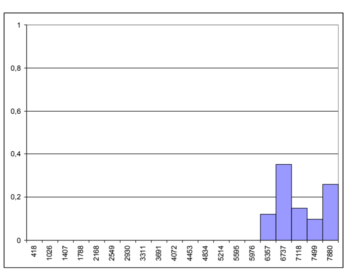
P_{Tn}



Nominal engine speed n_n = 2,092 [1/s]

Mean engine speed $\bar{n}$ = 2,070 [1/s]

P_{TP}



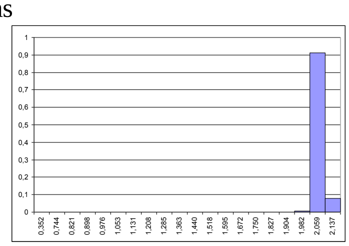
Nominal power output P_n = 8070 [kW]

Mean power output $\bar{P}$ = 7123 [kW]

Route no. 5b - P_{VE} = 0,97

Engine speed histograms

P_{Tn}

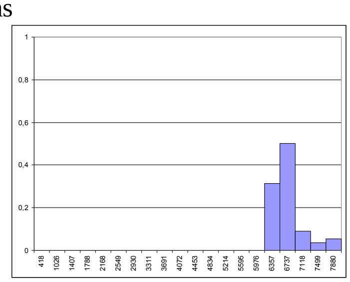


n[1/s]

Mean engine speed $\bar{n}$ = 2,047 [1/s]

Power output histograms

P_{TP}



[kW]

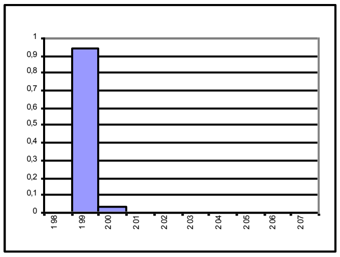
Mean power output $\bar{P}$ = 6756 [kW]

Fig. 8. Histograms and mean statistical values of speed and output of engine at different service margin values for routes no. 2b and 5b

Ship: M2 - assumed service speed = 7,72 [m/s] SM=15%
- mean fuel oil consumption in still water g = 199,00 g/kWh

Route 2b

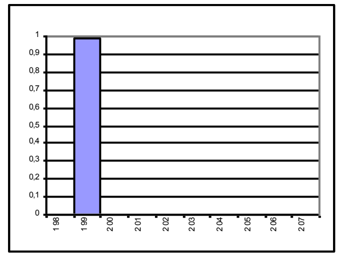
P_{Tg}



Mean fuel oil consumption = 199,01 g/kWh

Route 5b

P_{Tg}



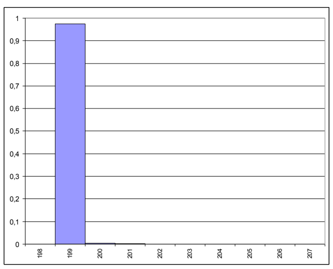
g[g/kWh]

Mean fuel oil consumption = 199,00 g/kWh

SM=20%

Route 2b

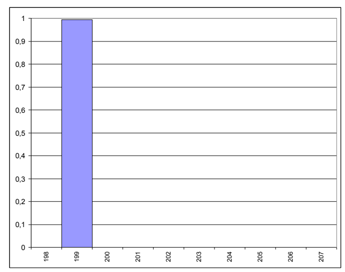
P_{Tg}



Mean fuel oil consumption = 199,01 g/kWh

Route 5b

P_{Tg}



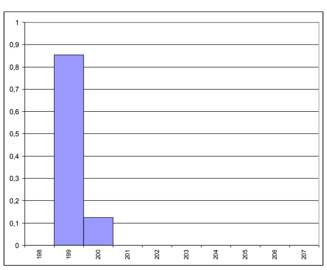
g[g/kWh]

Mean fuel oil consumption = 199,00 g/kWh

SM=25%

Route 2b

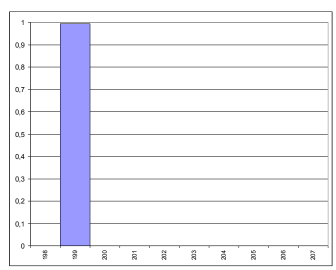
P_{Tg}



Mean fuel oil consumption = 199,13 g/kWh

Route 5b

P_{Tg}



g[g/kWh]

Mean fuel oil consumption = 199,00 g/kWh

Fig 9. Histograms and mean statistical values of fuel oil consumption at different service margin values for routes no. 2b and 5b

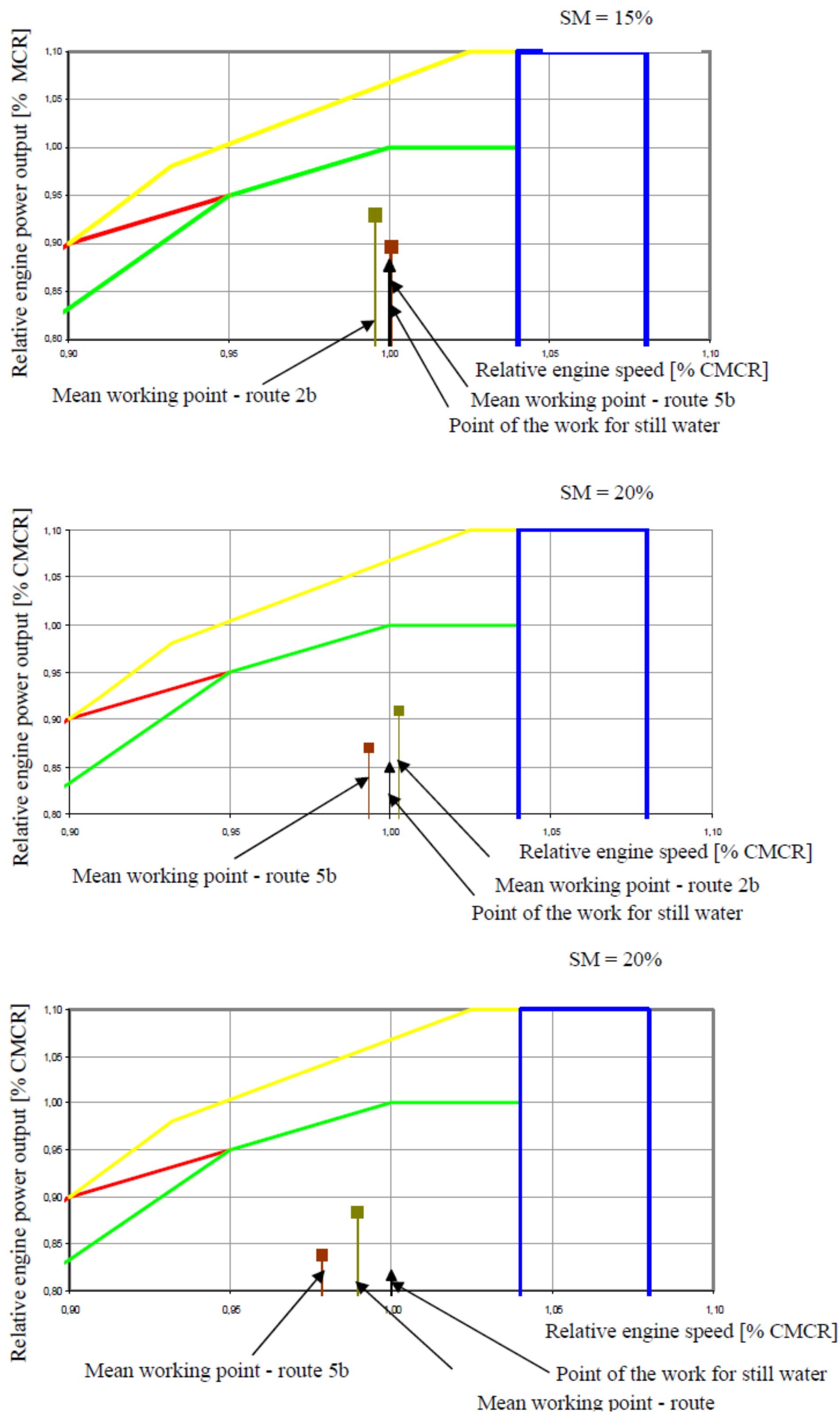
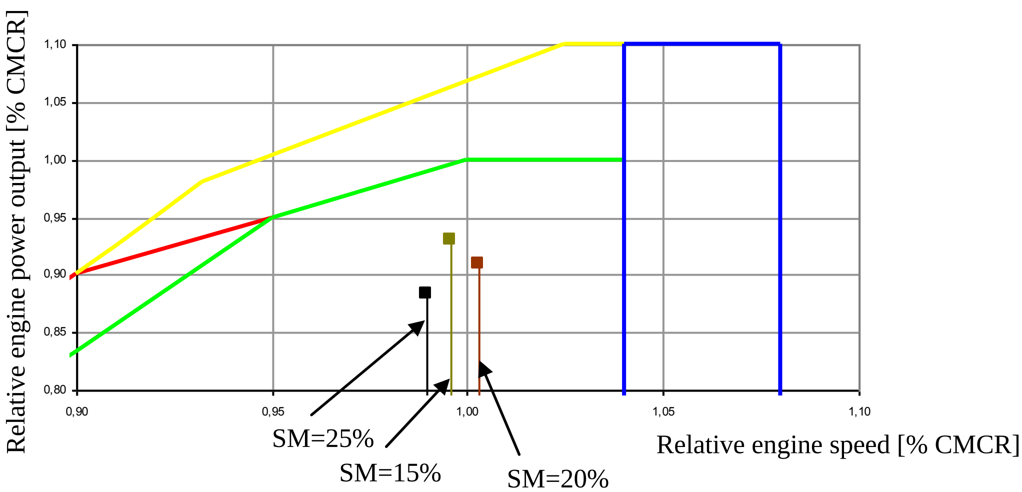


Fig 10. Mean, long-term working point of engine at different service margin values for routes no. 2b and 5b

Route 2b



Route 5b

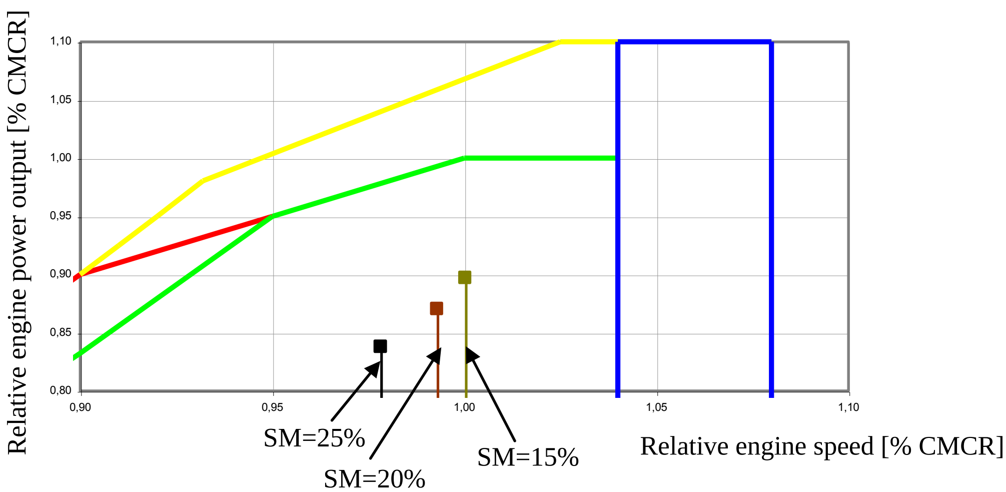


Fig. 11. Influence of the service margin of mean long-term working point of engine for routes no. 2b and 5b

Final conclusions

- Conclusion results 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 propulsion engine operation c (engine, speed, output and specific fuel oil consumption – SFOC) in the from of histograms are very similar to those of 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 (unfouled). 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 a assumed criterion of propulsion control; the presented calculations were performed for the criterion of maintaining the ship speed constant (Variant "b", Fig. 11) and if it is not possible – for a maximum available speed at the engine power output of 0,9 P_n at the most. The assumed criteria of ship propulsion (engine) control highly influence service parameters of propulsion system. This can be observed in the case of the SFOC distribution as well as occurrence probability of a given working point of engine on a given shipping route.
- The condition of maintaining the assumed ship speed may results in a somewhat greater SFOC value on a shipping route where statistically more favourable weather conditions occur than on those of more harsh weather conditions. Hence not only weather conditions occurring on a shipping route are decisive of fuel consumption level. Therefore to obtain a possibly low SFOC level the propulsion control should be optimized by using various criteria (Fig. 11) depending on a given situation. In real conditions also ship course can be changed that consequently is equivalent to shipping route optimization.
- The elaborated computer software makes it possible to choose different control criteria of ship propulsion and optimize booth its service parameters and entire shipping route.
- Calculations of probability of occurrence of propulsion engine working point (Fig. 10, 11 as for scheduling overhauls).
- The influence of the SM values on mean statistical service parameters of a ship is depends mainly on the assumed criterion of ship propulsion. In this article it is assumed, that the assumed speed of a ship with be maintained. As results the higher the SM value, the higher also mean statistical service speed of a ship and therefore the higher probability of maintaining the assumed service speed of a ship (Table 1). All the remaining parameters: thrust, propeller efficiency, power speed engine and average working point of the propulsion engine sent from the adopted criterion of maintaining the assumed service speed.

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