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Predicting Powering Margins

1. PURPOSE OF PROCEDURE

The purpose of this procedure is to present recommendations, procedures, methodologies for determining the additional power to be installed above the calm water power requirements to account for various environmental conditions encountered in service, such as wind, waves, hull and propeller fouling, and increase of roughness due to ageing.

2. DEFINITIONS

2.1 List of Symbols

D Propeller diameter

h Distance from the instantaneous free surface to the propeller centre

h_0 Distance from the calm water free surface to the propeller centre

$H_{W1/3}$ Significant wave height

J_0 Advance coefficient of propeller

J_{0C} Advance coefficient of propeller in calm water

K_Q Propeller torque coefficient

K_{QC} Propeller torque coefficient in calm water

K_T Propeller thrust coefficient

K_T^* Propeller thrust coefficient of full scale propulsion point

K_{TC} Propeller thrust coefficient in calm water

n Propeller rate of rotation (1/s)

P_{DS} Shaft power

P_{DSC} Shaft power in calm water

PM Powering Margin

R Propeller radius

R_{T0} Ship resistance in calm water

R_{AW} Ship added resistance in waves

t Thrust deduction

T_P Peak period of wave spectrum

w Taylor wake fraction

α Average wave heading

β Thrust diminution factor

ε Phase angle

$\eta_{R\zeta}$ Relative wave motion amplitude

ρ Water density

σ Area under the wave spectrum

ω Wave frequency

ω_E Wave frequency of encounter

ζ Wave amplitude

2.2 Definition of Margins

The terms powering margin and sea margin have been used in the past. For clarification, the following terms are defined

Calm Water Powering Margin: the power level above and beyond the tow tank prediction to ensure that a ship meets its calm water speed – power requirement. However, it depends on the practice of power estimation of each towing tank whether Calm Water Powering Margin is necessary or not. If the proper considerations are made for the selection of model-ship correlation factors to meet the calm water speed requirement, it is not necessary.

Sea Margin: Powering margin can be defined as the margin which should be added to the estimation of the speed-power relationship for a newly built ship in ideal weather conditions to allow for the operation of the ship in realistic conditions. In practice this does not mean that the ship must meet full speed in all weather conditions, but that it can sustain its service (design) speed over a realistic percentage of conditions. Powering margins should take into account environmental effects such as wind and waves on the route, (shallow water), steering effects and air- and water temperature based either on experience or on statistical values as well as the effects of aging and fouling on the hull and roughness of the hull and the propeller surface.

Engine Operation Margin: The engine operation margin describes the mechanical and the thermodynamic power reserve for the economical operation of the engine(s) with respect to reasonably low fuel and maintenance costs.

- **Light Running Margin:** This is the margin in propeller revolution considered for a new ship to absorb 100% engine power in future service conditions.

3. RESPONSIBILITIES

The Calm Water Powering Margin shall be given by the model testing institution, since it is closely related to their model - ship correlation.

To determine the sea margin, the ship operator supplies information about the intended operation of the ship. The determination of the margin is done using the hydrodynamic knowledge of the model testing institution, together with the operational information from the ship operator.

The Engine Operation Margin should be determined by the engine manufacturer using information received from the ship's operator.

The light running margin should generally be determined by the engine manufacturer in cooperation with the propeller manufacturer and the ship's builder.

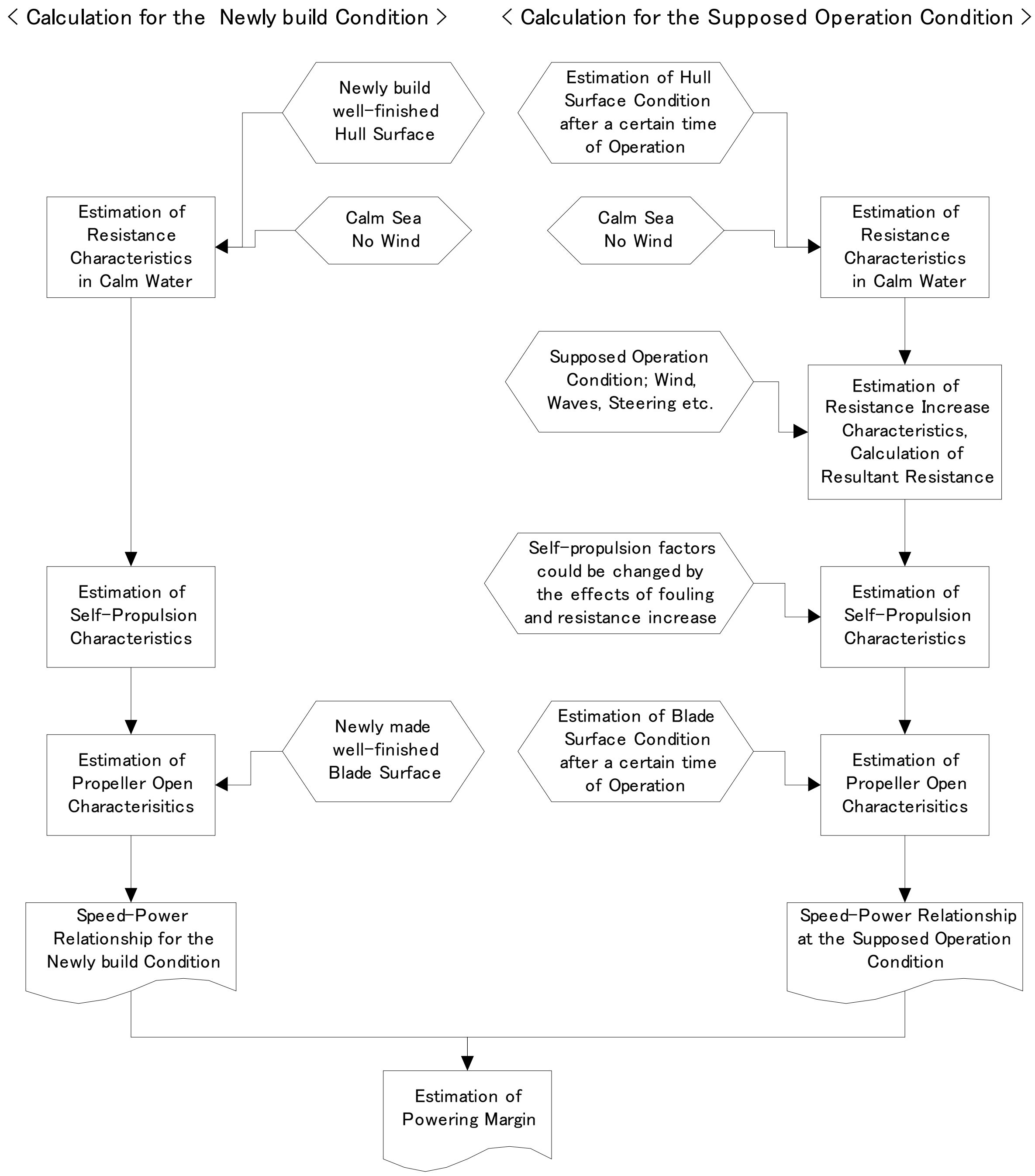

Figure 1
Simplified Flow Chart how to establish Powering Margin

4. PROCEDURE

The methods to establish margins (see Fig. 1) consist of

- the definition of the operating conditions of the ship, considering the ships displacement, sea states, relative wind speeds, current speeds and the relative direction of wind, waves and current; additionally aging effects (fouling, roughness) should be considered,
- the estimation of the resistance increase due to operational and environmental conditions and aging effects,
- a check of the propeller and engine characteristics taking into account the resistance increase of the ship in operation.

4.1 Resistance Increase due to Operational and Environmental Conditions

4.1.1 Calm Water Powering Margin

As an example, Reference 6 suggests that 6% power margin be applied to model tests with stock propellers and 4% power margin should be applied to model tests with design propellers. Reference 7 shows that with the 4% calm water power margin, all 20 Navy ship designs met their calm water speed goal.

The calm water powering margin may be included in the selected correlation allowance.

4.1.2 Resistance change due to the ship's displacement in service.

A method to consider the effects of changing displacement and trim on resistance is given in the ISO Standard 15016 and the ITTC Procedure 7.5-04-01-1.2 Procedure for the Analysis of Speed/Trial Data.

4.1.3 Resistance increase in waves

A method to consider the effect of waves on the resistance is given in the ISO Standard 15016 and the ITTC Procedure 7.5-02-07-02.2.

4.1.4 Resistance increase due to wind

A method to consider the effects of wind on the resistance is given in the ISO Standard 15016 and the ITTC Procedure 7.5-04-01-1.2.

4.1.5 Resistance increase due to shallow water operation

A method to consider the effects of shallow water on the speed loss is given in the ISO Standard 15016 and the ITTC Procedure 7.5-04-01-1.2.

An example of a method for correction of resistance for shallow water effect is found in ref 10.

4.2 Resistance Increase due to Aging Effects

4.2.1 Fouling

As fouling is a biological phenomenon whose occurrence is difficult to predict and control [1], there are many factors that influence a ship's degree of fouling. Among them, average voyage speed, types and age of antifouling paints, and average voyage duration were found to be highly significant accounting for 60% of variation in the available data. Of the three factors the most influential was the types and age of antifouling paints [2].The extent and rapidity of fouling is also significantly affected by the sea water temperature

By far the biggest causes of propeller surface roughness is fouling. A small roughness increase of the propeller causes large increases in the required power. In addition, propeller fouling can increase cavitation and noise radiation greatly [3]. Reference 8 provides analytic information on the influence of roughness on propeller performance.

There exists software to calculate hull roughness penalty which estimates the increase in power required over time for the four main antifouling technologies based on their average increase in physical hull roughness per year [1,4,5].

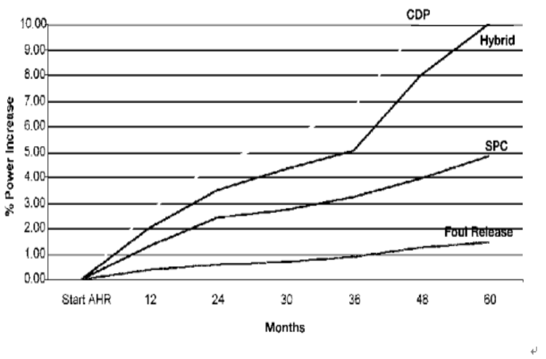

Figure 2:
Overall % power increase for a typical fast fine ship (e.g. Container Liner) vs. time for different antifouling types

The combined effects of physical roughness and the risk of fouling on ship power required to maintain ship speed is shown in Figure 2.

It has been shown that antifouling paints play a very main, even decisive, role in reducing ship fouling.

Up to now, there is no accurate and overall method to predict ship fouling. Only by studying a large number of ships over extended time periods can statistically reliable information be obtained. Utilizing different antifouling types is the mature measure, and further developing new and high effective, non-contaminative antifouling types is a most effective step to reduce ship fouling effect.

4.2.2 Roughness

Recently, it has been thought that the problem of fouling is much less important thanks to the great efficiency of modern antifouling paint such as TBT-SPC systems. However, alternatives to TBT-SPCs in preparation for the impending TBT ban of IMO (2001) have been examined. Candries (2001) compared the drag, boundary layer and roughness characteristics of the surfaces coated with new antifouling paint systems such as Tin-free SPC and Foul Release systems, which are considered as currently the most satisfactory alternatives.

Up to now, there is no accurate and overall method to predict the effect of ship roughness taking into account the use of the new antifouling paint systems.

4.3 Calculation of sea margin

4.3.1 Effect of thrust and torque from change of propeller submergence in waves

The instantaneous thrust and torque coefficients can be corrected for reductions in propeller submergence due to waves and ship motions according to the following approximations (adapted from Faltinsen and Minsaas, 1984) (ref. 11)

$$K_T = \beta . K_{TC} \qquad (1)$$

$$K_Q = \beta^{0.8} . K_{QC} \qquad (2)$$

K_{TC} and K_{QC} are the thrust and torque coefficients in calm water. Using the propeller open water diagram for the full scale propeller, K_{TC} and K_{QC} can be expressed as second-degree polynomials:

$$K_{TC} = a + b.J_0 + c.J_0^2 \qquad (3)$$

$$K_{QC} = d + e.J_0 + f.J_0^2 \qquad (4)$$

J_0 is the advance number of the propeller;

$$J_0 = V \cdot (1 - w) / (n \cdot D)$$

β is the thrust diminution factor, which can be approximated below in eq. (5) as:

$$\beta = \begin{cases} 1 - 0.675 \cdot (1 - 0.769 \cdot h/R)^{1.258} & , h/R < 1.3 \\ 1 & , h/R \geq 1.3 \end{cases}$$

Where h is the distance from the instantaneous free surface to the propeller centre and R is the propeller radius. The submergence ratio is approximated by superimposing the submergence in calm water operation h_0 with the relative motion amplitude $\eta_{R\zeta}$, disregarding the wave diffraction. The instantaneous value of the submergence ratio is then calculated as:

$$h/R = h_0/R + (\eta_{Ra} \sin(\omega_e t + \varepsilon))/R \qquad (6)$$

In relation to average speed loss in waves, the following average values of thrust and torque coefficients are used, again following Faltinsen and Minsaas (1984):

$$K_T = \bar{\beta} . K_{TC} \qquad (7)$$

$$K_Q = \bar{\beta}^{0.8} . K_{QC} \qquad (8)$$

Where $\overline{\beta}$ is found by averaging over a wave period.

The relative motion amplitude $\eta_{R\zeta}$ is typically found using a sea keeping calculation program, but can also be found from model tests in waves.

4.3.2 Calculating the added power in a regular wave

To find the added power in waves, the full scale propulsion point, including the effects of added resistance and thrust loss, is found from:

$$K_T^* = \frac{R_{T0} + R_{AW}}{\rho . n^2 . D^4 (1 - t)} \equiv const. J_0^2 \qquad (9)$$

In RAW, the wave and wind resistance, and resistance increase due to increase of roughness and fouling should also be included, so that the total added resistance is considered. The ship propulsion point J0 is found from the intersection between $K_T = \bar{\beta} . K_{TC}$ and K_T^*. When J_0 is known, K_{QC} is found from the ship propeller open water diagram, and K_Q is found from $K_Q = \bar{\beta}^{0.8} . K_{QC}$. The relative increase in ship propulsion power is now found as:

$$\frac{P_{DS}}{P_{DSC}} = \frac{K_Q}{K_{QC}} \left(\frac{J_{0C}}{J_C} \right)^3 = \frac{K_Q}{K_{QC}} . (1 - w)^3 \qquad (10)$$

where P_{DSC} is the shaft power in calm water, and K_{QC} is the propeller torque coefficient at the calm water propeller operating point.

4.3.3 Calculating the sea margin

To calculate the powering margin based on the method for calculating the added power in a given regular wave condition given as above, it is assumed that the waves are consistent with a narrow banded process and that they are long-crested. It is then legitimate to cut the wave record into successive regular wave parts with amplitude ζ and circular frequency ω. The probability density function for ζ and ω can, according to Sveshnikov (1966) (ref. 12) be written as:

$$f(\zeta,\omega)=\frac{\zeta^2}{\sigma^3\sqrt{2\pi}\sqrt{\omega_2^2-\omega_1^2}}\cdot\exp\left(-\frac{\zeta^2\left(\omega_2^2-2\omega_1\omega+\omega^2\right)}{2\sigma^2\left(\omega_2^2-\omega_1^2\right)}\right) \quad (11)$$

where σ^2 is the area under the wave spectrum curve. σ^2 can be related to the significant wave height: $\sigma^2 = H_{1/3}^2/16$. ω_1 and ω_2 are the circular frequency defined by the first and second moment of the wave spectrum. For a PM-spectrum, ω_1 and ω_2 can be calculated from the spectrum peak period according to:

$$\omega_1=\frac{2\pi}{T_1}=\frac{2\pi}{T_P}\cdot\frac{1.408}{1.086} \quad (12)$$

$$\omega_2=\frac{2\pi}{T_2}=\frac{2\pi}{T_P}\cdot 1.408 \quad (13)$$

The power increase in a given sea state ($H_{1/3}$ and T_P) and heading can be found as:

$$\frac{P_{DS}}{P_{DSC}}=\int_0^\infty d\zeta\int_{-\infty}^\infty d\omega . f(\zeta,\omega)\frac{K_Q}{K_{QC}}(1-w)^3 \quad (14)$$

To calculate the average power increase in a given route or set of routes, the probability p of each combination of $H_{W1/3}$, T_P and heading must be given. This probability is usually found from scatter diagrams for the areas of operation, and from a calculation of the relative period of time spent in the domain of each scatter diagram. The overall powering margin (*PM*) is now found as

$$PM=\left(\begin{array}{l}\sum_i\sum_j\sum_k p\left(H_{1/3}^{(i)},T_P^{(j)},\alpha^{(k)}\right)\\ \cdot\int_0^\infty\int_{-\infty}^\infty f(\zeta,\omega)\cdot\frac{K_Q}{K_{QC}}\cdot(1-w)^3\,d\omega d\zeta-1\end{array}\right)\cdot 100\% \quad (15)$$

Here $p\left(H_{1/3}^{(i)},T_P^{(j)},\alpha^{(k)}\right)$ is the probability for the occurrence of the given combination of $H_{1/3}$, T_P, and average wave heading α. Note that $\sum_i\sum_j\sum_k p\left(H_{1/3}^{(i)},T_P^{(j)},\alpha^{(k)}\right)=1$.

The definition of the operation, the operational area, and the time spent in each area should be discussed with the ship operator and agreed with the client.

4.4 Estimation of Powering Margins

In case either no model tests or other reliable performance data for the ship under trial conditions are available the following values, suggested by the major engine manufacturers, might be used to determine powering margins to consider operational, environmental and aging effects:

- Sea Margin: 15 to 25% on the specified MCR power

- Engine Operation Margin: 10 to 15% on the specified MCR power
- Light Running Margin: 5 to 7 % on the specified MCR power

Additional more specific recommendations for various trade routes are given in Ref 9, 13, and 14.

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