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GUIDELINES FOR DETERMINING MINIMUM PROPULSION POWER TO MAINTAIN THE MANOEUVRABILITY OF SHIPS IN ADVERSE CONDITIONS

1 The Marine Environment Protection Committee (the Committee), at its seventy-sixth session (10 to 17 June 2021), approved amendments to the 2013 *Interim Guidelines for determining minimum propulsion power to maintain the manoeuvrability of ships in adverse conditions* (MEPC.1/Circ.850/Rev.2) including the change of title to *Guidelines for determining minimum propulsion power to maintain the manoeuvrability of ships in adverse conditions*.

2 The *Guidelines for determining minimum propulsion power to maintain the manoeuvrability of ships in adverse conditions* are set out in the annex.

3 The Committee also agreed to keep the Guidelines under review and invited Member States and international organizations to report on the experiences gained in the implementation of the Guidelines to a future session of the Committee.

4 Member Governments are invited to bring the annexed *Guidelines for determining minimum propulsion power to maintain the manoeuvrability of ships in adverse conditions* to the attention of Administrations, industry, relevant shipping organizations, shipping companies and other stakeholders concerned.

5 This circular revokes MEPC.1/Circ.850/Rev.2.

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ANNEX

GUIDELINES FOR DETERMINING MINIMUM PROPULSION POWER TO MAINTAIN THE MANOEUVRABILITY OF SHIPS IN ADVERSE CONDITIONS

0 Purpose

The purpose of these Guidelines is to assist Administrations and recognized organizations in verifying that ships, complying with Energy Efficiency Design Index (EEDI) requirements set out in regulations on energy efficiency for ships, have sufficient installed propulsion power to maintain the manoeuvrability in adverse conditions, as specified in regulation 21.5 of chapter 4 of MARPOL Annex VI.

1 Definition

1.1 "Adverse conditions" mean sea conditions with the following parameters:

Significant wave height h_s, m	Peak wave period T_P, s	Mean wind speed V_w, m/s
6.0	7.0 to 15.0	22.6

JONSWAP sea spectrum with the peak parameter of 3.3 is to be considered for coastal waters.

1.2 The following adverse condition should be applied to ships defined as the following threshold value of ship size:

Ship length, m	Significant wave height h_s, m	Peak wave period T_P, s	Mean wind speed V_w, m/s
Less than 200	4.5	7.0 to 15.0	19.0
200 ≤ L_{pp} ≤ 250	Parameters linearly interpolated depending on ship's length		
More than 250	Refer to paragraph 1.1		

2 Applicability*

2.1 These Guidelines should be applied in the case of all new ships of types as listed in table 1 of appendix 1 required to comply with regulations on energy efficiency for ships according to regulation 21 of MARPOL Annex VI.

2.2 Notwithstanding the above, these Guidelines should not be applied to ships with non-conventional propulsion systems, such as pod propulsion.

2.3 These Guidelines are intended for ships in unrestricted navigation; for other cases, the Administration should determine appropriate guidelines, taking the operational area and relevant restrictions into account.

2.4 These Guidelines are applied in maximum summer load condition.

* These guidelines are applied to ships required to comply with regulations on energy efficiency for ships according to regulation 24 of MARPOL Annex VI (i.e. for those ship types as in table 1 of appendix 1 with the size of equal or more than 20,000 DWT).

3 Assessment procedure

3.1 The assessment can be carried out at two different levels as listed below:

.1 minimum power lines assessment; and

.2 minimum power assessment.

3.2 The ship should be considered to have sufficient power to maintain the manoeuvrability in adverse conditions if it fulfils one of these assessment levels.

4 Assessment level 1 – minimum power lines assessment

4.1 If the ship under consideration has installed power not less than the power defined by the minimum power line for the specific ship type, the ship should be considered to have sufficient power to maintain the manoeuvrability in adverse conditions.

4.2 The minimum power lines for the different types of ships are provided in appendix 1.

5 Assessment level 2 – minimum power assessment

5.1 The methodology for the minimum power assessment is provided in appendix 2.

5.2 If the ship under consideration fulfils the requirements as defined in the minimum power assessment, the ship should be considered to have sufficient power to maintain the manoeuvrability in adverse conditions.

6 Documentation

Test documentation should include at least, but not be limited to, a:

.1 description of the ship's main particulars;

.2 description of the ship's relevant manoeuvring and propulsion systems;

.3 description of the assessment level used and results; and

.4 description of the test method(s) used with references, if applicable.

APPENDIX 1

THE METHODOLOGY FOR THE MINIMUM POWER LINES ASSESSMENT

1 The minimum power line values of total installed MCR, in kW, for different types of ships should be calculated as follows:

Minimum Power Line Value = $a \times (DWT) + b$

where:

DWT is the deadweight of the ship in metric tons; and

a and *b* are the parameters given in table 1 for tankers, bulk carriers and combination carriers.

Table 1: Parameters a and b for determination of the minimum power line values for the different ship types

Ship type	a	b
Bulk carrier which DWT is less than 145,000	0.0763	3374.3
Bulk carrier which DWT is 145,000 and over	0.0490	7329.0
Tanker	0.0652	5960.2
Combination Carrier	see tanker above	

2 The total installed MCR of all main propulsion engines should not be less than the minimum power line value, where MCR is the value specified on the EIAPP Certificate.

APPENDIX 2

THE METHODOLOGY FOR THE MINIMUM POWER ASSESSMENT

1 Minimum Power Assessment is based on the solution of a one degree-of-freedom manoeuvring equation in longitudinal direction to demonstrate that the ship can move with the speed of 2.0 knots through water in wind and wave directions from head to 30 degrees off-bow for a situation of weather vaning. The assessment consists of the following steps:

.1 calculate the maximum total resistance in the longitudinal ship direction over wind and wave directions from head to 30 degrees off-bow;

.2 calculate corresponding required brake power and rotation speed of the installed engine, considering the resistance and propulsion characteristics of the ship including appendages; and

.3 check whether the required brake power does not exceed the maximum available brake power of the installed engine, defined according to the engine manufacturer data at the actual rotation speed of the installed engine.

2 The maximum total resistance is defined as sum of the resistance in calm-water at the 2.0 knots forward speed U and the maximum added resistance in seaway X_a over wind and wave directions from head to 30 degrees off-bow.

Requirement

3 To satisfy the requirements of Minimum Power Assessment, the required brake power P_B^{req} in the adverse conditions at the forward speed 2.0 knots through water should not exceed the available brake power of the installed engine P_B^{av} in the same conditions:

$$P_B^{req} \leq P_B^{av}$$

4 The required brake power P_B^{req} is calculated as

$$P_B^{req} = \frac{2\pi n_P Q}{\eta_s \eta_g \eta_R}$$

where

n_P (1/s) is the propeller rotation rate in the specified adverse conditions and the specified forward speed;

Q (N·m) is the corresponding propeller torque;

η_s is the mechanical transmission efficiency of the propeller shaft, approved for the EEDI verification;

η_g is the gear efficiency, approved for the EEDI verification; and

η_R is the relative rotative efficiency.

5 The available brake power P_B^{av} in the adverse conditions at the forward speed is defined as the maximum engine output at the actual rotation speed, taking into account maximum torque limit, surge/air limit and all other relevant limits in accordance with the engine manufacturer's data.

Definition of propulsion point

6 The propeller rotation rate n_P and the corresponding propeller advance ratio J in the adverse conditions at the forward speed are defined from the propeller open-water characteristics by solving the following equation:

$$\frac{K_T}{J^2} = \frac{T}{\rho u_a^2 D_P^2}$$

where

K_T	is the thrust coefficient of the propeller, defined from the propeller open-water characteristics;
T (N)	is the required propeller thrust;
ρ (kg/m^3)	is the sea water density, ρ = 1025 kg/m^3;
u_a (m/s)	is the propeller advance speed; and
D_P (m)	is the propeller diameter.

7 The corresponding torque of the propeller is calculated as

$$Q = K_Q \rho n_P^2 D_P^5$$

where

K_Q	is the torque coefficient of the propeller, defined from the propeller open-water characteristics.

8 The propeller advance speed u_a is calculated as

$$u_a = U(1 - w)$$

where

U (m/s)	is the forward speed 2.0 knots through water; and
W	is the wake fraction.

Definition of required propeller thrust

9 The required propeller thrust T is defined from the equation

$$T = \frac{X_s + X_a}{1 - t}$$

where

X_s (N)	is the resistance in calm-water at the forward speed including resistance due to appendages;
X_a (N)	is the maximum added resistance in seaway X_a; and
t	is the thrust deduction factor taking into account suction force on the ship hull due to propeller thrust.

Definition of calm water characteristics

10 The calm-water characteristics used for the assessment, such as calm-water resistance, self-propulsion factors and propeller open-water characteristics, are defined by the methods approved for EEDI verification, including:

.1 the calm-water resistance X_s, defined from the following equation:

$$X_s = (1 + k)C_F \frac{1}{2} \rho S U^2$$

where k is the form factor, C_F is the frictional resistance coefficient, ρ is sea water density, ρ = 1025 kg/m^3, S is the wetted surface area of the hull and the appendages and U is the forward speed;

.2 the thrust deduction factor t and wake fraction w at the forward speed and relative rotative efficiency η_R. Default conservative estimate may also be used for thrust deduction factor and wave fraction; t=0.1 and w=0.15 respectively; and

.3 the propeller open-water characteristics $K_T(J)$ and $K_Q(J)$.

Definition of added resistance

11 The maximum added resistance in seaway X_a is defined as sum of maximum added resistance due to wind X_w, maximum added resistance due to waves X_d and maximum added rudder resistance due to manoeuvring in seaway X_r over wind and wave directions from head to 30 degrees off-bow.

Definition of wind resistance

12 The maximum added resistance due to wind X_w is calculated as

$$X_w = 0.5 X'_w(\varepsilon) \rho_a v_{wr}^2 A_F$$

where

$X'_w(\varepsilon)$	is the non-dimensional aerodynamic resistance coefficient;
ε (degree)	is the apparent wind angle;
ρ_a (kg/m^3)	is the air density, $\rho_a = 1.2$ kg/m^3;
v_{wr} (m/s)	is the relative wind speed, $v_{wr} = U + v_w \cos\mu$;
v_w (m/s)	is the absolute wind speed, defined by the adverse conditions in paragraph 1 of these guidelines; and
A_F (m^2)	is the frontal windage area of the hull and superstructure.

13 The maximum added resistance due to wind X_w is defined as maximum over wind directions from head $\varepsilon = 0$ to 30 degrees off-bow $\varepsilon = 30$.

14 The non-dimensional aerodynamic resistance coefficient X'_w is defined from wind tunnel tests or equivalent methods verified by the Administrations or the Recognized Organizations. Alternatively, it can be assumed with $X'_w = 1.1$, as the maximum over wind directions from head to 30 degrees off-bow. If deck cranes are installed in the ship and the lateral projected area of the deck cranes is equal to or exceeds 10% of the total lateral

projected area above the waterline of the ship, $X'_w = 1.4$ should be assumed instead of $X'_w = 1.1$.

Definition of added resistance due to waves

15 The maximum added resistance due to waves X_d is defined in accordance with either

.1 expression

$$X_d = 1336(5.3 + U)\left(\frac{B \cdot d}{L_{PP}}\right)^{0.75} \cdot h_s^2$$

where

L_{PP} (m)	is the length of the ship between perpendiculars;
B	is the breadth of the ship;
d	is the draft at the specified condition of loading; and
h_s (m)	is the significant wave height, defined according to paragraph 1 of these guidelines.

This expression defines the maximum added resistance over wave directions from head to 30 degrees off-bow.

.2 or spectral method

$$X_d = 2\int_0^{\infty}\int_0^{2\pi}\frac{X_d(U,\mu',\omega')}{A^2}S_{\varsigma\varsigma}(\omega')D(\mu-\mu')\,d\omega'\,d\mu'$$

where

$\frac{X_d}{A^2}$ (N/m^2)	is the quadratic transfer function of the added resistance in regular waves and A is the wave amplitude;
$S_{\varsigma\varsigma}(\omega')$	is the seaway spectrum specified as JONSWAP spectrum with the peak parameter 3.3;
$D(\mu-\mu')$	is the spreading function of wave energy with respect to mean wave direction specified as cos^2-directional spreading;
ω' (rad/s)	is the wave frequency of component;
μ (rad)	is the encountered angle between ship and wave; and
μ' (rad)	is the direction of the wave component.

16 The maximum added resistance due to waves X_d is defined as maximum over wave directions from head $\mu = 0$ to 30 degrees off-bow $\mu = 30$. The range of peak wave periods T_P applied in the assessment is from $3.6\sqrt{h_s}$ to the greater one of $5.0\sqrt{h_s}$ or 12.0 seconds, with the step of peak wave period not exceeding 0.5 seconds.

17 The added resistance in short-crested irregular head waves may be regarded as the maximum added resistance over wave directions from head to 30 degrees off-bow, because in short-crested waves, the maximum added resistance over wave directions from head waves to 30 degrees off-bow occurs in head waves.

18 The spreading function $D(\mu-\mu')$ is defined as cos^2-directional spreading. Alternatively, long-crested seaway may be assumed with $D(\mu-\mu') = 1$; in this case, the

maximum added resistance due to waves X_d can be determined by multiplying the added resistance in long-crested irregular head waves by the correction factor 1.3, to consider that maximum of the added resistance in long-crested waves does not always correspond to head wave direction.

19 The quadratic transfer functions of added resistance in regular waves $\frac{X_d}{A^2}$ are defined from seakeeping tests or equivalent methods verified by the Administrations or the Recognized Organizations. Alternatively, the semi-empirical method specified in appendix of this document can be used.

Definition of added rudder resistance due to manoeuvring in seaway

20 The maximum additional rudder resistance due to manoeuvring in seaway X_r may be calculated for practicality in a simplified way as

$X_r = 0.03 \cdot T_{er}$, where T_{er} is the propeller thrust excluding X_r from T.

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APPENDIX TO APPENDIX 2

SEMI-EMPIRICAL METHOD FOR QUADRATIC TRANSFER FUNCTIONS OF ADDED RESISTANCE IN REGULAR WAVES

The method for the calculation of the quadratic transfer functions of added resistance give in this appendix can be applied to wave directions from head to beam. Therefore, this method can be used for obtaining the added resistance in short-crested irregular waves of the head mean wave direction.

The quadratic transfer functions of added resistance in regular head to beam waves $\mathrm{X}'_{\mathrm{d}} = \frac{\mathrm{X_d}}{\mathrm{A}^2}$, N/m^2, can be calculated as a sum

$$\mathrm{X}'_{\mathrm{d}} = \mathrm{X}'_{\mathrm{dM}} + \mathrm{X}'_{\mathrm{dR}}$$

of $\mathrm{X}'_{\mathrm{dM}}$, the component of added resistance due to motion (radiation) effect, and $\mathrm{X}'_{\mathrm{dR}}$, the component of added resistance due to reflection (diffraction) effect in regular waves.

The expression of X'_{dM} is given as follows:

$$\mathrm{X}'_{\mathrm{dM}} = 4\rho g \frac{B^2}{L_{pp}} a_1 a_2 \overline{\omega}^{b_1} e^{\frac{b_1}{d_1}(1-\overline{\omega}^{d_1})}$$

where

$$\overline{\omega} = \begin{cases} 2.142\sqrt[3]{k_{yy}}\sqrt{\frac{L_{pp}}{\lambda}}\left[1-\frac{0.111}{C_B}\left(\ln\frac{B}{d}-\ln 2.75\right)\right]\frac{(2-\cos\beta)}{3}(Fr+0.62) & \text{for } Fr < 0.1 \\ 2.142\sqrt[3]{k_{yy}}\sqrt{\frac{L_{pp}}{\lambda}}\left[1-\frac{0.111}{C_B}\left(\ln\frac{B}{d}-\ln 2.75\right)\right]\frac{(2-\cos\beta)}{3}Fr^{0.143} & \text{for } Fr \geq 0.1 \end{cases}$$

$$a_1 = 60.3C_B^{1.34}(4\mathrm{k_{yy}})^2\left(\frac{0.87}{C_\mathrm{B}}\right)^{-(1+\mathrm{Fr})\cos\beta}\left(\ln\frac{\mathrm{B}}{\mathrm{d}}\right)^{-1}\frac{(1-2\cos\beta)}{3} \quad \text{for } \frac{\pi}{2} \leq \beta \leq \pi$$

$$a_2 = \begin{cases} 0.0072 + 0.1676Fr & \text{for } Fr < 0.12 \\ Fr^{1.5}exp(-3.5Fr) & \text{for } Fr \geq 0.12 \end{cases}$$

for $C_B > 0.75$

$$\mathrm{b}_1 = \begin{cases} 11.0 & \text{for } \overline{\omega} < 1 \\ -8.5 & \text{elsewhere} \end{cases}$$

$$\mathrm{d}_1 = \begin{cases} 566\left(\frac{\mathrm{L_{PP}}}{\mathrm{B}}\right)^{-2.66} & \text{for } \overline{\omega} < 1 \\ -566\left(\frac{\mathrm{L_{PP}}}{\mathrm{B}}\right)^{-2.66} \times 6 & \text{elsewhere} \end{cases}$$

for $C_B \leq 0.75$

$$\mathrm{b}_1 = \begin{cases} 11.0 & \text{for } \overline{\omega} < 1 \\ -8.5 & \text{elsewhere} \end{cases}$$

$$\mathrm{d}_1 = \begin{cases} 14.0 & \text{for } \overline{\omega} < 1 \\ -566\left(\frac{\mathrm{L_{PP}}}{\mathrm{B}}\right)^{-2.66} \times 6 & \text{elsewhere} \end{cases}$$

where

$\beta = \pi - \mu$	is the wave direction, $\beta=\pi$ means head seas;
λ (m)	is the length of the incident wave;
B (m)	is the beam of the ship;
d (m)	is the draft of the ship; and
$\mathrm{k_{yy}}$	is the non-dimensional radius of gyration of pitch.

The expression of X'_{dR} is given as follows:

$$X'_{dR} = \sum_{i=1}^{4} {X'_{dR}}^{i}$$

where

${X'_{dR}}^{i}$ is the added resistance due to reflection/diffraction effect of the S_i waterline segment, as shown in Figure 1.

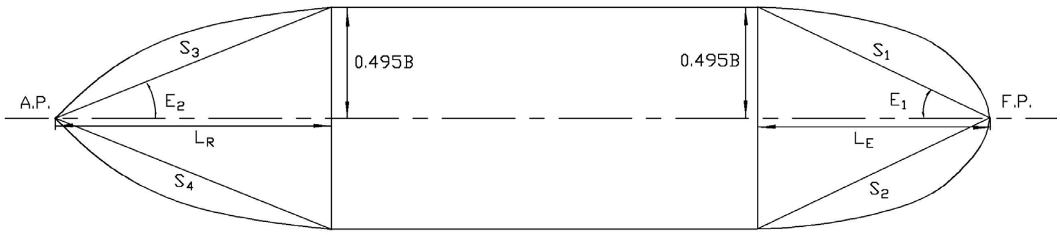

Figure 1: Sketch of the waterline profile of a ship and related definitions

when $E_1 \le \beta \le \pi$

$${X'_{dR}}^{1} = \frac{2.25}{4}\rho g B \alpha_{d^*}\left\{\sin^2(E_1-\beta) + \frac{2\omega_0 U}{g}\left[\cos E_1 \cos(E_1-\beta) - \cos\beta\right]\right\}\left(\frac{0.87}{C_B}\right)^{(1+4\sqrt{Fr})f(\beta)}$$

when $\pi - E_1 \le \beta \le \pi$

$${X'_{dR}}^{2} = \frac{2.25}{4}\rho g B \alpha_{d^*}\left\{\sin^2(E_1+\beta) + \frac{2\omega_0 U}{g}\left[\cos E_1 \cos(E_1+\beta) - \cos\beta\right]\right\}\left(\frac{0.87}{C_B}\right)^{(1+4\sqrt{Fr})f(\beta)}$$

when $0 \le \beta \le \pi - E_2$

$${X'_{dR}}^{3} = -\frac{2.25}{4}\rho g B \alpha_{d^*}\left\{\sin^2(E_2+\beta) + \frac{2\omega_0 U}{g}\left[\cos E_2 \cos(E_2+\beta) - \cos\beta\right]\right\}$$

when $0 \le \beta \le E_2$

$${X'_{dR}}^{4} = -\frac{2.25}{4}\rho g B \alpha_{d^*}\left\{\sin^2(E_2-\beta) + \frac{2\omega_0 U}{g}\left[\cos E_2 \cos(E_2-\beta) - \cos\beta\right]\right\}$$

where

ω_0 is the frequency of the incident wave;

α_{d^*} is the draft coefficient, calculated as

$$\alpha_{d^*} = \begin{cases} 0 & \text{for } \dfrac{\lambda}{L_{pp}} > 2.5 \\ 1 - \exp\left[-4\pi\left(\dfrac{d^*}{\lambda} - \dfrac{d^*}{2.5L_{pp}}\right)\right] & \text{for } \dfrac{\lambda}{L_{pp}} \le 2.5 \end{cases}$$

where for S_1 and S_2 segments

$$d^* = d$$

and for S_3 and S_4 segments

$$d^* = \begin{cases} \dfrac{d\left(4 + \sqrt{|\cos\beta|}\right)}{5} & \text{for } C_B \leq 0.75 \\ \dfrac{d\left(2 + \sqrt{|\cos\beta|}\right)}{3} & \text{for } C_B > 0.75 \end{cases}$$

$$f(\beta) = \begin{cases} -\cos\beta & \text{for } \pi - \mathrm{E}_1 \leq \beta \leq \pi \\ 0 & \text{for } \beta < \pi - \mathrm{E}_1 \end{cases}$$

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