No. 172
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(Rev.2 Jun 2025)

EEXI Implementation Guidelines

Introduction

The objective of these Guidelines for the Energy Efficiency Existing Index (EEXI) implementation is to provide guidance for applying attained EEXI requirements and to assist the verifier in their role of conducting surveys and certifications in accordance with the following IMO Resolutions:

- MEPC.350(78) "2022 Guidelines on the method of calculation of the attained energy efficiency existing ship index (EEXI)".
- MEPC.351(78) "2022 Guidelines on survey and certification of the attained energy efficiency existing ship index (EEXI)".
- MEPC.335(76) "2021 Guidelines on the shaft/engine power limitation system to comply with the EEXI requirements and use of a power reserve" as amended by MEPC.375(80) and MEPC.390(81)

These guidelines apply to all cases of Class Societies' participation in conducting the survey, and certifying EEXI in accordance with regulations 5, 6, 7, 8 and 9 of MARPOL Annex VI, particularly in cases where EEXI Technical File is submitted.

These guidelines are applicable to ships with a gross tonnage of 400 and above falling within the ship categories defined under regulation 2 of MARPOL Annex VI, to which Regulation 23 of MARPOL Annex VI applies.

The calculation and verification of EEXI according to these guidelines apply to:

1. each ship; and
2. each ship which has undergone a major conversion.

These guidelines don't apply to ships which have non-conventional propulsion, such as diesel-electric propulsion, turbine propulsion or hybrid propulsion systems, with the exception of cruise passenger ships with diesel-electric propulsion and LNG carriers having diesel-electric or steam turbine propulsion systems.

These guidelines don't apply to category A ships as defined in the Polar Code.

1 Capacity

- For ships where the capacity refers to deadweight, the deadweight of the ship should be taken as the one in the approved stability information or loading manual.
- For ships where the capacity refers to gross tonnage, the gross tonnage should be taken from the International Tonnage Certificate.

1.1 Multiple Loadlines

In case of a ship with multiple load line certificates or with a load line certificate containing multiple summer load lines, the maximum summer draught should be used to calculate and verify the required and attained EEXI.

No.

172
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2 Ship Type

The ship type should match the ship type mentioned in the IEE Certificate, except for LNG Carriers that were categorized as Gas Carriers (see paragraph 7.1) and Cruise Passenger Ships that were categorized as Passenger Ships under Phase 1 of EEDI. Some ship sizes may have only an *Attained EEXI* without a *Required EEXI* (e.g. a bulk carrier of 5,000 DWT is subject to the *Attained EEXI*, but not the *Required EEXI*). The reduction factor of the *Required EEXI* for Cruise passenger ships with conventional propulsion is not specified in MARPOL Convention at this stage. Cruise passenger ships with conventional propulsion are excluded from *Attained and Required EEXI*.

Cement carriers should be classified as Bulk Carriers within the scope of MARPOL Annex VI, unless otherwise agreed by the flag state, either in response to a specific owner’s request or as per previously issued general instructions.

If, upon flag instruction, the cement carrier is categorized differently from a bulk carrier, the following criteria must be verified:

• The Statement of Compliance for the carriage of solid bulk cargoes should list only “cement”.

• The Cargo Ship Safety Certificate * can’t indicate “bulk carrier” in the “type of ship”. The ship type specified on the certificate should correspond to the flag's instructions.

** or alternatively Cargo Ship Safety Construction Certificate and Cargo Ship Safety Equipment Certificate.*

3 EEXI Technical File

3.1 EEDI Technical File vs EEXI Technical File

The EEDI Technical File (EEDI TF) can be submitted for EEXI verification in case the *Attained EEDI*, as documented in the IEE Certificate regardless of the guideline applied at the time of construction, complies with *Required EEXI*. If verification is based on EEDI TF which has been approved by another Classification Society different from the one re-issuing the new IEE Certificate, the supporting documentation should include:

- Cover letter explaining that the ship has not undergone major modification as defined in MARPOL Annex VI, Reg.2.2.17.
- EEDI TF
- IEEC Supplement and/or Review/Approval Letter

3.2 Dealing with mistakes in EEDI Technical File

In case a mistake is found in a submitted EEDI TF, which was reviewed/approved at ship’s delivery, then for cases where a power limitation is implemented to satisfy the *Required EEXI*, the *Attained EEXI* will be calculated based on the corrected data and an EEXI Technical File is to be reviewed/approved.

3.3 Pre-EEDI SOVC Consideration

Irrespective of whether a pre-EEDI ship has a Statement of Voluntary Compliance (SOVC) or a Preliminary Approved EEDI TF, then the ship will still need to prepare an EEXI Technical File and the *Attained EEXI* will be reflected in the IEEC Supplement.

3.4 Approval of EEXI Technical File prior EPL/SHaPoLi on board

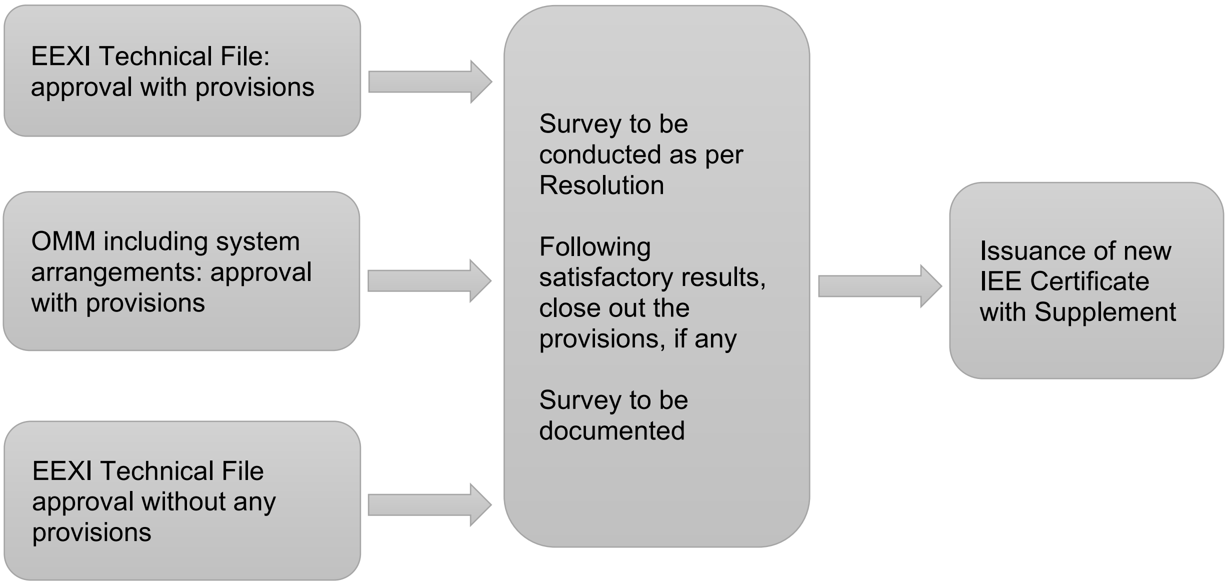
In case of EPL/SHaPoLi is intended to be implemented to satisfy the *Required EEXI*, the EEXI Technical File can be approved provided the following supporting documentation is included:

- SFC at new PME to be included. See Section 5 on SFC considerations.

- For ships subject to the NOx Technical Code: in case of change of engine critical settings or components, affecting NOx Technical File, then NOx Technical File to be amended.

3.5 EEXI Technical File & OMM Approval Process

The following flowchart explains the route to the issuance of the new IEE Certificate with supplement:



Note: Provisions refer to the requirement that the power limitation as described in the EEXI Technical File will be installed.

Unless advised otherwise by Flag Administration, the approval of EEXI Technical File & Onboard Management Manual (OMM) will be carried out based on the IMO resolutions as listed in Chapter 1 and these guidelines.

4 Ship speed V_{ref}

4.1 Transfer from Service/Design draft to EEXI draft

There are three different options to transfer a known speed/power curve from a specific draft to the EEXI draft that could be accepted:

1. Model tests/CFD calculation: Curves are determined for both drafts, so that the relation is known.

2. Admiralty equation: This well-known, experience-based method is based on the relation of the displacement of both drafts.

3. The formula in MEPC.350(78) para 2.2.3.4: A factor is calculated from the relation of the deadweight of both drafts.

Only model test or CFD calculation can be applied for the transfer from trimmed ballast draft to the EEXI draft. Admiralty equation and the formula in MEPC.350(78) para 2.2.3.4 can only be used for the transfer from design or service draft on even keel to EEXI draft.

Although MEPC.350(78) para 2.2.3.4 refers to the service power point only, the speed/power curve in design load draft should be considered for the transfer to the EEXI draft following the formula in MEPC.350(78) para 2.2.3.4.

Applying the actual speed/power curve from model tests or sea trials gives more accurate results than applying the cubic law as included in Admiralty equation and in the formula in MEPC.350(78) para 2.2.3.4 for the transfer from service speed power to P_{ME}.

The whole speed/power curve is shifted along the x-axis (speed) by multiplying each speed point with the constant factor calculated from Admiralty equation or the formula in MEPC.350(78) para 2.2.3.4 as given in the next paragraphs.

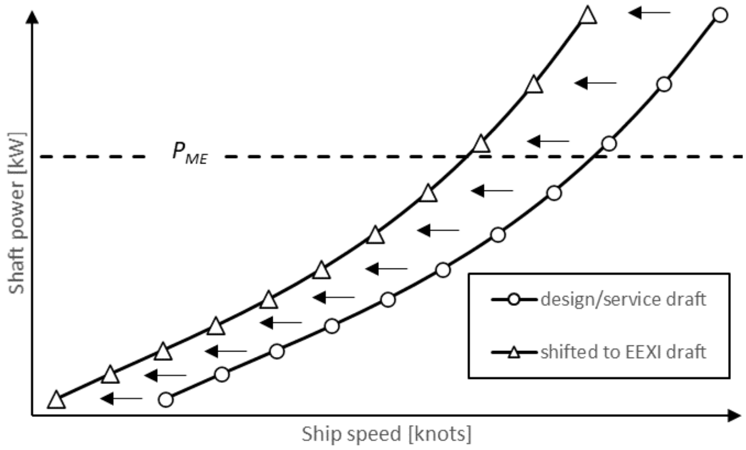


Figure 4.1 Shift of design/service draft model test curve to EEXI draft

Only if no curve is given in the report, then a cubic curve is drawn through the given point, transferred to EEXI draft and then the speed for the EEXI relevant power can be taken from this curve.

4.1.1 Ships other than bulk carriers, tankers and containerships

The Admiralty equation is a well-known formula for estimation of required power *P* depending on displacement Δ and ship speed *V*:

$$P = const \cdot \Delta^{\frac{2}{3}} \cdot V^3$$

This relation can be applied to calculate the influence of different draft on power and ship speed.

Case A

The curve at design load draft (service) is available. At this draft the speed V_d is derived at the P_{ME}. Subsequently, the V_{ref} at EEXI draft is calculated based on the formula below:

$$V_{ref} = \left(\frac{\Delta_{s,service}}{\Delta_{EEXI}}\right)^{\frac{2}{9}} * V_d$$

Case B

The curve at design load draft (service) is not available and only one service point is available ($P_{s,service}$, $V_{s,service}$). The V_{ref} at EEXI draft is calculated based on the formula below:

$$V_{ref} = \left(\frac{\Delta_{s,service}}{\Delta_{EEXI}}\right)^{\frac{2}{9}} * V_{s,service} * \left(\frac{P_{ME}}{P_{s,service}}\right)^{\frac{1}{3}}$$

Applicability criteria

Case	The following criteria to be assessed at P_{ME} in the original unlimited power case.
For case A	V_{ref} to be within the performance margin m_V of V_d, which should be 5% of V_d or one knot, whichever is lower. In case $(V_d - V_{ref}) > m_v$, then the Admiralty equation is not to be applied, instead $V_{ref,app}$ to be used.
For case B	V_{ref} to be within the performance margin m_V of $V_{s,service} * \left(\frac{P_{ME}}{P_{s,service}}\right)^{\frac{1}{3}}$ which should be 5% of the above or one knot, whichever is lower. When $(V_{s,service} * \left(\frac{P_{ME}}{P_{s,service}}\right)^{\frac{1}{3}} - V_{ref}) > m_v$, then the Admiralty equation is not to be applied, instead $V_{ref,app}$ to be used.

No.

172

(cont)

4.1.2 Bulk carriers and tankers

Admiralty equation not to be applied for bulk carriers and tankers. For bulk carriers and tankers, the formula in MEPC.350(78) para 2.2.3.4 with scale coefficient *k* as defined in MEPC.350(78) can be applied to transfer the speed-power curve from a draft that is below the maximum summer load draft. The term *DWT* for *k* factor definition refers to the DWT at the summer load draft (and not the $DWT_{s,service}$).

In case the curve at design load draft (service) is available, the speed V_d is derived at the P_{ME}. Subsequently, the V_{ref} at EEXI draft is calculated based on the formula below:

$$V_{ref} = k^{\frac{1}{3}} * \left(\frac{DWT_{s,service}}{Capacity}\right)^{\frac{2}{9}} * V_d$$

In case the curve at design load draft (service) is not available and only one service point is available ($P_{s,service}$, $V_{s,service}$), then the V_{ref} at EEXI draft is calculated based on the formula below:

$$V_{ref} = k^{\frac{1}{3}} * \left(\frac{DWT_{s,service}}{Capacity}\right)^{\frac{2}{9}} * V_{s,service} * \left(\frac{P_{ME}}{P_{s,service}}\right)^{\frac{1}{3}}$$

In MEPC.350(78) there is no limit for the DWT relation given when applying the formula in MEPC.350(78) para 2.2.3.4. The service draft to be on even keel, a trimmed draft cannot be applied for the formula in MEPC.350(78) para 2.2.3.4.

If more than one speed-power curve is available for a loaded draft on even keel (e.g. design draft and scantling draft before DWT increase), the curve of the draft that is closer to EEXI draft is to be applied for the transfer to EEXI draft. The even keel definition to be taken as the one described at the sea trial analysis ISO standard applicable at the time.

4.1.3 Containerships

Admiralty equation not to be applied for containerships. For containerships, the formula in MEPC.350(78) para 2.2.3.4 with scale coefficient *k* as defined in MEPC.350(78) can be applied to transfer the speed-power curve from a draft that is different from the EEXI draft. For containerships this different draft might be larger or smaller than the EEXI draft which is defined by *70% DWT*.

Service draft to be on even keel. There is no limitation for the relation of the DWT for both drafts, but trimmed conditions cannot be accepted.

If more than one speed-power curve is available for a loaded draft on even keel (e.g. design and scantling draft), the curve of the draft that is closer to EEXI draft is to be applied for the transfer to EEXI draft.

The V_{ref} at EEXI draft is calculated based on the containership size as per table below.

In the table below the term *DWT* refers to the DWT at the summer load draft (and not the $DWT_{s,service}$) and the term *Capacity* refers to MEPC.364(79) chapter 2.2.3.

No. 172 (cont)

Ship size applicability	Derivation of V_{ref}
Where: *($DWT_{s,service}$ / Capacity)* **<** *1.0* or where: *DWT ≤ 120,000 tonnes* and *($DWT_{s,service}$ / Capacity)* **>** *1.08* or where: *DWT* **>** 120,000 tonnes and *($DWT_{s,service}$ / Capacity)* **>** *1.12*	In case the curve at service draft is available, the speed V_d is derived at the P_{ME}. Subsequently, the V_{ref} at EEXI draft is calculated based on the formula below: $$V_{ref} = k^{\frac{1}{3}} * \left(\frac{DWT_{s,service}}{Capacity}\right)^{\frac{2}{9}} * V_d$$ In case the curve at service draft is not available and only one service point is available ($P_{s,service}$, $V_{s,service}$), then the V_{ref} at EEXI draft is calculated based on the formula below: $$V_{ref} = k^{\frac{1}{3}} * \left(\frac{DWT_{s,service}}{Capacity}\right)^{\frac{2}{9}} * V_{s,service} * \left(\frac{P_{ME}}{P_{s,service}}\right)^{\frac{1}{3}}$$
Where: *DWT > 120,000 tonnes* and *1.0 < ($DWT_{s,service}$ / Capacity) ≤ 1.12*	V_{ref} to be derived from the available curve at P_{ME}.
Where: *DWT ≤ 120000 tonnes* and *1.0 < ($DWT_{s,service}$ / Capacity) ≤ 1.08*	V_{ref} to be derived from the available curve at P_{ME}.

4.2 Change of EEXI draft

In case of change of EEXI draft:

- The new speed may be derived following the application of Admiralty equations as described earlier, or
- $V_{ref,app}$, or
- V_{ref} as per the formula in MEPC.350(78) para 2.2.3.4, extrapolating from design draft to new EEXI draft or from the old EEXI draft to new EEXI draft.

The maximum summer load draft deadweight is to be used, according to paragraph 2.2.4 of MEPC.364(79). In absence of the speed power curve at summer load draft, reference can be made to the so-called “scantling draft” speed power curve, which is to be adjusted as per above.

No.

172

(cont)

4.3 Extrapolation of speed/power curves

In case the final V_{ref} is below or above the range of speeds from the sea trial and/or model tests and/or numerical analysis, an extrapolation of the speed power curve can be used based on power law (power exponent) $e.g. P = a * V^b$.

4.4 Service Speed & Power Definition

As per discussions at the Correspondence Group before the MEPC76, based on submissions ISWG-GHG 7/2/31, the service speed and service power are defined as follows:

- Service Power = $\frac{NCR}{1+SM}$ or $\frac{CSR}{1+SM}$
- with *NCR* = *CSR*, as shown in the sea trials and/or model test report and/or ship's technical specification
- and *SM* stands for Sea Margin as per the sea trials and/or model test and/or ship's technical specification
- Service speed is the speed corresponding to the service power.

4.5 Sister ship V_{ref}

A sister ship is one built in a series by same shipyard with identical main dimensions, body lines, appendages, and propulsion system.

Results from model tests or numerical calculation can be considered valid also for the sister ships. the model test curve can be calibrated by the sea trial results only if the latter is adequately conducted and documented for the ship in accordance with the related Guidelines of IMO (e.g., in case only single run is available, the calibration is not feasible). The sea trial result from one ship of the series is not accepted for the calibration of the model test curve for the other sisters.

In a case of identical Propulsion Improvement Device retrofitted on sister ships, the percentage of power savings verified (*by either sea trials, or model tests, or numerical analysis, as applicable*) for one ship of the series can be applied to the sisters with means of deriving a new speed-power curve.

4.6 Pre-EEDI ship with Sea Trial Report

MEPC.351(78) states that sea trial results are acceptable when in accordance with "ISO 15016:2002 or equivalent". Equivalence is difficult to define, especially in regard of the fact that the 2015 version of the guideline follows a different approach than the 2002 version. For example, the BSRA method is similar with ISO 15016:2015 but different from ISO 15016:2002. The minimum requirement to a pre-EEDI sea trial report is that double runs were performed, and the results of the single runs can be identified.

For Pre-EEDI ships, the sea trial analysis report at the time, can be considered as valid supporting documentation for the EEXI calculation, even if the speed-power curve is uncorrected at a weather condition. In such case, a re-evaluation of sea trial report with regard to weather conditions is not acceptable. If the sea trial analysis report contains the speed-power curve from model tests, the V_{ref} derived from this curve would be acceptable.

No. 172 (cont)

4.7 Pre-EEDI ship with Sea Trial Report and Model Tests Report

In case the ship has a model tests report and a sea trial report based on ISO 15016:2002 or equivalent, then the EEXI calculation can be based on a speed-power curve from either the model tests report or the sea trial report.

4.8 Performance of new Sea Trials based on ISO 15016:2015

For both pre-EEDI and EEDI certified ships, in case of new sea trials, the analysis is to be based on ISO 15016:2015:

- Prior the sea trials, the sea trial plan to be submitted to Class for confirmation that it is according to ISO 15016:2015. Power settings may be selected with the view to potential power limitation.
- Sea trials to be witnessed by Class Surveyor and a witnessing statement to be issued.
- Sea trial analysis can be carried out only if relevant data at EEXI draft and sea trial draft are available from model tests and/or numerical calculation.
- The sea trial analysis software program utilized must be acceptable to Class.
- The EEXI Technical File will include the sea trial analysis and the Surveyor's statement are to be submitted as supporting documentation along with the EEXI Technical file.

4.9 PID retrofit with comparative model tests

In case of retrofitted propulsion improvement device (PID) where comparative model tests have been carried out, the V_{ref} derived from the following processes will be acceptable. Other processes where the propulsion power savings from comparative model tests are applied for the derivation of V_{ref}, may be acceptable to Verifier. For instance, when the original speed-power curve is available, then that can be applied instead of a cubic curve approach.

Case No	Available information	Process to be followed where applicable (see note)
1a	- Original sea trial design draft without PID - Comparative model tests EEXI draft with and without PID	- Apply the formula in MEPC.350(78) para 2.2.3.4 including the k scale factor to original sea trial design draft without PID → speed-power curve at EEXI draft without PID - Comparative model tests EEXI draft with and without PID → power savings percentages at different speeds - At these speeds, the estimated power curve at EEXI draft with PID is calibrated
1b	- Original sea trial design draft without PID - Comparative model tests EEXI draft with and without PID	- Comparative model tests EEXI draft with and without PID → power savings percentages at different speeds - At these speeds, the original sea trial at design draft is calibrated - Apply the formula in MEPC.350(78) para 2.2.3.4 including the *k* scale factor
2a	- Original sea trial design draft without PID	- Apply the formula in MEPC.350(78) para 2.2.3.4 including the k scale factor to original sea trial design draft without PID → speed-power curve at EEXI draft without PID

	- Comparative model tests design draft with and without PID	- Comparative model tests design draft with and without PID → power savings percentages at different speeds - At these speeds, the estimated power curve at EEXI draft with PID is calibrated
2b	- Original sea trial design draft without PID - Comparative model tests design draft with and without PID	- Comparative model tests design draft with and without PID → power savings percentages at different speeds - At these speeds, the original sea trial at design draft is calibrated - Apply the formula in MEPC.350(78) para 2.2.3.4 including the *k* scale factor
3	- Original sea trial with design draft without PID - Comparative model tests with design and EEXI drafts, with and without PID	- Derive deviation between the original sea trial design draft and the comparative model tests design draft WITHOUT PID → power deviation percentage at different speeds - The power deviation percentage is applied to the EEXI draft WITH PID from the comparative model tests
4	- Original sea trial with ballast draft without PID - Comparative model tests with ballast and design drafts, with and without PID	- Derive deviation between the original sea trial ballast draft and the comparative model tests ballast draft WITHOUT PID → power deviation percentage at different speeds - The power deviation percentage is applied to the design draft WITH PID from the comparative model tests - Apply the formula in MEPC.350(78) para 2.2.3.4 including the *k* scale factor
5	- Original sea trial with ballast draft without PID - Comparative model tests with ballast and EEXI drafts, with and without PID	- Derive deviation between the original sea trial ballast draft and the comparative model tests ballast draft WITHOUT PID → power deviation percentage at different speeds - The power deviation percentage is applied to the EEXI draft WITH PID from the comparative model tests
6	- No sea trials are available - Comparative model tests at design draft with and without PID	- Apply the model tests results at design draft with PID - Apply the formula in MEPC.350(78) para 2.2.3.4 including the *k* scale factor
7	- No sea trials are available - Comparative model tests at EEXI draft, with and without PID	- Apply the model tests results at EEXI draft

Note: for ship types other than bulk carriers, tankers and containerships where the formula in MEPC.350(78) para 2.2.3.4 including the *k* scale factor approach is not applicable, the formula per para 4.1.1should be applied

4.10 Propeller trimmed cases

Not all propeller trimmed cases are the same. Some cases are cropping off blades for balancing purposes (*usually after a damage of one or more blades*), whilst other cases may be pitch reduction to ease off the ship from a heavy operating range, i.e. to bring operation from the left of the propeller curve onto or to the right of the propeller curve. From an EEXI perspective:

- Trailing edge pitch reduction will not be considered as affecting the ship's performance. In other words, the original sea trial will be considered valid for EEXI calculations and supporting documentation.

- Cropping off blades remaining in the cropped condition, will be treated as "new propeller". In such case the original sea trial is no longer valid for EEXI calculation. This infers that as in the case of "new propeller" the Owner is to be required to submit supporting documentation, which could be new model tank tests and/or comparative numerical analysis. Alternatively, the V_{ref} will be based on the $V_{ref,app}$ formula which in most cases results to a lower conservative value.

4.11 Lower Friction Hull Coatings

In case of lower friction hull coatings, which are considered an EET (Energy Efficiency Technology) in Category A as per IMO MEPC.1/Circ 896, the V_{ref} may be determined as follows:

- for both pre-EEDI and EEDI ships by new sea trials which, if carried out at a draft other than EEXI draft, may be calibrated by the original model test or CFD without the effect of low friction coating

- for pre-EEDI ships by:

  - re-evaluation of model test or
  - model scale CFD calculation or
  - model test supplemented with CFD calculation following the requirements in the Annex of this document without any calibration by sea trials provided that the CFD are based on IACS Rec 173. In case of CFD, the new average hull roughness is not to be taken into account directly in the numerical simulations.

5 SFC and Fuel Conversion Factor considerations

In case of new type of fuel nozzles or optimization of injection:

- The new SFC specified by the main engine designer is acceptable, provided the approved NOx Technical File of the engine is amended accordingly.

In case of power limitation:

- In case where the main engine designer is involved, the main engine designer to provide *SFC* at new P_{ME}, based on interpolation from test bed measurements ISO corrected and this is to be shown in the main engine designer's power limitation report. The *SFC* value at P_{ME} to be used in the EEXI calculation is to be to the satisfaction of the Verifier.

- In case the main engine designer is not involved, the *SFC* value at P_{ME} to be used in the EEXI calculation to be confirmed by the Verifier.

No. 172 (cont)

The EEXI calculation should be based on the *SFC* value according to the following options:

Options	1	2	3	4
	Parent Engine ISO corrected is available	Member engine ISO corrected is available	Parent Engine not ISO corrected is available but corrected as best as possible based on available data (e.g. *LCV*)	Member engine not ISO corrected is available but corrected as best as possible based on available data (e.g. *LCV*)
Pre-EEDI with power limitation	Acceptable	Acceptable	Acceptable	Acceptable
Pre-EEDI without power limitation	To be used	Acceptable only in case of 1 is not available	Acceptable	Acceptable
EEDI with power limitation	Acceptable	Acceptable	Acceptable	Acceptable
EEDI without power limitation	Value used in EEDI TF to be used			

Notes:

- Not ISO-corrected values are acceptable only in case ISO corrected values are not available
- If fuel flow (e.g. gr/h) is only available (instead of SFC) this can be converted to SFC. This is equivalent to measured SFC.
- If two or more sets of measurements at the same rating are submitted for the various loads of the same engine, then the average to be used.
- If shop test results and/or NOx Technical file for ME or AE of individual ship and parent engine are not available, those of a sister ship can be used.
- Scrubber retrofits are not considered to affect EEXI calculation in terms of *SFC*.

The fuel used when determining corrected SFC corresponds to the value of the CF conversion factor, according to the table provided under paragraph “CF ; Conversion factor between fuel consumption and CO2 emission” of the IMO EEDI Calculation Guidelines. (Res. MEPC.364(79), as amended)

- In case SFC is corrected to ISO standard reference conditions with standard LCV of LFO (41,200 kJ/kg), SFC and the conversion factor, Cf (3.151), are to correspond to LFO.
- In case SFC is corrected to ISO standard reference conditions with standard LCV of MDO (42,700kJ/kg), SFC and the conversion factor, Cf (3.206), are to correspond to MDO.

No.

172

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6 Power Limitation

In MEPC.335(76) as amended by MEPC.375(80) and MEPC.390(81) IMO defines measures to limit the propulsion power to be considered in the EEXI calculation. It is distinguished between two different power limitation methods: EPL and SHaPoLi. EPL limits the engine power by restricting the fuel rack (mechanically controlled engines) or the fuel index (electronically controlled engines). Besides, EPL might directly limit the power in electronically controlled engines. SHaPoLi measures the shaft power with an independent torque meter and the limitation is based on this value. The power limitation as described in MEPC.335(76) as amended by MEPC.375(80) and MEPC.390(81) is defined as overridable.

All power limitation measures that are equivalent to power limitation as described in MEPC.335(76) as amended by MEPC.375(80) and MEPC.390(81) regarding limitation method, are to be regarded as overridable and P_{ME} is to be taken as 83% of MCR_{lim}, except for the case of overridable power limitation and shaft generators as detailed in 6.1.

This means in detail that all limitation of the fuel rack is considered in this way, independent from whether the crew can easily remove the blockage by breaking a seal or a tool is needed to remove the mechanical blockage.

A different method of power limitation is the permanent engine derating,. This limitation is considered in the EEXI calculation following MEPC.364(79) by replacing MCR with MCR_{lim}, meaning that P_{ME} is 75% of MCR_{lim}. In the same way a turbocharger cut-out is considered. If the turbocharger is dismantled or blocked with a bolted or welded plate, P_{ME} is 75% of the limited power. However, if the turbocharger is locked with a butterfly valve, even if sealed, then P_{ME} is 83% of MCR_{lim}.

When there is no modification on engine side, but the propulsion system is limited to a certain power, e.g. by propeller retrofit, P_{ME} is calculated according MEPC.364(79) chapter 2.2.5.2, option 2, meaning that P_{ME} is 75% of the power the propulsion system is limited to. Whilst this option was limited to propulsion arrangements with a PTO in the EEDI regime, the option is to be applied to all propulsion arrangements regarding EEXI.

The term “propeller retrofit” infers the case where shaft power limitation has or will be applied to avoid damage. The new maximum power after the propeller retrofit is documented in the propeller description or certificate. If for EEXI purposes, the power needs to be reduced below the new maximum power, then the case will be considered as overridable.

Overridable	Non-overridable (permanent during ship operation)
EPL or SHaPoLi (see Note 1)	Propeller retrofit with shaft power limitation to prevent damage on the propeller or shaft (see Note 2)
Turbocharger cut-out by butterfly valve (see Note 1)	Turbocharger dismantling (see Note 2)
	Turbocharger cut-out by removable blinding plate, e.g. bolted, or permanent blinding plate, e.g. welded (see Notes 2 and 3)
	Permanent adjustment of fuel index (see Notes 2 and 3)
	Permanent Engine derating (see Note 2)

No. 172 (cont)

Notes:

1. The 83% approach is applicable to overridable power limitation cases. Password protected systems are to be considered as overridable.

2. The 75% approach is applicable.

3. All the following provisions to be satisfied:
   a. Permanent physical sealing subject to annual survey.
   b. Description of the power limitation to be included in the EEXI Technical File.
   c. The limited power value is to be stated in the EEXI Technical File and if applicable, in the reissued EIAPP.

Depending on the power limitation method, different *MCR* values are to be considered in the EEXI formula according to the following table:

Parameter	**Source**		**Variable**	**Overridable** [1]	**Non-overridable other than propeller retrofit** [2]	**Non-overridable propeller retrofit** [3]
	Reference	**Chapter**		**function of**	**function of**	**function of**
P_{ME}	MEPC.350(78)	2.2.1	MCR_{lim}	83% MCR_{lim}		
	MEPC.364(79)	2.2.5.1			75% MCR_{lim}	
	MEPC.364(79)	2.2.5.2				75% MCR_{lim}
P_{AE}	MEPC.364(79)	2.2.5.6	*MCR*	*MCR*	MCR_{lim}	*MCR*
$f_{j,ICE}$	MEPC.364(79)	2.2.8.1	*MCR*	*MCR*	MCR_{lim}	*MCR*
$f_{j,RoRo}$	MEPC.350(78)	2.2.6	$V_{ref,F}$	75% *MCR*		
	MEPC.364(79)	2.2.8.3	V_{ref}		$P_{ME}= f(MCR_{lim})$	$P_{ME}= f(MCR_{lim})$
$f_{j,GeneralCargo}$	MEPC.364(79)	2.2.8.4	V_{ref}	$P_{ME}= f(MCR_{lim})$	$P_{ME}= f(MCR_{lim})$	$P_{ME}= f(MCR_{lim})$

Notes:

1. calculation following MEPC.350(78)

2. calculation following MEPC.364(79) by replacing *MCR* with MCR_{lim}

3. calculation following MEPC.364(79) chapter 2.2.5.2 option 2

6.1 PTO

For cases with shaft generator PTO and overridable power limitation, the formula for P_{ME} is as follows, unless it is decided otherwise at IMO.

$$P_{ME} = 0.75 * (MCR_{lim} - P_{PTO}) \text{ with } P_{PTO} \leq \frac{P_{AE}}{0.75}$$

If in this case a ShaPoLi is applied on the shaft between coupling out for electric power (reduction gear, shaft generator) and propeller, the power limit of the ShaPoLi is reduced by P_{PTO}, the power of the shaft generator which is available without limitation.

No.

172

(cont)

This means that the power limit of the ShaPoLi is $MCR_{lim} - P_{PTO}$ and accordingly P_{ME} is 75% of the power limit of the ShaPoLi.

6.2 Cruise passenger ships with diesel electric propulsion

For cruise ships with diesel electric propulsion, the propulsion power of the electric engines MPP is the relevant power for the EEXI calculation. A limitation of this electric power by technical means (e.g. restriction of current) is an EPL with relevant power MPP_{lim}. Alternatively, the propulsion power can be limited by measuring the shaft power with a SHaPoLi system.

The rated output of the electric propulsion motors *MPP* can be identified with the quantity noted $P_{PTI,Shaft}$ in MEPC.364(79) for the calculation of the EEXI value:

$$\sum P_{PTI(i)} = \frac{\sum(0.75 \cdot MPP(i))}{\eta_{PTI} \cdot \eta_{Gen}}$$

In case of power limitation, P_{PTI} is calculated as follows:

$$\sum P_{PTI(i)} = \frac{\sum(0.75 \cdot MPP_{lim}(i))}{\eta_{PTI} \cdot \eta_{Gen}}$$

V_{ref} is obtained at 75% of *MPP* or 75% of MPP_{lim}, respectively.

The diesel engines of the cruise ship are considered as auxiliary engines. The *SFC* is to be taken at 75% of *MCR* power of the diesel engines as the P_{AE} value is significantly different from total power used at normal seagoing (MEPC.364(79), chapter 2.2.7.1). The *SFC* is independent from potential limitation of the electric propulsion motors.

6.3 LNG carriers with diesel electric propulsion

For LNG carriers with diesel electric propulsion, the propulsion power of the electric motor $MPP_{(i)}$ is the relevant power for the EEXI calculation (see also 7.5). A limitation of this electric power by technical means (e.g. restriction of current) is an EPL with relevant power MPP_{lim}. Alternatively, the propulsion power can be limited by measuring the shaft power with a SHaPoLi system.

P_{ME} is calculated as follows:

$$P_{ME(i)} = 0.83 \cdot \frac{MPP_{(i)}}{\eta_{electrical}}$$

And in case of power limitation:

$$P_{ME(i)} = 0.83 \cdot \frac{MPP_{lim}}{\eta_{electrical}}$$

V_{ref} is obtained at 83% of *MPP* or 83% of MPP_{lim}, respectively.

No.

172
(cont)

The diesel engines of the LNG carrier are called main engines. The SFC_{ME} is taken at 75% of *MCR* power of the diesel engines. The SFC_{ME} is independent from potential limitation of the electric propulsion motor.

The same diesel engines of the LNG carrier are considered as auxiliary engines at the same time. The SFC_{AE} is taken at 75% of *MCR* power of the diesel engines.

In case of overridable power limitation, P_{AE} is to be kept constant as in the original unlimited power case.

6.4 Minimum Propulsion Power

For overridable cases:

- For pre-EEDI bulk carriers, tankers, and combination carriers of 20,000 tonnes deadweight and above, there is no requirement for Minimum Propulsion Power Assessment as per MEPC.1/Circ.850, unless the ship has undergone a major modification which is so extensive that the ship is regarded by the Administration as a newly constructed ship. In the latter case, the Minimum Propulsion Power Assessment to be verified according to MEPC.1/Circ.850 latest revision at the time of modification.

- For EEDI bulk carriers, tankers, and combination carriers of 20,000 tonnes deadweight and above, there is no need to reassess the Minimum Propulsion Power Assessment as per MEPC.1/Circ.850.

For non-overridable (permanent during ship operation) cases:

- For both EEDI and pre-EEDI bulk carriers, tankers, and combination carriers of 20,000 tonnes deadweight and above, the Minimum Propulsion Power Assessment is to be verified according to MEPC.1/Circ.850 latest revision at the time of modification.

6.5 Manoeuvring

For overridable cases:

- Ships that had a manoeuvering booklet, pilot card and wheelhouse poster before installing a power limitation should update the information in accordance with “Provision and display of manoeuvring information onboard ships “adopted by Resolution A.601(15) to state the limiting power and to provide the Master with the necessary information in the updated characteristics when the ship has all shaft and engine power available, and when shaft or engine power has been limited.

For non-overridable (permanent during ship operation) cases:

- The stopping times and distances, and the data of the turning circles as per SOLAS Reg. II-1/28.3 and Res.MSC.137(76) respectively, to be recorded on new trials

- Ships that had a manoeuvering booklet, pilot card and wheelhouse poster before installing a power limitation should update the information in accordance with “Provision and display of manoeuvring information onboard ships “adopted by Resolution A.601(15) to state the limiting power and to provide the Master with the necessary information in the updated characteristics when the ship has all shaft and engine power available, and when shaft or engine power has been limited.

No. 172 (cont)

6.6 Onboard Management Manual (OMM)

6.6.1. Regarding Resolution MEPC.335(76) as amended by MEPC.375(80) and MEPC.390(81), section 2.1.1.3 *"a control unit for calculation and limitation of the power transmitted by the shaft to the propeller(s)":* If this control is independent from the engine automation the following should be satisfied:

- Override or exceeding of the limitation is indicated by giving an alarm on the bridge, clearly informing the ship's master or officer in charge of navigational watch (OICNW):
    - In case of exceedance, the ship's master or OICNW to manually reduce the power within the limit;
    - In case of deliberate use of power reserve, data recording to commence automatically at the initiation of the alarm;
- Data recording device is to be installed and comply with MEPC.335(76) as amended by MEPC.375(80) and MEPC.390(81) as defined in section 2.1.1.2.
- In case of short-term unintentional exceedance of the power limit the system may inhibit the initiation of the exceedance alarm for up to a maximum of 5 minutes.

The OMM should clearly define this confirmation of the alarm as the deliberate action in agreement with requirement in chapter 2.2.1.

6.6.2. Regarding Resolution MEPC.335(76) as amended by MEPC.375(80) and MEPC.390(81), section 2.1.3 "*where technically possible and feasible, the SHaPoLi/EPL system should be controlled from the ships' bridge and not require attendance in the machinery space by ship's personnel*" : It is clarified that strictly speaking there is no mandatory requirement to retrofit a new control system from bridge provided in any critical operating condition *(such as adverse weather, piracy, traffic separated zone, manoeuvring),* other than normal seagoing, the engine control room will be manned as per ship's safety management system procedures. If applicable, this needs to be covered in the OMM.

6.6.3. A SHaPoLi / EPL system (or each sub system) in the context of section 2.2 of MEPC.335(76) as amended by MEPC.375(80) and MEPC.390(81), is considered tamper-proof if it prevents the following actions:

- Overriding the limitation without authorization, from any operating or control position;
- If applicable, intentionally disabling the alerting-monitoring system;
- In case of SHaPoLi, intentionally disabling sensors, control unit, data recording and processing devices.

6.6.4. Regarding Resolution MEPC.335(76) as amended by MEPC.375(80) and MEPC.390(81), section 2.2.5.2 "*for EPL, a fuel index sealing system or power limitation system which can indicate and record the use of unlimited mode."* : It is clarified that the indication and recording can be addressed via fuel index alarm set up and recording as per ship's existing systems, if suitable, provided these are stated in the OMM.

6.6.5. Regarding Resolution MEPC.335(76) as amended by MEPC.375(80) and MEPC.390(81), section 3.5 "*The reactivation or replacement of the SHaPoLi / EPL* *system should be confirmed (e.g. validation of mechanical sealing) with supporting evidence (e.g. engine power log, photo taken at the occasion of resetting the mechanical sealing) by the Administration or the RO at the earliest opportunity".* : In respect of the above requirement, confirmation may be based on supporting evidence submitted by the owner, if accepted by the Administration or the RO acting on its behalf.

6.6.6. The surveyor may issue the IEEC after the EPL/OMM survey where the Surveyor verifies that the arrangements indicated in the OMM are in place.

6.7 NOx

	Amendment to NOx TF	Change engine name plate	EIAPP certificate to be reissued	OMM	MPP (see note 2)
Overridable					
EPL or SHaPoLi	No (see note 1)	No	No	Yes	No
Turbocharger cut-out by butterfly valve	Yes	No	No	Yes	No
Non-overridable (permanent during ship operation)					
Propeller retrofit with restricted shaft power to prevent damage	No	No	No	No	Yes (Level 2 assessment is required)
Turbocharger dismantling Turbocharger cut-out by removable blinding plate, e.g. bolted, or permanent blinding plate, welded	Yes	Yes	Yes (see note 3)	No	Yes
Permanent adjustment of fuel index	No	No	No	No	Yes (Level 2 assessment is required)
Permanent Engine derating	New NOx Technical File	Yes	Yes	No	Yes

Notes:

1. For EPL or SHaPoLi, in case of change of engine critical settings or components, affecting NOx Technical File (NTF), then NTF to be amended.

2. Minimum Propulsion Power Assessment as per Circular 850 is applicable only to bulk carriers, tankers, and combination carriers of 20,000 tonnes deadweight and above.

3. Only in case dismantling of turbocharger results in changed NOx emission value (g/kWh).

6.8 Barred Speed Range

The following should apply to ensure the safety.

Overridable	EPL or SHaPoLi	- The RPM corresponding to New MCR Power after the power limitation is to be outside the Barred Speed Range limit (RPM) with an operational margin of 25%, based on IACS UR M68. - The Barred Speed Range as indicated in the Torsional Vibration Calculation document needs to be made available during the review of EEXI Technical File.
Non-overridable	Permanent adjustment of fuel index	
Overridable	Turbocharger cut-out by butterfly valve	- New Torsional Vibration Calculations to be carried out and reviewed/approved. - The new Barred Speed Range as indicated in the newly Torsional Vibration Calculation document needs to be made available during the review of EEXI Technical File. - The RPM corresponding to new MCR Power after the power limitation is to be outside the new Barred Speed Range limit (RPM) with an operational margin of 25%, based on IACS UR M68.
Non-overridable	Turbocharger dismantling Turbocharger cut-out by removable blinding plate, i.e., bolted, or permanent blinding plate, e.g. welded	
Non-overridable	Propeller retrofit with restricted shaft power to prevent damage	- The RPM corresponding to new MCR Power after the power limitation is to be outside the new Barred Speed Range limit (RPM) with an operational margin of 25%, based on IACS UR M68.
Non-overridable	Permanent Engine derating	

7 LNG Carriers

7.1 Treatment of LNG Carriers

EEXI requirements are to be applied based on the definitions in Regulation 2 of MARPOL Annex VI as they will stand upon EEXI entry into force, i.e. separate definitions and ship categories for gas carriers (regulation 2.26) and LNG carriers (regulation 2.38) (see also Chapter 2).

For the purposes of compliance with EEXI, a ship constructed or adapted and used for the carriage in bulk of liquefied natural gas (LNG) will be considered a LNG carrier regardless of the ship's delivery date and/or the ship type applied when her *Attained EEDI* was verified.

It is recognized that there may be confusion in case ship was delivered before 1 September 2019 with an IEEC stating Gas Carrier as ship type. For all other cases the ship is anyway considered as LNG Carrier.

No. 172 (cont)

Therefore, to clarify the case when an LNG Carrier delivered before 1 September 2019 with an IEEC stating Gas Carrier as ship type, the requirements are shown in the table below as applicable.

IEEC Gas Carrier delivered before 1 Sept 2019		
If there is EEDI TF and the *Attained EEDI* (as Gas Carrier in the original EEDI TF) is below the *Required EEXI* as LNG Carrier, then this is acceptable.	If there is EEDI TF and the *Attained EEDI* (as Gas Carrier in the original EEDI TF) is above the *Required EEXI* as LNG Carrier, then *Attained* and *Required EEXI* to be calculated as per LNG Carrier.	If there is no EEDI TF, then the *Attained* and *Required EEXI* to be calculated as per LNG Carrier.
At the re-issuance of the revised IEEC (following the verification of the ship's attained EEX)during the first annual/intermediate or renewal IAPP survey on or after 1st January2023, the IEEC ship type is to be changed to "LNG Carrier"		

7.2 Excessive natural boil off gas

The power from combustion of the excessive natural boil-off gas in the engines or boilers to avoid releasing to the atmosphere or unnecessary thermal oxidation, can be deducted from P_{ME}. This deduction is applied only:

- If excessive boil off gas is generated as a result of an installation of an overridable power limitation and
- if no reliquefication plan is installed.

In case of overridable power limitation, P_{AE} is to be kept constant as in the original unlimited power case. The auxiliary engine power required to reliquefy the excessive natural boil-off gas generated following an overridable power limitation doesn't need to be taken into account in the P_{AE} calculation.

7.3 Calculation of Attained EEXI for steam-turbine LNG Carriers

According to MEPC.350 (78) par. 2.2.1, the power from combustion of excessive natural boil-off gas in the engines or boilers to avoid releasing to the atmosphere or unnecessary thermal oxidation, is to be deducted from $P_{ME(i)}$ with the approval of the verifier.

The formula for the *Attained EEXI* for steam turbine LNG carriers becomes straightforward as according to MEPC.364(79) no separate term for the auxiliary power is needed:

$$Attained\ EEXI = \frac{P_{ME} \cdot SGC \cdot C_{F,LNG}}{DWT \cdot V_{ref}}$$

In case of power limitation and after deduction of the power from combustion of excessive natural boil-off gas, the formula changes as follows:

$$Attained\ EEXI = \frac{P_{ME\_revised} \cdot SGC(P_{ME\_lim}) \cdot C_{F,LNG}}{DWT \cdot V_{ref}(P_{ME\_lim})}$$

No. 172 (cont)

Nomenclature

MCR	Maximum Continuous Rating (Value of MCR specified on the Steam Heat Balance and Flow Diagram as Maximum Propulsion Power)
P_{ME}	0.83 MCR
V_{ref}	Reference Speed
SFC	Certified specific fuel consumption, given in g/kWh, of the assembly of boiler(s) and steam turbines, including the consumption (when P_{AE} is considered as 0(zero) according to MEPC.364(79), 2.2.5.6.5) relevant to auxiliary steam powered generators usually related to HFO with lower caloric value of 40,200 kJ/kg
SGC	Specific gas consumption, the result of SFC's correction to the value of LNG using the standard lower calorific value of the LNG (48,000 kJ/kg) at SNAME Condition (condition standard; air temperature 24°C, inlet temperature of fan 38°C, sea water temperature 24°C)
$C_{F,LNG}$	Conversion factor between fuel consumption and CO2 emission, for LNG, C_F=2.750 t-CO2/t-Fuel
MCR_{lim}	The new MCR to which the propulsion system must be limited to comply with the *Required EEXI*
P_{ME_lim}	$0.83\ MCR_{lim}$
R_f	Reduction factor *Rf (Rf < 1)* with $MCR_{lim} = R_f \cdot MCR$
P_{BOG}	Is the nominal power generated by consuming all boil-off gas from the cargo tanks
$P_{Excessive}$	The excessive power from combustion of excessive natural boil-off gas is defined as the difference between nominal power generated by consuming all boil-off gas from the cargo tanks and MCR_{lim}, $P_{Excessive} = P_{BOG} - MCR_{lim}$
$P_{ME\_revised}$	The relevant power value after deduction of $P_{Excessive}$. This value will be used in the calculation of the *Attained EEXI*, $P_{ME\_revised} = 0.83\ MCR_{lim} - P_{Excessive}$
BOR_{LNG}	Daily boil-off rate, in t/day, $BOR_{LNG} = 0.000864 \cdot V_{Cargo}$
V_{Cargo}	Cargo Tank Volume to be taken as the 100% net volume, as per capacity plan, in m^3

Based on the daily boil-off rate BOR_{LNG} and inputs from the ship's Steam Heat Balance and Flow Diagram, P_{BOG} can be determined. If $P_{BOG} > MCR$ then $P_{BOG} = MCR$.

No. 172 (cont)

Steam Heat Balance and Flow Diagram provides the Fuel Oil Consumption at Different Power Levels in kg/h (minimum 4 points) or the corresponding fuel oil rate in g/kWh. The Fuel Oil Consumption is converted to Daily LNG Consumption using the ratio of the Lower Calorific values as stated by IMO in MEPC.364(79).

Daily LNG consumption (tons LNG/day) is calculated at the different power levels as follows:

$$LNG\ Consumption = \frac{Fuel\ Oil\ Consumption\ (\frac{kg}{h})\cdot 24}{1000}\cdot\frac{LCV_{FO}}{LCV_{LNG}}\ (\frac{tons}{day})$$

P_{BOG} can be read from the relation between the calculated Daily LNG consumption and the corresponding power. Typical curves given as example in following figure.

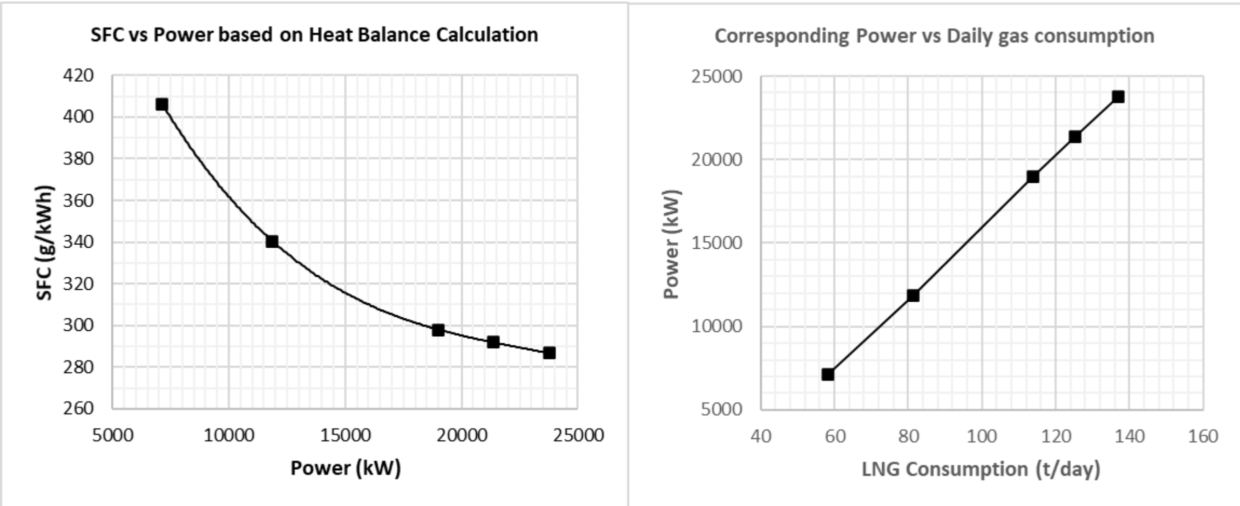

Figure 7.3.1 Example of SFC vs Power from heat balance and Corresponding Power vs Daily Gas Consumption curves for a typical steam ship.

Once the power of the ship's engine is limited, this results in a limited power, namely MCR_{lim}. The calculation of the MCR_{lim} is an iterative process as a reduction factor R_f (R_f < 1) should be applied to the documented *MCR* until the *Attained EEXI* is less than or equal to the *Required EEXI*.

7.4 SGC for steam-turbine LNG Carriers

Regarding the Specific Gas Consumption (SGC) calculation for the steam-turbine, when the SGC at varying loads is available at the Steam Heat Balance & Flow Diagram (with 3 or more load points), SGC is to be calculate using the Steam Heat Balance & Flow diagram. Otherwise, the SGC corrected from SFOC is to be instead.

The Specific Fuel Oil Consumption (SFOC) to be corrected to the value of LNG as per MEPC.364(79) para 2.2.7.2.2. The SFOC should be multiplied with the ratio of the lower calorific values (*LCV*) of the respective Fuel oil and LNG. Conversion of SFOC to SGC, is taken as follows:

$$SGC = SFOC\cdot\left(\frac{LCV_{(Fuel\ Oil)}}{LCV_{(LNG)}}\right)$$

No. 172 (cont)

7.5 $V_{ref,app}$ for steam-turbine LNG Carriers

The formula for steam-turbine LNG carriers is to be as follows:

$$V_{ref,app} = (V_{ref,avg} - m_V) \cdot \left[\frac{\sum MCR_{SteamTurbine}}{MCR_{avg}}\right]^{\frac{1}{3}}$$

and in case of power limitation:

$$V_{ref,app} = (V_{ref,avg} - m_V) \cdot \left[\frac{\sum MCR_{lim}}{MCR_{avg}}\right]^{\frac{1}{3}}$$

7.6 Calculation of Attained EEXI for Diesel Electric propulsion LNG Carriers

The below methodology considers LNG as the primary fuel. DFDEs are fitted with dual fuel auxiliary engines with no dedicated LNG fuel tanks.

The formula for the *Attained EEXI* for Diesel Electric LNG carriers is the below:

$$Attained\ EEXI = \frac{P_{ME} \cdot \left(C_{FME_{Gas}} \cdot SFC_{ME_{Gas}} + C_{FME_{Pilotfuel}} \cdot SFC_{ME_{Pilotfuel}}\right) + P_{AE} \cdot \left(C_{FAE_{Gas}} \cdot SFC_{AE_{Gas}} + C_{FAE_{Pilotfuel}} \cdot SFC_{AE_{Pilotfuel}}\right)}{Capacity . V_{ref}}$$

Simplified:

$$Attained\ EEXI = \frac{(P_{ME} + P_{AE}).\left(C_{FME_{Gas}}.SFC_{ME_{Gas}} + C_{FME_{Pilotfuel}}.SFC_{ME_{Pilotfuel}}\right)}{Capacity\ .V_{ref}}$$

This simplification is justified since DFDEs – do not have separate MEs & AEs but have a number of 4-stroke Dual Fuel Gensets all acting as MEs. Thus,

$\left(C_{FME_{Gas}}.SFC_{ME_{Gas}} + C_{FME_{Pilotfuel}}.SFC_{ME_{Pilotfuel}}\right)$ and $\left(C_{FAE_{Gas}}.SFC_{AE_{Gas}} + C_{FAE_{Pilotfuel}}.SFC_{AE_{Pilotfuel}}\right)$

are exactly the same.

In case of electric motor power limitation (see also section 6.3) and after deduction of the power from combustion of excessive natural boil-off gas, the formula changes as follows:

$$Attained\ EEXI = \frac{(P_{ME\_revised} + P_{AE}).\left(C_{FME_{Gas}}.SFC_{ME_{Gas}} + C_{FME_{Pilotfuel}}.SFC_{ME_{Pilotfuel}}\right)}{Capacity\ .V_{ref}(P_{MElim})}$$

Nomenclature

MCR	Maximum Continuous Rating
MPP	Rated output of motor (kW)
P_{ME}	*0.83 MPP / $\eta_{electrical}$*
V_{ref}	Reference Speed
$\eta_{electrical}$	0.913

No. 172 (cont)

SFC_{MEgas}	Specific fuel consumption, given in g/kWh, of the 4-stroke dual fuel gensets (considered as ME in this case), on gas mode at 75% of MCR
$SFC_{MEPilotfuel}$	Specific fuel consumption of pilot fuel for dual fuel ME at 75% MCR according to testbed result
C_F	Conversion factor between fuel consumption and CO2 emission, for LNG, C_F=2.750 t-CO2/t-Fuel
MPP_{lim}	The new MPP to which the motor must be limited to comply with the *Required EEXI*
P_{ME_lim}	$0.83\ MPP_{lim} / \eta_{electrical}$
R_f	Reduction factor *Rf (Rf < 1)* with $MCR_{lim} = R_f \cdot MCR$
P_{BOG}	Is the nominal power generated by consuming all boil-off gas from the cargo tanks
$P_{Excessive}$	The excessive power from combustion of excessive natural boil-off gas is defined as the difference between nominal power generated by consuming all boil-off gas from the cargo tanks and ($MPP_{lim} / \eta_{electrical} + P_{AE}$), $P_{Excessive} = P_{BOG} - (MPP_{lim} / \eta_{electrical} + P_{AE})$
$P_{ME\_revised}$	The relevant power value after deduction of $P_{Excessive}$, This value will be used in the calculation of the *Attained EEXI*, $P_{ME\ revised} = 0.83\ MPP_{lim} / \eta_{electrical} - P_{Excessive}$
BOR_{LNG}	Daily boil-off rate, in t/day, $BOR_{LNG} = 0.000864 \cdot V_{Cargo}$
V_{Cargo}	Cargo Tank Volume as per capacity plan, in m^3

Based on the daily boil-off rate BOR_{LNG} and inputs from the Gensets NOx Technical File (Parent Engine), P_{BOG} can be determined. The SFC_{MEgas} to be used is the weighted average corresponding to the 75% of the engines' MCR values.

$$P_{BOG} = \frac{BOR_{LNG} \cdot 1000000}{SFC_{MEgas} \cdot 24} \text{ [kW]}$$

If $P_{BOG} > ($ MPP / $\eta_{electrical} + P_{AE})$ then $P_{BOG} = ($ MPP / $\eta_{electrical} + P_{AE})$

Typical curve given as example in following figure.

No. 172 (cont)

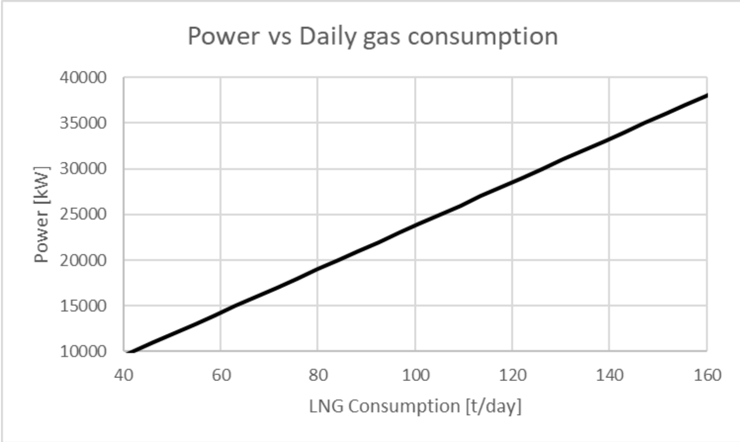

Figure 7.6.1 Example of daily LNG consumption vs Power for a typical DFDE ship.

Once the power of the ship's engine is limited, this results in a limited power, namely *MPP_{lim}*. The calculation of the *MPP_{lim}* is an iterative process as a reduction factor R_f ($R_f < 1$) should be applied to the documented MPP until the *Attained EEXI* is less than or equal to the *Required EEXI*.

7.7 Calculation of Attained EEXI for Dual Fuel conventional propulsion LNG Carriers

The below methodology considers LNG as the primary fuel. The formula for the *Attained EEXI* is the below:

$$Attained\ EEXI = \frac{P_{ME}\cdot\left(C_{FME_{Gas}}.SFC_{ME_{Gas}} + C_{FME_{Pilotfuel}}.SFC_{ME_{Pilotfuel}}\right) + P_{AE}\cdot\left(C_{FAE_{Gas}}.SFC_{AE_{Gas}} + C_{FAE_{Pilotfuel}}.SFC_{AE_{Pilotfuel}}\right)}{Capacity\ .V_{ref}}$$

In cases where overridable shaft or engine power limitation is installed and after deduction of the power from combustion of excessive natural boil-off gas, the formula changes as follows:

$$Attained\ EEXI = \frac{P_{ME\_revised}\cdot\left(C_{FME_{Gas}}.SFC_{ME_{Gas}lim} + C_{FME_{Pilotfuel}}.SFC_{ME_{Pilotfuel}\,lim}\right) + P_{AE}\cdot\left(C_{FAE_{Gas}}.SFC_{AE_{Gas}} + C_{FAE_{Pilotfuel}}.SFC_{AE_{Pilotfuel}}\right)}{Capacity\ .V_{ref}}$$

Nomenclature

MCR	Maximum Continuous Rating
P_{ME}	*0.75 MCR*
V_{ref}	Reference Speed
$SFC_{ME_{Gas}}$	Certified specific fuel consumption, given in g/kWh, of the main engine on gas mode at 75% of MCR
$SFC_{ME_{Gas}lim}$	Specific fuel consumption, given in g/kWh, of the main engine on gas mode at P_{ME_lim}

No.

172
(cont)

$SFC_{ME_{Pilotfuel}}$	Specific fuel consumption of pilot fuel for dual fuel ME at 75% *MCR* according to testbed result
$SFC_{ME_{Pilotfuel}\,lim}$	Specific fuel consumption of pilot fuel for dual fuel ME at P_{ME_lim}
C_F	Conversion factor between fuel consumption and CO2 emission, for LNG, C_F=2.750 t-CO2/t-Fuel
MCR_{lim}	The new value of *MCR* to which the engine or shaft must be limited to comply with the *Required EEXI*
P_{ME_lim}	*minimum of 0.83* MCR_{lim} and 0.75 MCR
P_{BOG}	Is the nominal power generated by consuming all boil-off gas from the cargo tanks
$P_{Excessive}$	The excessive power from combustion of excessive natural boil-off gas is defined as the difference between nominal power generated by consuming all boil-off gas from the cargo tanks and (MCR_{lim} + P_{AE}), $P_{Excessive} = P_{BOG} - (MCR_{lim} + P_{AE})$
$P_{ME\_revised}$	The relevant power value after deduction of $P_{Excessive}$, This value will be used in the calculation of the *Attained EEXI*, $P_{ME\ revised} = P_{ME\_lim} - P_{Excessive}$
BOR_{LNG}	Daily boil-off rate, in t/day, $BOR_{LNG} = 0.000864 \cdot V_{Cargo}$
V_{Cargo}	Cargo Tank Volume as per capacity plan, in m^3

Based on the daily boil-off rate BOR_{LNG} and inputs from the main engine NOx Technical File (Parent Engine), P_{BOG} can be determined. The SFC_{MEgas} to be used is the weighted average corresponding to the 75% of the engines' *MCR* values.

$$P_{BOG} = \frac{BOR_{LNG} \cdot 1000000}{SFC_{MEgas} \cdot 24} \text{ [kW]}$$

If $P_{BOG} > (MCR + P_{AE})$ then $P_{BOG} = MCR + P_{AE}$

7.8 Primary Fuel

The primary fuel of LNG Carriers with duel fuel engines (using cargo as fuel) is gas by default.

7.9 Reliquefaction Plants and compressors Considerations

Reliquification plants are to be considered according to MEPC.364(79) chapter 2.2.5.6.3 except when the full amount of BOG can be used for propulsion or auxiliary engines (see also 7.2). The following parameters can be sourced from the respective documents:

No. 172 (cont)

Parameter	**Sourcing document**
$COP_{cooling}$ is the coefficient of design performance of reliquefaction	Typically, 0.166 for *$COP_{cooling}$* is used according to 2.2.5.6.3.1 of MEPC.364(79). Alternatively, a value calculated by the manufacturer and verified by the administration or RO according to the regulation 2.2.5.6.3.1 of MEPC.364(79).
$R_{reliquefy}$ is the ratio of boil-off gas (BOG) to be re-liquefied to entire BOG **$R_{reliquefy} = BOG_{reliquefy} / BOG_{total}$**	$BOG_{reliquefy}$ and density of BOG are derived from the ship's technical specification. In case of overridable power limitation, **$BOG_{reliquefy}$** is to be kept constant as in the original unlimited power case.
COP_{comp} is the design power performance of compressor	Typically, 0.33 is used according to the regulation 2.2.5.6.3.2 of MEPC.364(79). Alternatively, a value calculated by the manufacturer and verified by the administration or RO according to the regulation 2.2.5.6.3.2 of MEPC.364(79).

Annex

Assessment of Lower Friction Hull Coatings for the purpose of deriving the V_{ref} in the framework of the EEXI Regulation based on re-evaluation of model tests

1. Application

This Annex contains requirements for the derivation of reference speed (V_{ref}) exclusively in the framework of the EEXI (see paragraph 4.11 of this document)

If a propulsion improvement device has been retrofitted and lower friction hull coatings are also applied, then:

- If a new speed-power curve has been derived for the propulsion improvement device based on CFD analysis or comparative model tests, then the impact of the lower friction hull coatings can be derived on the basis this Annex.
- If a new speed-power curve has been derived on the basis of new sea trials, then this Annex is not applicable.

If a vessel's EEXI calculation has been derived based on this Annex, any change (e.g. the same or equivalent lower friction coating is not used at the repainting) will be evaluated in a case-by-case basis.

If a vessel for which the EEXI calculation has been derived on the basis of this Annex and subsequently a hull and/or rudder and/or propeller retrofit is carried out, then the vessel's EEXI will have to be verified based on the principles established in these guidelines

2. Supporting Guidelines

The following supporting guidelines are to be followed and referred to when performing calculations.

- 75-02-03-01.4- 1978 ITTC Performance Prediction Method - Effective Date 2008 – Rev 01
- 75-02-03-01.4- 1978 ITTC Performance Prediction Method - Effective Date 1999 – Rev 00

3. Witnessing and acceptance of measurements

- New hull roughness measurements should be carried out according to the standard of NACE SP0616-2022 "Standard for Hull Roughness Measurements on Ship Hulls in Dry Dock".

- The measurements should be carried out by a third-party measurement company. The measurement company should be accepted only if the company can demonstrate to verifier their previous experience with such measurements and reports and to confirm that there is no relationship between the measurement company and the coating manufacturer.

- The measurements should be carried out at drydock for the hull surface corresponding to the design or scantling or EEDI/EEXI draft as covered in the model tests report.

- The hull surface is to be divided to at least 100 patches with twelve Rt50 values taken per patch. Rt50 averages one min-max peak within a one directional distance of 50 mm. The mean hull roughness (MHR) of each patch is to be calculated, which in turn should result to an average hull roughness (AHR).
- A report is to be prepared and submitted to the verifier's attending surveyor, including details on the measurements and final average hull roughness value for the draft under consideration.
- The verifier's attending surveyor should confirm that the measurements have been carried out as per above. In case there are patches lacking homogeneity, the measurements of such patches should be repeated to the satisfaction of the attending surveyor.

  A witnessing statement, or similar, should be issued by the verifier's attending surveyor accepting the measurements report.

4. Additional documentation to be included in the EEXI Technical File

- Model tests report
- CFD report (In case of re-evaluation of model scale CFD)
- Hull Roughness Measurements Report, including the derived AHR and acceptance of the measurements report by verifier's attending surveyor.
  - For cases where the measurements report was carried out prior the date of this IACS PR, the measurements report will be accepted provided the measurement company can demonstrate previous experience with such measurements and reports and to confirm that there is no relationship between the measurement company and with the coating manufacturer.
  - For cases where the measurements report is carried out after the date of this IACS PR, the measurements will need to be witnessed by verifier's attending Surveyor at drydock.
  - For cases where the measurements report was carried out prior the retrofitting of a rudder and/or propeller, the measurements report will be accepted if the measurements were carried out in accordance with the previous paragraphs
- Calculation report of new V_{ref} as per applicable method, or calculation report by the towing tank facility where the original model tank tests were conducted. The calculation report is to detail the calculation process, the intermediate numerical results and the final speed-power curves, for both the original coating and the low friction coating.
  - For model tests conducted on the basis of ITTC 3D method, i.e. use of Hughes-Prohaska form factor, the calculation method as described in section 5 should be applied.
  - For model tests conducted on the basis of ITTC 2D method, the calculation method as described in section 6 should be applied.

No. 172 (cont)

5. Calculation of V_{ref} in case the model tests are conducted with the 3D Method

5.1. Required Data

In order to estimate V_{ref} after roughness modification, the following are required:

- Model test report, including EEDI draft full-scale power prediction
- Full-scale propeller open water characteristics
- Relevant model-ship dimensions: $L_{BP}, L_{WL}, B, T, C_b, A_T$ (Transverse Wind Area) , S (Wetted Surface Area).

If EEDI draft model test data are not available, this method can be applied on design draft and already known formulas to extrapolate to EEDI draft can be applied – see, e.g., MEPC.350(78) – 2.2.3.4.

5.2. Model tests standard procedure

The standard model test procedure is to measure R_{TM} in model scale and calculate C_{TM} using the definition $C_{TM} = R_{TM}/(0.5\rho_M V_M^2 S_M)$, where R_{TM}, ρ_M, V_M, S_M are respectively the total model resistance, the basin water density, the model speed and the model wetted surface area.

Then, C_{FM} is calculated using (1) as per ITTC 57 Model-Ship correlation line:

$$C_{FM} = \frac{0.075}{(log_{10}(Re_M) - 2)^2} \tag{1}$$

Where Re_M is the Reynolds number defined as $Re_M = V_M \cdot L_{WL}/(\lambda \cdot \nu_M)$, $L_{WL}$is the length at the waterline, λ is the scale ratio and ν_M is the kinematic viscosity coefficient of the basin water.

Then, the residual coefficient is calculated as follows:

$$C_{WM} = C_{TM} - (1 + k)C_{FM} \tag{2}$$

Where k is the form factor. C_W is introduced and $C_W = C_{WS} = C_{WM}$ based on Froude's assumption. The residual coefficient denomination C_W corresponds to the nomenclature of *75-02-03-01.4- 1978 ITTC Performance Prediction Method - Effective Date 2008 – Rev 01* or later, but could be renamed C_R to be in line with the nomenclature of *75-02-03-01.4- 1978 ITTC Performance Prediction Method - Effective Date 1999 – Rev 00.*

The frictional coefficient in full scale C_{FS} is calculated as

$$C_{FS} = \frac{0.075}{(log_{10}(Re_S) - 2)^2} \tag{2}$$

Where Re_S is the Reynolds number defined as $Re_S = V_S \cdot L_{WL}/\nu_S$, V_S is the vessel speed and ν_S is the kinematic viscosity coefficient of the sea water.

The total resistance coefficient in full scale C_{TS} is defined as:

$$C_{TS} = \frac{R_{TS}}{0.5 \cdot \rho_S \cdot {V_S}^2 \cdot S_s} \tag{4}$$

Where R_{TS}, ρ_S, S_s are respectively the total resistance, the sea water density and the vessel wetted surface area.

The calculation of C_{TS} depends on which revision of *75-02-03-01.4- 1978 ITTC Performance Prediction Method* the calculation is based on.

5.2.1. Original towing tank test according to ITTC 78 - Rev00

In case the 3D model tests have been performed as per *75-02-03-01.4- 1978 ITTC Performance Prediction Method - Effective Date 1999 – Rev 00*, then the total resistance coefficient is calculated as follows:

$$C_{TS} = \frac{S_S + S_{BK}}{S_S}\Big((1+k) \cdot C_{FS} + \Delta C_{F,1999}\Big) + C_W + C_{AA} \tag{5}$$

Where:

k is the form factor

C_{AA} is the air resistance coefficient

S_{BK} is the bilge keel surface area

$\Delta C_{F,1999}$ is the roughness allowance calculated with the formula below

$$\Delta C_{F,1999} = \left[105(k_s/L_{WL})^{\frac{1}{3}} - 0.64\right] \times 10^{-3} \tag{6}$$

where k_S is the hull roughness value.

5.2.2. Original towing tank test according to ITTC 78 - Rev01 or later

In case the 3D model tests have been performed as per *75-02-03-01.4- 1978 ITTC Performance Prediction Method - Effective Date 2008 – Rev 01* or later, then the total resistance coefficient is calculated as follows:

$$C_{TS} = \frac{S_S + S_{BK}}{S_S}\Big((1+k) \cdot C_{FS} + \Delta C_{F,2008} + C_A\Big) + C_W + C_{AA} \tag{7}$$

Where:

k is the form factor

C_{AA} is the air resistance coefficient

S_{BK} is the bilge keel surface area

No. 172 (cont)

$\Delta C_{F,2008}$ is the roughness allowance calculated with the formula below

$$\Delta C_{F,2008} = 0.044\left[\left(\frac{k_S}{L_{WL}}\right)^{\frac{1}{3}} - 10 \cdot {Re_S}^{-\frac{1}{3}}\right] + 0.000125 \quad (8)$$

and C_A is provided by towing tank facility (refer to ITTC 78, Rev. 01 for more details).

5.3. Procedure to calculate effective power P_E after roughness modification (Resistance Part)

Whether the original C_{TS} was calculated with *75-02-03-01.4- 1978 ITTC Performance Prediction Method - Effective Date 1999 – Rev 00* or *with 75-02-03-01.4- 1978 ITTC Performance Prediction Method - Effective Date 2008 – Rev 01* or later, the new total resistance coefficient C_{TS_1} after roughness modification is calculated with:

$$C_{TS_1} = C_{TS} + \frac{S_S + S_{BK}}{S_S}\left(\Delta C_{F,2008}(k_{S_1}) - \Delta C_{F,2008}(k_{S_0})\right) \quad (9)$$

Where:

k_{S_0} is the original value of hull roughness given in the original model test report

k_{S_1} is the AHR measured on the ship after application of low-friction coatings, as mentioned in the measurement report.

$\Delta C_{F,2008}(k_{S_0})$ is the roughness allowance with formula (8) using k_{S_0}

$\Delta C_{F,2008}(k_{S_1})$ is the roughness allowance with formula (8) using k_{S_1}

The total resistance readily follows from definition:

$$R_{TS_1} = C_{TS_1} \cdot 0.5\rho_S V_S^2 S_S \quad (10)$$

Subsequently, the effective power P_{E_1} is calculated:

$$P_{E_1} = C_{TS_1} \cdot 0.5\rho_S V_S^3 S_S \quad (11)$$

5.4. Procedure to calculate new delivered power P_D after roughness modification (Self-Propulsion part)

The propeller will run at a different advance coefficient $J = V_A/n_S D_S$, where $V_A = V_S(1 - w_{TS})$, n_S is the propeller revolutions and D_S is the propeller diameter. To find the new value of J, we consider the following:

$$K_T/J^2 = \frac{T/\rho_S n_S^2 D_S^4}{V_A^2/n_S^2 D_S^2} = \frac{R_{TS_1}}{\rho_S(1-t)(1-w_{TS})^2 V_S^2 D_S^2} = C \Rightarrow K_T = CJ^2 \quad (3)$$

where K_T is the thrust coefficient.

For the calculation of K_T/J^2, the wake fraction at full scale w_{TS} is to be recalculated to adjust for new roughness value.

In case the 3D model tests have been performed as per *75-02-03-01.4- 1978 ITTC Performance Prediction Method - Effective Date 2008 – Rev 01*, then the new full-scale wake fraction is to be calculated as follows:

$$w_{TS_1} = (t + w_R) + (w_{TM} - t - w_R) \times \frac{(1+k)C_{FS} + \Delta C_{F,2008}\left(k_{S_1}\right)}{(1+k)C_{FM}} \tag{4}$$

Where w_{TM} is the wake fraction at model scale and w_R stands for the effect of rudder on the wake fraction. If there is no estimate for w_R, the standard value of $w_R = 0.04$ is to be used. If $w_{TS_1} > w_{TM}$, then $w_{TS_1} = w_{TM}$.

In case the towing tank facility which performed the original model test did not use the *75-02-03-01.4- 1978 ITTC Performance Prediction Method - Effective Date 2008 – Rev 01*, then the new full-scale wake fraction is to be calculated as follows:

$$w_{TS_1} = w_{TS_0} \frac{w_{TS_1,calc}}{w_{TS_0,calc}} \tag{5}$$

where w_{TS_0} is the full-scale prediction for the wake fraction from the original towing tank tests, and $w_{TS_0,calc}$, $w_{TS_1,calc}$ are the values calculated through (13) using initial and new AHR, respectively. If $w_{TS_1} > w_{TM}$, then $w_{TS_1} = w_{TM}$.

Factor C in equation (12) can be easily calculated for every model test speed, using the total resistance value from (10).

To find the new value of J, the following equation must be solved:

$$K_T(J) = CJ^2 \tag{6}$$

To analytically solve (15) with respect to J, the thrust coefficient curve is approximated with 2nd-degree polynomial regression: $K_T(J) \approx \bar{K}_T = aJ^2 + bJ + k$. Thus:

$$aJ^2 + bJ + k = CJ^2 \Rightarrow (a - C)J^2 + bJ + k = 0 \tag{7}$$

The solutions to (16) are:

$$J = \frac{-b \pm \sqrt{Det}}{2(a - C)}, Det = b^2 - 4(a - C)k \tag{8}$$

Rejecting one of the solutions (it turns out to be negative), we now have the new advance coefficient value J_1. For each speed, the new delivered power is calculated as follows:

$$P_{D_1}(V) = \frac{P_{E_1}(V)}{\eta_D} = \frac{P_{E_1}(V)}{\eta_0(V, J_1)\eta_H(V)\eta_R(V)} \tag{9}$$

where $\eta_H(V) = (1 - t)/\left(1 - w_{TS_1}\right)$ and w_{TS_1} is calculated according to (13) or (14).

5.5. Calculation of new V_{ref} value

New brake power prediction is $P_{B_1} = P_{D_1}/\eta_S$, η_S: shaft efficiency. From the new speed-power prediction curve, $V_S - P_{B_1}$, substituting $P_{B_1} = P_{ME}$, we get the new prediction for the new reference speed $V_{ref,1}$.

6. Calculation of V_{ref} in case the model tests are conducted with the 2D Method

6.1. Required Data

In order to estimate V_{ref} after roughness modification, the following are required:

- Model test report, including EEDI draft full-scale power prediction
- Full-scale propeller open water characteristics
- Relevant model-ship dimensions: $L_{BP}, L_{WL}, B, T, C_b, A_T$ (Transverse Wind Area) , S (Wetted Surface Area).

If EEDI draft model test data are not available, this method can be applied on design draft and already known formulas to extrapolate to EEDI draft can be applied – see, e.g., MEPC.350(78) – 2.2.3.4.

6.2. Model tests standard procedure

The standard model test procedure is to measure R_{TM} in model scale and calculate C_{TM} using the definition $C_{TM} = R_{TM}/(0.5\rho_M V_M^2 S_M)$, where R_{TM}, ρ_M, V_M, S_M are respectively the total model resistance, the basin water density, the model speed and the model wetted surface area.

Then, C_{FM} is calculated using (19) as per ITTC 57 Model-Ship correlation line:

$$C_{FM} = \frac{0.075}{(log_{10}(Re_M) - 2)^2} \tag{109}$$

Where Re_M is the Reynolds number defined as $Re_M = V_M \cdot L_{WL}/(\lambda \cdot \nu_M)$, $L_{WL}$is the length at the waterline, λ is the scale ratio and ν_M is the kinematic viscosity coefficient of the basin water.

Then, the residual coefficient is calculated as follows:

$$C_{RM} = C_{TM} - C_{FM} \tag{20}$$

C_R is introduced and $C_R = C_{RS} = C_{RM}$ based on Froude's assumption.

The frictional coefficient in full scale C_{FS} is calculated as

$$C_{FS} = \frac{0.075}{(log_{10}(Re_S) - 2)^2} \tag{21}$$

Where Re_S is the Reynolds number defined as $Re_S = V_S \cdot L_{WL}/\nu_S$, V_S is the vessel speed and ν_S is the kinematic viscosity coefficient of the sea water.

The total resistance coefficient in full scale C_{TS} is defined as:

$$C_{TS} = \frac{R_{TS}}{0.5 \cdot \rho_S \cdot {V_S}^2 \cdot S_s} \tag{22}$$

Where R_{TS}, ρ_S, S_s are respectively the total resistance, the sea water density and the vessel wetted surface area.

The total resistance coefficient C_{TS} is calculated with:

No. 172 (cont)

$$C_{TS} = \frac{S_S + S_{BK}}{S_S}(C_{FS} + C_A) + C_R + C_{AA} \tag{23}$$

Where:

C_A is the correlation allowance, usually set by the towing tank facility and including uncertainty effects, roughness effects, etc.

C_{AA} is the air resistance coefficient

S_{BK} is the bilge keel surface area

6.3. Procedure to calculate effective power P_E (Resistance Part)

According to *75-02-03-01.4- 1978 ITTC Performance Prediction Method - Effective Date 2008 – Rev 01* or later, the roughness effect is considered by the following formula:

$$\Delta C_{F,2008} = 0.044\left[(k_s/L_{WL})^{\frac{1}{3}} - 10Re_S^{-\frac{1}{3}}\right] + 0.000125 \tag{24}$$

The new total resistance coefficient C_{TS_1} after roughness modification is calculated with:

$$C_{TS_1} = C_{TS} + \frac{S_S + S_{BK}}{S_S}\left(\Delta C_{F,2008}(k_{S_1}) - \Delta C_{F,2008}(k_{S_0})\right) \tag{25}$$

Where:

k_{S_0} is the original value of hull roughness given in the model test report. If no value is given in the report, $k_{S_0} = 125 \cdot 10^{-6}\ m$ can be used.

k_{S_1} is the AHR measured on the ship after application of low-friction coatings, as mentioned in the measurement report.

$\Delta C_{F,2008}(k_{S_0})$ is the roughness allowance with formula (24) using k_{S_0}

$\Delta C_{F,2008}(k_{S_1})$ is the roughness allowance with formula (24) using k_{S_1}

The total resistance readily follows from definition:

$$R_{TS_1} = C_{TS_1} \cdot 0.5\rho_S V_S^2 S_S \tag{26}$$

Subsequently, the effective power P_{E_1} is calculated:

$$P_{E_1} = C_{TS_1} \cdot 0.5\rho_S V_S^3 S_S \tag{27}$$

6.4. Procedure to calculate delivered power P_D (Self-Propulsion part)

The propeller will run at a different advance coefficient $J = V_A/n_S D_S$, where $V_A = V(1 - w_{TS})$, n_S is the propeller revolutions and D_S is the propeller diameter. To find the new value of J, we consider the following:

$$K_T/J^2 = \frac{T/\rho_S n_S^2 D_S^4}{V_A^2/n_S^2 D_S^2} = \frac{R_{TS_1}}{\rho_S(1-t)(1-w_{TS})^2 V_S^2 D_S^2} = C \Rightarrow K_T = CJ^2 \tag{11}$$

No. 172 (cont)

where K_T is the thrust coefficient.

For the calculation of K_T/J^2, the wake fraction at full scale w_{TS} is to be recalculated to adjust for new roughness value.

In case the towing tank facility which performed the original model test used the following formula for the original full-scale wake fraction prediction:

$$w_{TS_0} = (t + w_R) + (w_{TM} - t - w_R) \times \frac{C_{FS} + C_A}{C_{FM}} \tag{12}$$

Then, the new full-scale wake fraction is to be calculated as follows:

$$w_{TS_1} = (t + w_R) + (w_{TM} - t - w_R) \times \frac{C_{FS} + C_A + \Delta C_{F,2008}(k_{S_1}) - \Delta C_{F,2008}(k_{S_0})}{C_{FM}} \tag{30}$$

Where w_{TM} is the wake fraction at model scale and w_R stands for the effect of rudder on the wake fraction. If there is no estimate for w_R, the standard value of $w_R = 0.04$ is to be used. If $w_{TS_1} > w_{TM}$, then $w_{TS_1} = w_{TM}$.

In case the towing tank facility which performed the original model test did not use equation (30), then the new full-scale wake fraction is to be calculated as follows:

$$w_{TS_1} = w_{TS_0} \frac{w_{TS_1,calc}}{w_{TS_0,calc}} \tag{13}$$

where w_{TS_0} is the full-scale prediction for the wake fraction from the original towing tank tests, and $w_{TS_0,calc}$, $w_{TS_1,calc}$ are the values calculated through (29) and (30) respectively. If $w_{TS_1} > w_{TM}$, then $w_{TS_1} = w_{TM}$.

Factor C in equation (28) can be easily calculated for every model test speed, using the total resistance value implied from the coefficient calculated in (26).

To find the new value of J, the following equation must be solved:

$$K_T(J) = CJ^2 \tag{14}$$

To analytically solve (32) with respect to J, the thrust coefficient curve is approximated with 2nd-degree polynomial regression: $K_T(J) \approx \bar{K}_T = aJ^2 + bJ + k$. Thus:

$$aJ^2 + bJ + k = CJ^2 \Rightarrow (a - C)J^2 + bJ + k = 0 \tag{15}$$

The solutions to (33) are given by the following:

$$J = \frac{-b \pm \sqrt{Det}}{2(a - C)}, Det = b^2 - 4(a - C)k \tag{16}$$

Rejecting one of the solutions (it turns out to be negative), we now have the new advance coefficient value J_1. For each speed value, the new delivered power is calculated as follows:

$$P_{D_1}(V) = \frac{P_{E_1}(V)}{\eta_D} = \frac{P_{E_1}(V)}{\eta_0(V, J_1)\eta_H(V)\eta_R(V)} \tag{17}$$

where $\eta_H(V) = (1 - t)/(1 - w_{TS_1})$ and w_{TS_1} is calculated according to (30) or (31).

No.

172
(cont)

6.5. Calculation of new V_{ref} value

New brake power prediction is $P_{B_1} = P_{D_1}/\eta_S$, η_S: shaft efficiency. From the new speed-power prediction curve, $V_S - P_{B_1}$, substituting $P_{B_1} = P_{ME}$, we get the new prediction for the new reference speed $V_{ref,1}$.

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