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Noise Exploration Program To Understand Noise Emitted by Seagoing ships

NOISE MEASUREMENT PROTOCOL MOORED SHIPS

Version 2.0

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1 Preliminary remarks

This measurement protocol has the objective to provide a uniform, worldwide applicable measurement standard describing how to measure, analyze, evaluate and classify individual ships (e.g. container ships, cruise ships, tankers, RoRo/RoPax and bulk carriers) concerning their airborne noise emission when moored at berth in ports. The measurement protocol shall especially ensure that the measurements are carried out in a comparable manner in different ports and by different persons. The measurements should be carried out by acoustic specialists / measurement institutes that are accredited for the test procedures and standards specified in this measurement protocol according to country-specific requirements. The respective country-specific accreditation companies should be assigned to the umbrella association *International Laboratory Accreditation Cooperation* (*ILAC*).

The measurements shall preferably be performed as sound emission measurements on board of the respective ship. The noise emission measurements on board of the ship will be performed to determine the sound power level of the most dominant noise sources on this (respective) ship. The total sound power level of the ship will then be calculated from the sound power levels of the individual sound sources.

Only in exceptional cases, such as proven denied access to the ship, complementary sound pressure measurements at a certain distance from the ship can be performed to estimate the total sound power level of the ship (provided that the measurement requirements for measurements at a certain distance can be met).

Apart from providing guidance for carrying out the acoustic measurements, the protocol will inform about which details need to be documented during the measurements and what results are required as an outcome of each measurement to be used for a noise label.

The results of each measurement need to be documented in a separate short report and filled in an Excel-spreadsheet provided by NEPTUNES (to be found on the www.neptunes.pro).

2 Normative references

[1] IEC 61672-1: Electroacoustics. Sound level meters. Part 1: Specifications. 2014-07.

[2] IEC 61672-2: Electroacoustics. Sound level meters. Part 2: Pattern evaluation tests. 2018-01.

[3] IEC 60942: Electroacoustics. Sound calibrators. 2018-07.

[4] IEC 61043: Electroacoustics. Instruments for the measurement of sound intensity – Measurement with pairs of pressure sensing microphones. 2017-05.

[5] ISO 1996-1: Acoustics – Description, measurement and assessment of environmental noise. Part 1: Basic quantities and assessment procedure. 2016-03.

[6] ISO 1996-2: Acoustics – Description, measurement and assessment of environmental noise. Part 2: Determination of environmental noise levels. 2017-07.

[7] ISO 3746: Acoustics – Determination of sound power levels and sound energy levels of noise sources using sound pressure – Survey method using an enveloping measurement surface over a reflecting plane. 2011-03.

[8] ISO 9614-2: Acoustics – Determination of sound power levels of noise sources using sound intensity – Part 2: Measurement by scanning. 1996-12.

[9] DIN 45635-47: Measurement of airborne noise emitted by machines; enveloping surface method, chimneys. 1985-06.

[10] ISO 6798: Reciprocating internal combustion engines – Measurement of emitted airborne noise – Engineering method and survey method. 1995-12.

[11] ISO 9613-2: Acoustics – Attenuation of sound during propagation outdoors – Part 2: General method of calculation, 1999-10.

[12] ISO 12354-4: Building acoustics – Estimation of acoustic performance of buildings from the performance of elements – Part 4: Transmission of indoor sound to the outside. 2017-11

3 Definitions and symbols

3.1 Terms

The acoustic quantities used in this document are stated in Table 1 together with their symbol and the SI unit.

Table 1. Applied acoustic quantities and symbols.

Quantity	Symbol	(SI) unit[1]
Sound pressure	p	Pa
Sound power	P	W
Sound intensity	I	W/m^2
Sound pressure level	L_p	dB
Sound intensity level	L_{In}	dB
Sound power level	L_W (L_p)	dB
A-weighted sound pressure level	L_{pA}	dB(A)
A-weighted sound intensity level	L_{InA}	dB(A)
A-weighted sound power level	L_{WA}	dB(A)
C-weighted sound pressure level	L_{pC}	dB(C)
95 % percentile A-weighted sound pressure level	L_{AF95}	dB(A)
Maximum sound pressure level	$L_{AF,max}$	dB(A)

Further level quantities together with their definitions are given in section **Fout! Verwijzingsbron niet gevonden.**.

3.2 Level parameters

For this measuring instruction, especially the level parameters as defined in the following apply:

L_{Aeq} A-weighted continuous sound level for continuous sound signals,
L_{Ceq} C-weighted continuous sound level for continuous sound signals,
L_{InA} A-weighted continuous sound intensity level for continuous sound signals,
L_{AF95} 95 % exceedance level,
L_{AF10} 10 % exceedance level,
$L_{AF,max}$ maximum sound pressure level during the measurement interval,

1 According to the standards of DIN, IEC and ISO, the described physical level quantities have to be marked by a corresponding index. Besides, information on the weighting and other supplements (like time and frequency weightings) have to be added to the evaluated quantity, and not to the (pseudo) unit dB. Nevertheless, the non-standard notation dB(A) can still be found in textbooks or legislative texts and should be stated here.
The correct notation would be, for example, L_{pAF}= 75 dB(A) (spectral A-weighted sound pressure level, temporally weighted with the time constant „fast“.)

L_{WA} A-weighted sound power level.

The applied level quantities are in accordance with the definitions given in ISO 3746 [7] and ISO 9614-2 [8], but are not identical with these.

3.2.1 Time-averaged sound pressure level (equivalent continuous sound pressure level) L_{eq}[2]

$$L_{eq} = 10 \lg \frac{1/T \int_0^T p(t)^2 dt}{p_0^2} \quad \text{in dB} \qquad (1)$$

where

L_{eq} is the time-averaged sound pressure level (equivalent continuous sound pressure level) in dB,

$p(t)$ is the sound pressure in Pa,

p_0 is the reference sound pressure (here p_0 = 20 µPa) and

T is the averaging time in s [3].

3.2.2 Sound intensity level L_{In}

$$L_{In} = 10 \lg \frac{1/T \int_0^T \overrightarrow{I(t)} dt \times \vec{n}}{I_0} \quad \text{in dB} \qquad (2)$$

where

L_{In} is the time averaged sound intensity level,

$\overrightarrow{I(t)}$ is the instant flow of sound energy through an area unit in the direction of local momentary sound velocity,

$\vec{n}$ is the unit normal vector, which is defined to point out of the space enclosed by the measuring surface,

I_0 is the reference Intensity (here $I_0 = 10^{-12}$ W/m²) and

T is the averaging time.

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2 The weighted levels will be stated with an additional subscript, e.g. L_{Aeq}, L_{Ceq}.

3 According to ISO 1996-1 the equivalent continuous sound level can also be marked with the index T, L_{eqT}.

3.2.3 Sound power level L_W

$$L_W = 10 \lg \frac{P}{P_0} \quad \text{in dB} \qquad (3)$$

where

P is the sound power and

P_0 is the reference sound power P_0 = 1 pW.

3.2.4 95 % exceedance level L_{AF95}

The 95 % exceedance level L_{AF95} represents the A-weighted sound pressure level, which is present or exceeded during 95 % of the measurement interval (measurement time), measured with the time weighting fast.

3.2.5 Residual noise or background noise

Residual noise or background noise describes an extraneous sound which can be heard while listening to or monitoring other sounds. For example, when measuring the sound emission from individual sound sources on a ship residual noise from e.g. cargo handling during loading and unloading can be heard and recorded.

4 Measuring equipment

4.1 Acoustic measuring equipment

The equipment for acoustic measurements must consist of:

- Integrating sound level meter with a microphone, (cable) and windscreen, in compliance with IEC 61672-1 [1] and IEC 61672-2 [2], class 1.
- Acoustic calibrator in compliance with IEC 60942, class 1 [3].
- *Optional equipment: Sound intensity probe in compliance with IEC 61043 [4].*

The microphones need to be equipped with a windscreen (diameter ≥ 6 cm) for each measurement.

The calibration of the measuring system needs to be checked with the sound calibrator before and after each measurement series.

For post-processing, analysis software is required comprising the following methods[4]:

- Third-octave band analysis according to IEC 61672-1 [1].
- Frequency weighting, time weighting and averaging.

During all measurements the time weighting fast will be used.

Optional equipment: If sound intensity measurements are carried out, a 12 mm spacer between the microphones for all sound sources and especially for measurements at the funnel outlet additionally a 50 mm spacer necessarily need to be used for the respective frequency response of interest.

4.2 Additional measuring equipment

Besides the acoustic measuring equipment, the following equipment is needed for the measurements:

- Distance measurement device (accuracy of 2 % with results from 0.1 to 600 m).
- Photo camera.
- Tripod with a height of at least 6 m.
- *Optional equipment: Grid airflow measurement device (10 % accuracy).*
- *Optional equipment: Wind speed measurement device (anemometer) and wind direction measurement device at a height of 10 m or higher in free field (10 % accuracy). Preferably these data should be recorded by the ship crew during the measurements.*
- *Optional equipment: Headphones for monitoring of the measured signal*
- *Optional (recommended) equipment: connecting bar and extension cable for positioning the microphone or the intensity probe at remote positions*

[4] Post-processing might already be part of the sound level meter.

5 Classification of ships and sound sources

5.1 Ship types

This measurement protocol shall especially be applicable for the following ship types:

a) Container ships

b) Cruise ships

c) Tankers

d) RoRo/RoPax

e) Bulk carriers

f) General cargo/service ship

5.2 Sound sources on board of the ships

The overall sound emission radiated from each ship can be traced back to several individual sound sources on board of the ship. Some of these individual sound sources exist for all aforementioned ship types, whereas others can only be found for specific ship types/ships.

Based on experience the most relevant sound sources that have to be measured are listed below.[5] The sources are assigned to the ship types from section 5.1.

(1) The funnel outlet(s) of the auxiliary engine(s), all ship types (a) to (f).
(2) The opening(s) of engine room ventilation inlet and outlet, all ship types (a) to (f).
(3) The opening(s) of the cargo holds ventilation and air conditionings inlet(s) and outlet(s), all ship types (a) to (f).
(4) The opening(s) of the ventilation and air-conditioning of passenger rooms, ship types b) and RoPax d).
(5) Further relevant ventilation openings (e.g. sanitary or galley exhaust)[6]
(7) Pumps on deck, ship type c).

The operation of cooled containers / reefers on container ships is strongly depending on several indicators such as (cooling) type of the container, type and size of the ship, ships load and port conditions. Furthermore, their operation is also belonging to the cargo handling process of a ship at berth. Therefore, the cooled containers / reefers are not considered for measurements and will not be considered for the calculation of the total sound power level of the measured ship in this measurement protocol.

[5] The smaller sound sources like HVAC systems on the bridge and ventilation of galleries etc. will typically not be considered because, in general, they do not contribute to the sound emission of a ship in total.

[6] All further ventilation openings on board should be checked for relevant sound emissions.

5.3 Operating conditions during sound measurements

During the measurements, the ship shall be operating in the characteristic/normal load of the ship at berth. It must be ensured that the load condition during measurements is chosen in such a way that the measured sound emissions will not be exceeded at berth in any further calling port (in most cases during high / maximum load conditions of the ship). It is important that the electric load is kept as constant as possible during all measurements.

To adjust the electric load of the auxiliary engine(s) to the representative load, consumers on board might need to be switched on or off. Consumers that (in most cases) can be controlled manually are, e.g.:

- cargo hold fans,
- engine room fans,
- fans and air-conditioning of passenger rooms and
- further fans on board.

Furthermore, the operating conditions during all measurements need to be documented in detail, see also section 7.

6 Measuring instructions

6.1 General overview

The measurements for each ship to be measured shall be performed as

1. Sound emission measurements on board of the respective ship and/or
2. In exceptional cases only: Complementary acoustic measurements at a certain distance from the ship (provided that the measurement requirements for measurements can be met at a certain distance; e.g. low residual noise and accessibility).

The sound emission measurements should preferably be performed on board. Nevertheless, if due to not predictable circumstances (such as proven denied accessibility to the ship) measurements on board of the ship cannot be performed, the acoustic measurements at a certain distance can complementary be performed. The performance of measurements at a certain distance presupposes certain stricter requirements to the measurement environment (e.g. low residual noise and accessibility). Details are shown in chapter 0.

The two measurement methods are described in detail in the following chapters 6.2 and 6.3.

This report gives a general recommendation for carrying out measurements for both methods. If the measurements cannot be strictly carried out in the given manner, they shall be performed in a close approximation to these instructions. Each deviation from the measuring instructions needs to be carefully documented (see also section 7). Among other things, possible reasons for deviation from the measuring instructions could e.g. be limited accessibility to measurement positions and too high residual noise at the measurement positions.

The measurements should be carried out by acoustic specialists / measurement institutes that are accredited for the test procedures and standards specified in this measurement protocol according to country-specific requirements. The respective country-specific accreditation companies should be assigned to the umbrella association *International Laboratory Accreditation Cooperation (ILAC)*.

6.2 Measuring conditions for all measurements

The required operating conditions of the ship during measurements are specified in section 5.3.

The measuring system must have a calibration certificate and a valid calibration status at the time of the measurement.

The measuring system is to be calibrated (single point calibration) before and after the measurements. The calibration signal must be recorded accordingly (see also section 4.1).

Residual noise is to be avoided as far as possible in the vicinity of the measuring positions. It must be assured that the measurements are not distorted by ambient noise (e. g. from cargo handling or port noise). If possible, the berthing site for the ship shall be chosen in such a way that the residual noise level is as low as possible during the measurements.

Measurements shall only be performed when no rain or snow is present (≤ 0.1 mm/m²). Further conditions for the individual measurements are shown in chapter 6.4.1 and 6.3.1.

6.3 Sound emission measurement on board of the ship

6.3.1 General remarks

The sound emission measurements on board of the ship will be performed to identify the most dominant sound sources on a ship. Furthermore the measurement results will give an overview of the sound power level of the individual sound sources on board of the ship.

During measurements the wind speed shall be below 6 m/s for all measurements on board of the ship.

The flow velocity at the measurement positions (e.g. caused by the exhaust of the funnel or the fans of the ventilation systems) shall be as low as possible, preferably below 6 m/s. If the flow velocity is too high at the measurement positions, another measurement surface with lower flow velocity needs to be chosen (e.g. sideways from the ventilation opening). The divergent measurement surface preferably needs to be chosen following a comparable measurement surface as stated in section 6.3.2. Each deviation must be documented including a sketch of the alternatively chosen measurement surface, see also section 7.

If not stated differently in the following, measurements shall be performed as sound pressure measurements in accordance with ISO 3746 [7] or alternatively as sound intensity measurements in accordance with ISO 9614-2 [8].

Note:

Sound intensity measurements have the advantage that the present environment is basically not influencing the measurements (e.g. measurements can be performed even if there is a high residual noise from other sound sources). Furthermore, measurements in the near field of the sound sources are less susceptible to interferences. Nevertheless, for sound intensity measurements advanced measurement equipment and advanced acoustic knowledge are required. If such equipment and advanced acoustic knowledge are available, sound intensity measurements are to be preferred.

6.3.2 Measuring instructions

If not stated otherwise in the following, the measurements shall preferably be performed by continuous meandering averaging over the surface area (both horizontally and vertically), as shown in Figure 1. The averaging shall take place with a speed of between 0.1 m/s and 0.5 m/s. If the averaging surface is divided into several segments, the averaging needs to be performed subsequently for all segments to obtain one averaged sound pressure level for the whole measurement surface area[7]. The averaging time for each segment shall not be shorter than 20 s. Further details on the measurement method can be found in ISO 9614-2 [8].

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7 This represents a simplified measuring method. According to [7] and [8] each segment of the measuring surface shall be measured separately and the overall sound power level will be calculated as the logarithmic sum of all individual sound power levels from all segments.

Note

To simplify the measurement effort, the continuous meandering averaging shall be applied in the same manner for the sound pressure measurements in accordance with ISO 3746 [7].

Alternatively, measurements at several discrete measurement positions distributed over the measurement surface can be chosen in accordance with ISO 3746 [7]. This method can, for example, be advantageous for measurements on a hemispherical measurement surface, as suggested for measuring the sound emission of cooled containers/reefers.

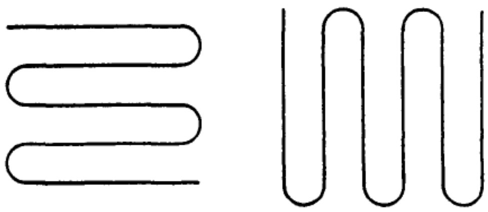

Figure 1. Example of the meandering averaging surface in both horizontal and vertical direction.

There may be a large number of sources for each source type (e.g. a great number of ventilation inlet and outlet openings from the cargo hold of a container ship). To minimize the number of separate measurements, it will be sufficient to measure up to three representative sound sources for each source type (e.g. three different openings of ventilation outlets from the cargo hold), implying that all sources have a similar subjective sound emission. The overall sound power level of those sources needs to be subsequently extrapolated to the number of such sources in operation during measurements.

In the following, the preferred measurement surface(s) for the most relevant sound sources from section 5.2 are described in detail.

A) Funnel outlet of the auxiliary engine(s), all ship types

The sound emission of the funnel outlet of the auxiliary engine(s) shall be measured in accordance with DIN 45635-47 [9][8]. Following DIN 45635-47 [9], the sound pressure will be measured at two measurement positions (MP 1 and MP 2[9]) as shown in Figure 2. The distance from the outer wall of the funnel outlet to the measurement positions will be 1 m. The arrangement of the measuring points in the horizontal direction is arbitrary[10]. The measurement time for each measurement position shall be at least 30 seconds. The measurement positions (1) and (2) from Figure 2 shall be chosen from the axis of the opening. The calculation of the surface areas S_1 and S_2 is shown in Figure 2.

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8 The measurement procedure described in DIN 45635-47 [9] is similar to the approach described in ISO 6798 [10].

9 The choice of two measurement positions (in front and behind of the outlet) is especially important for the comparability with additional measurements (e.g. measurement on the deck house and measurements in a certain distance from the ship).

10 The influence of directivity in horizontal direction is negligible.

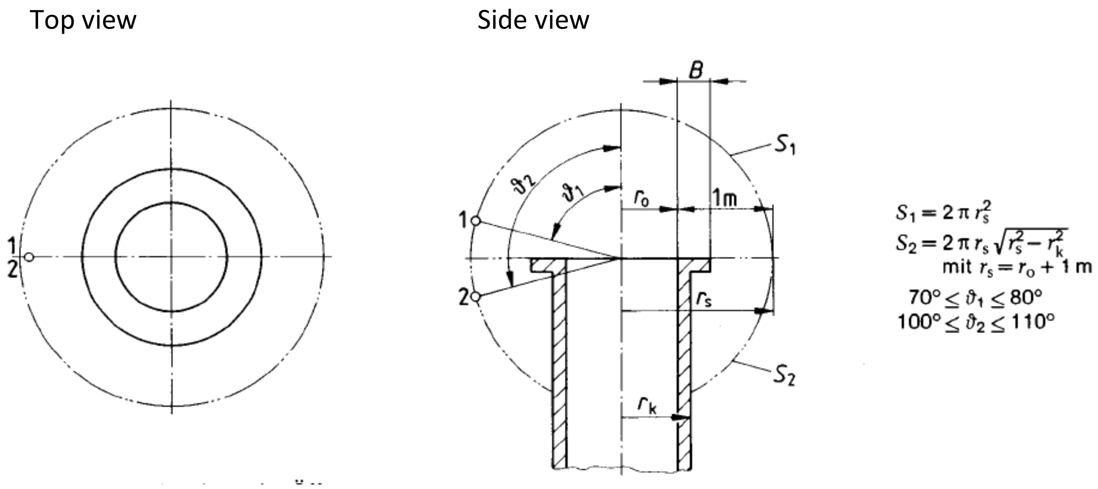

Figure 2. Measurement positions for measuring at the funnel outlet(s). The figure is taken from DIN 45635-47, Figure 1 [9].

Note: In the near field of sound sources, the sound pressure and the sound velocity are out of phase, which can lead to unusual high sound pressure levels that are measured in the near field. Especially high care should be taken to this phenomenon when measuring at the funnel outlet, since it is very often radiating high sound emissions in the low frequency range (especially for 1/3 octave frequency bands ≤ 160 Hz). When measuring at a distance of one meter from the funnel outlet the determined sound power level could, therefore, be higher than the actual sound power level relevant for the noise radiation into the environment. Alternatively, sound intensity measurements in the near field and/or sound pressure measurements in a larger distance (recommended ≥ 10 m) from the funnel outlet can lead to more precise measurement results.

B) Opening of ventilation inlets and outlets

The measurement surface shall be chosen in the plane of the shape of the opening at a distance of 0.25 m ≤ d_v ≤ 0.5 m in front of the opening. The surface area *S* corresponds to the surface area of the opening (mostly rectangular or round surfaces are expected) and is calculated by $S = a \cdot b$, where a and b are the side lengths of a rectangular surface, or $S = \pi \times r^2$, where *r* is the radius of a round surface.

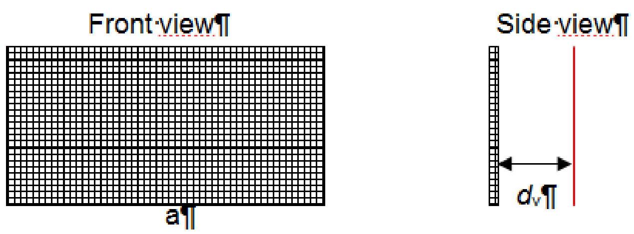

Figure 3. Sketch of a rectangular measurement surface for measuring the sound emission in front of a rectangular opening of a ventilation inlet or outlet. The contour of the measurement surface is marked red.

Alternative approach for ventilation openings

The ventilation openings are not always accessible or sometimes only hardly accessible (such as the outlets of the engine room ventilation). In such situations the following alternative approach can be used for passive ventilation openings that are accessible from the inside, unless the fans are directly connected to the opening itself.

The spatial average sound pressure level inside and in front of the respect opening shall be measured in 1 m distance to the opening. The determined sound pressure level will then be used for calculating the sound power level that is radiated from the opening into the environment in accordance with ISO 12354-4 [12].

Alternative approach for ventilation openings with high air flow

If due to high air flow (flow speed ≥ 6 m/s) measurements in front of the ventilation openings on the above mentioned measurement surface are not possible, a suitable alternative measurement surface should be chosen.

As an alternative measurement surface, a hemisphere with a radius of 0.5 m ≤ r ≤ 2 m from the acoustic centre of the opening could be chosen. The surface area S will then be calculated by

$$S = 2 \times \pi \times r^2.$$

C) Cooled containers/reefers

The sound emission of the cooling containers/reefers (sound source (5) from section 5.2) is mainly caused by the sound emission from the fan and the compressor next to the fan.

As measurement surface, a hemisphere with a radius of 1 m ≤ r ≤ 2 m from the acoustic centre between the fan and the compressor shall preferably be chosen. The surface area S will then be calculated by $S = 2 \times \pi \times r^2$. A sketch of the measurement surface is shown in Figure 4.

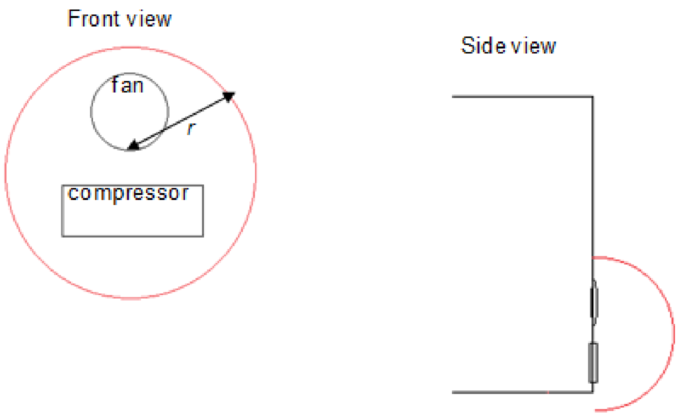

Figure 4. Sketch of the hemispherical measurement surface for measuring the sound emission of a cooled container. The contour of the measurement surface is marked red.

D) Pumps

The measurement surface shall preferably be a square with a distance of d_p= 1 m from the contour of the pump to each side including the drive. The surface area S will then be calculated by $S = (a + b) \times 2 \times c + a \times b$. In a suitable measurement environment (especially low residual noise) a hemispherical measurement surface with a radius of 1 m ≤ r ≤ 2 m can alternatively be chosen. The surface area S will then be calculated by $S = 2 \cdot \pi \cdot r^2$.

A sketch of a rectangular measurement surface is shown in Figure 5.

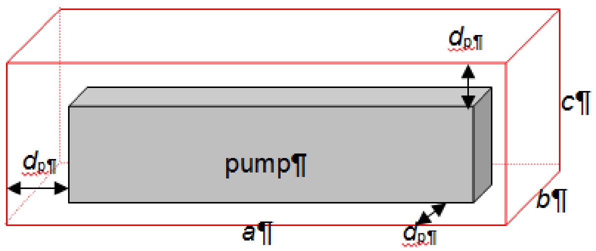

Figure 5. Sketch of the square measurement surface for measuring the sound emission of pumps. The contour of the measurement surface is marked red, the pump is marked grey.

6.3.3 Acoustic data to be recorded

During each individual measurement the following data shall be recorded:

L_{Aeq}	equivalent A-weighted continuous sound pressure level,
L_{AFmax}	maximum sound pressure level during the measurement interval.

All data shall be recorded as 1/3 octave band level from 25 Hz to 10 kHz and total level including those 1/3 octave bands; the L_{AFmax} only needs to be recorded as the total level.

6.3.4 Evaluation of the measurement results – sound power level L_{WA}

From sound pressure level measurements (A-weighted equivalent continuous sound pressure level L_{Aeq}) the sound power level of the specific sound source (i) need to be calculated in accordance with ISO 3746 [7] for each 1/3 octave frequency band from 25 Hz to 10 kHz by

$$L_{WA,i} = L_{Aeq} - K + 10 \lg \frac{S_i}{S_0} \quad \text{in dB} \qquad (4)$$

where

$L_{WA,i}$	is the A-weighted sound power level in dB with a reference sound power level of 10^{-12} W for the specific sound source (i),
L_{Aeq}	is the A-weighted equivalent continuous sound pressure level averaged over the measurement surface area S,

S is the area, in square meters, of the measurement surface,
S_0 is the reference surface of 1 m² and
K is the correction factor for residual noise and environmental issues (in this measurement protocol K = 0…3 dB).

From sound intensity measurements (A-weighted sound intensity level L_{AIn}) the sound power level of the specific sound source (i) will be calculated in accordance with ISO 9614-2 [8] for each 1/3 octave frequency band from 25 Hz to 10 kHz by

$$L_{WA,i} = L_{AIn} - K + 10\lg\frac{S_i}{S_0} \quad \text{in dB} \qquad (5)$$

where

$L_{WA,i}$ is the sound power level in dB with a reference sound power level of 10^{-12} W for the specific sound source (i),
L_{AIn} is the sound intensity level averaged over the measurement surface area S_i.

As an exception, the sound power level of each measured funnel outlet (j) will be calculated as shown in equation (4) separately for the measurement surfaces $S_{1,j}$ and $S_{2,j}$. The total sound power level of each funnel outlet (j) will then be calculated as shown in equation (6) for each 1/3 octave frequency band from 25 Hz to 10 kHz

$$L_{WA,funnel,j} = 10\lg\left(10^{\frac{L_{WA,1,j}}{10}} + 10^{\frac{L_{WA,2,j}}{10}}\right) \quad \text{in dB} \qquad (6)$$

where

$L_{WA,funnel,j}$ is the total sound power level of each funnel outlet (j) and
$L_{WA,1,j}$ and $L_{WA,2,j}$ are the sound power levels calculated for both separate measurement positions of each funnel outlet (j).

Correction for residual noise

If temporary residual noise cannot be fully avoided during an individual measurement, the sound power level needs to be corrected by the factor K = 0 … 3 dB, see equation (4) and (5). All corrections of the sound power level need to be documented (see also section 7). The magnitude of correction up to 3 dB can e.g. be chosen based on the subjective impression. Here, simplifying, a correction of K = 0 dB means that the measurement is not influenced by residual noise and a factor of K = 3 dB means that basically the residual noise and the sound from the source under test are perceived with the same loudness. The correction factor K shall be chosen constant for all 1/3 octave band frequencies.

Total sound power level

The total sound power level of the measured ship will be calculated from the calculated sound power level of all individual sound sources as shown in equation (6) for each 1/3 octave frequency band from 25 Hz to 10 kHz.

$$L_{WA,total} = 10\lg\left(\sum_i 10^{\frac{L_{WA,i}}{10}} + \sum_j 10^{\frac{L_{WA,funnel,j}}{10}}\right) \quad \text{in dB} \qquad (7)$$

The broadband total sound power level will then be calculated by the energetic sum of the total sound power levels for all 1/3 octave frequency bands from 25 Hz to 10 kHz.

The low frequency total sound power level will then be calculated by the energetic sum of the total sound power levels for all 1/3 octave frequency bands from 25 Hz to 160 Hz.

6.4 Complementary measurements at a certain distance from the ship

6.4.1 General remarks

Sound pressure level measurements at a certain distance from the ship should be performed only complementary, if due to not predictable circumstances (such as denied accessibility to the ship) measurements on board of the ship cannot be performed. The performance of measurements at a certain distance presupposes certain stricter requirements (e.g. low residual noise and accessibility) to the measurement environment, which are described below.

Furthermore, the sound pressure level measurements at a certain distance can also be performed in addition to the sound emission measurement on board of the ship. The measurements can indicate the presence of low frequency noise at a certain distance and can be used for comparisons with the sound emission measurements on board of the ship.

During measurements the wind speed shall be below 5 m/s. From 2 m/s to 5 m/s the wind has to come within 60 degrees from source (ship) to receiver (microphone position)[11].

The measurements need to be performed in accordance with ISO 1996-2 [6].

Residual noise

For performing measurements at a certain distance from the ship it is important that the measurements are not disturbed by residual noise (e.g. noise caused by cargo handling, noise caused by ships that are berthed nearby or passing ships)[12].

Before starting the actual measurements at a certain distance from the ship, the residual sound pressure level (background noise level) shall be recorded at each measurement position from section 6.4.2. The recording time shall be at least 5 minutes. The residual noise level needs to be at least 3 dB below the sound pressure level caused by the ship at each measurement position to fulfil

[11] To make sure that wind noise is not disturbing the measurement, the signal can e.g. be checked by headphones.

[12] To avoid noise caused by cargo handling, it could be helpful to perform the measurements at a certain distance before starting/after finishing the cargo handling on that ship or in breaks/changes of working shifts of the port staff.

the measurement requirements. The recording of residual noise is e.g. possible at large distance from the vessel or before the arrival or after the departure of the ship. It needs to be assured, that the ambient conditions do not change significantly during measurements, e.g. by observing the surrounding and monitoring the background noise at a larger, but representative distance.

6.4.2 Measuring instructions

The measurements at a certain distance from the ship shall be performed at least at three measurement positions (MP). The measurement positions shall be chosen sideways from the ship, so that the most dominant sound sources of the ship will be captured with the measurement. If one side of the ship is subjectively much noisier than the other side (e.g. due to the presence of ventilation openings only at one side of the ship), both sides shall be measured if possible. However, in most cases measurements at one side of the ship will be representative for the overall sound radiation from the ship.

It is recommended to choose the following three measurement positions sideways from the ship:

- **MP 1**: one position sideways from the funnel outlet of the auxiliary engine,
- **MP 2**: one position midway between the ship bow and the centre of the ship,
- **MP 3**: one position sideways from the stern or behind the stern of the ship. It is important that there is a clear view from the microphone position to the ventilation openings at the deckhouse or at the stern of the ship.

If due to the location of the funnel the measurement position MP 1 lies within less than 10 m to MP 2 or MP 3, another representative measurement position needs to be chosen for the concerning MP 2 or MP 3 (e.g. centre of the ship). In at least one measurement position there shall be a clear line of sight between microphone and exhaust pipe outlet to avoid acoustic screening by structures like bridge wings.

The measurements can be performed successively at the different measurement positions.

The horizontal distance (d_H) from the funnel outlet of the auxiliary engine in operation and the measurement position MP 1 shall preferably be chosen in such a way that the angle (α) between the direct distance to the funnel outlet (d_c) and the horizontal distance d_h fulfils the relation $5° \leq \alpha \leq 20°$. For measurement positions MP 2 and MP 3 the same horizontal distances to the ship hull as for MP 1 shall be chosen. Deviations from the suggested angle α (e.g. by choosing a measurement position closer to the ship) are allowed, as long as there is a clear sight from the microphone to the funnel outlet of the ship available.

The height of the measurement position is to be chosen at least h_m = 6 m above the quay ground.

An exemplary calculation of the horizontal distance d_h from the funnel outlet to the measurement position MP 1 is shown in the Appendix.

The recording time for each measurement position shall be at least 2 minutes[13] of extraneous noise free measurement time. Depending on the presence of residual noise, the measurement time might need to be extended.

A sketch of the measurement positions is shown in Figure 6 and Figure 7.

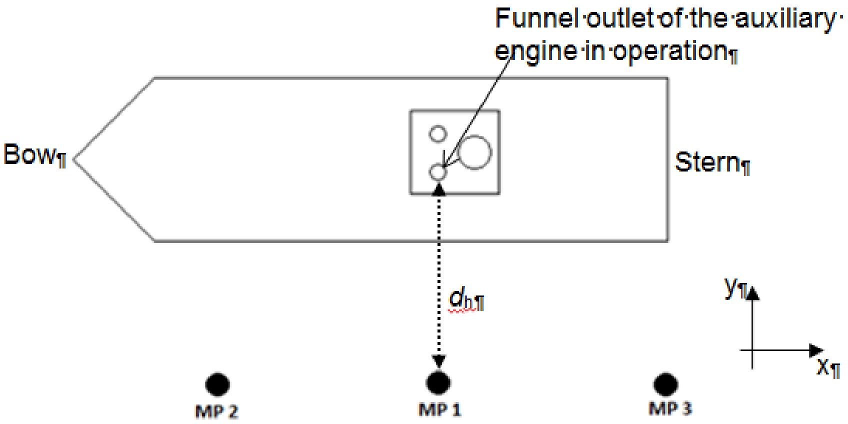

Figure 6. Sketch of the measurement positions sideways from the axis of the ship at a certain horizontal distance d_h.

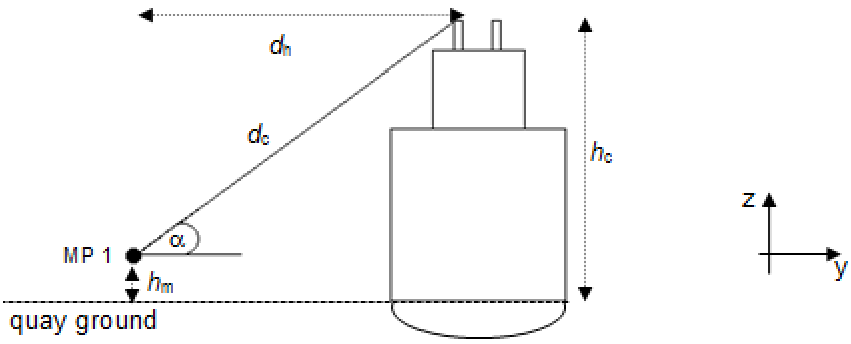

Figure 7. Sketch showing the relative position of the measurement position MP 1 to the funnel outlet of the auxiliary engine in operation. h_c is the height of the funnel outlet above quay ground, h_m is the microphone height above quay ground at the measurement position MP 1, d_h is the horizontal distance from MP 1 to the funnel outlet and d_c is the direct distance between the funnel outlet and MP1.

13 Under normal conditions, the measurement time at each measurement position will most likely be between 2 and 10 minutes.

Note

The measurement position shall preferably be chosen in such a way that no reflections or screening from surrounding objects (e.g. buildings) will disturb the measurements. If reflections and screenings from surrounding objects and/or temporary residual noise cannot fully be avoided by changing the measurement position, detailed documentation of the surroundings and the time and nature of residual noise is essential (see also section 7). The measurement results might need to be corrected to account for the influence of reflections.

6.4.3 Acoustic data to be recorded

During measurements the following data shall be recorded for each measurement position:

$L_{\mathrm{Aeq,k}}$	equivalent A-weighted continuous sound pressure level at the measurement position (*k*),
$L_{\mathrm{Ceq,k}}$	equivalent C-weighted continuous sound pressure level at the measurement position (*k*),
$L_{\mathrm{AF95,k}}$	95 % percentile sound pressure level at the measurement position (*k*),
$L_{AF10,k}$	10 % percentile sound pressure level at the measurement position (*k*),
$L_{\mathrm{AF,max,k}}$	maximum sound pressure level during the measurement interval at the measurement position (*k*),
Time signal	preferably uncompressed in .wav format.

All data shall be recorded as 1/3 octave band level from at least 25 Hz to 10 kHz and total level including those 1/3 octave bands; the $L_{\mathrm{AF,max,k}}$ only needs to be recorded as the total level.

Residual noise during measurements is to be avoided as far as possible. If temporary residual noise cannot be fully avoided, times with high residual noise need to be excluded from the measurements, if possible.

If, for the evaluated measurement series, the residual sound pressure level (background noise level) is 10 dB or more below the measured sound pressure level, the results do not have to be corrected.

For cases when the residual sound pressure level is within a range of 3 dB to 10 dB below, (only) the measured equivalent continuous sound pressure level needs to be corrected according to ISO 1996-2 [6] as

$$L_{Aeq,corr,k} = 10\lg\left(10^{\frac{L_{Aeq,k}}{10}} - 10^{\frac{L_{residual,k}}{10}}\right) \quad \text{in dB} \qquad (8)$$

where

$L_{\mathrm{Aeq,corr,k}}$	is the corrected equivalent sound pressure level at the measurement position (k) and
Lresidual,k	is the residual sound pressure level (background noise level) at the measurement position (k).

In case of determining $L_{\mathrm{Ceq,corr,k}}$, $L_{\mathrm{Aeq,k}}$ from equation (8) is replaced by $L_{\mathrm{Ceq,k}}$

If the residual sound pressure level is less than 3 dB below the measured sound pressure level, no corrections are allowed. In this case, the measurement uncertainty is too large. The correction can be applied for each 1/3 octave band, if the conditions are conspicuous (e.g. low-frequency noise from ships passing by).

6.4.4 Evaluation of the measurement results – sound power level L_{WA}

From sound pressure measurements at a certain distance from the ship the sound power level of the measured ship will be calculated for each measurement position (k) from the (corrected) sound pressure level as shown in equation (9) for each 1/3 octave frequency band from 25 Hz to 10 kHz.

$$L_{WA,k} = 10\lg\left(\frac{1}{2\times\pi\times d_{c,k}^{2}}\right) + L_{Aeq,corr,k} \qquad \text{in dB} \qquad (9)$$

where

$L_{WA,k}$ is the calculated sound power level at the measurement position (*k*).

Total sound power level

The total sound power level of the measured ship will be calculated from the calculated sound power level of all individual measurement positions as the quadratic (energetic) average as shown in equation (10) for each 1/3 octave frequency band from 25 Hz to 10 kHz.

$$L_{WA,total} = 10\lg\left(\frac{1}{n}\sum_{i}10^{\frac{L_{WA,k}}{10}}\right) \qquad \text{in dB} \qquad (10)$$

where

n is the total number of measurement positions (*k*).

The <u>broadband total sound power level</u> will then be calculated by the energetic sum of the total sound power levels for all 1/3 octave frequency bands from 25 Hz to 10 kHz.

The <u>low frequency total sound power level</u> will then be calculated by the energetic sum of the total sound power levels for all 1/3 octave frequency bands from 25 Hz to 160 Hz.

Note: The calculations of the sound power level are based on the assumption, that the exhaust of the funnel outlet is the main noise source of the ship. If the acoustic centre of the ship is different (due to other dominant noise sources on board, e.g. the engine room ventilation), the distance term $d_{c,k}$ needs to be adjusted to be the distance between the respect measurement position and the actual centre of noise of the ship.

7 Documentation of results

The report is to be written in .docx and .pdf format and need to be send to the members of the central project team of NEPTUNES (info@neptunes.pro). Furthermore, the results need to be filled in the Excel-spreadsheet which also needs to be send to the members of the central project team of NEPTUNES. The Excel-spreadsheet can be downloaded from the NEPTUNES website (www.neptunes.pro).

All measured data (raw time data); evaluated data and sound propagation models must be kept available for further assessments and will be made available to the project board of NEPTUNES on request.

In the following sections, the contents of the report will be described in detail. All contents shall be stated as far as the information is accessible. If some data is not available, this shall be marked with "N/A" in the report.

7.1 Formal details in the report

Front page

The front page is to contain at least the following information:

- Ship type and name of ship including registration number
- Company name (performing the measurements)
- Address of the company
- Report date
- Date of the measurements
- Position of the measurements (name of the port and berth)
- Names of the persons involved (author(s) and measurement personal)
- Information on the report's total number of pages, including appendices
- (optional) quality procedure items

Constant information on the following pages

All pages following the front page must contain the following information:

- Company name
- Date
- Numbering

Signatures

Generally, the report is to be signed by its author (optional: and the quality reviewer).

7.2 Content to be documented in the report

General information

a) Day, time and place (port name and berth name) of the measurements;

b) Meteorological conditions during measurements (including wind speed, wind direction, temperature, barometric pressure, humidity). This information shall preferably be requested from the ship owners/crew (measurement data from the ship itself);

General Information on the ship

c) Ship type

d) Name of ship including IMO registration number

e) Year of built of the ship

f) Dead weight tonnage

g) Length and width of the ship

h) (Simplified) sketch of the ship's contour, indicating relevant sound sources, the position of the funnel outlet(s), bow and stern of the ship;

Technical Information on the ship

Preferably to be requested from the ship owner/crew:

i) Number of auxiliary engines (including number and type of different auxiliary engine systems; number of funnel outlets)

j) The existence of a silencer in the exhaust system of the auxiliary engines

k) Maximum possible load of each auxiliary engine in kW

l) Rotational speed of the auxiliary engine(s) in maximum possible load

m) Maximum combined electric load of all pumps/heaters/lights etc. installed that could be used while moored in kW

n) Number of each sound source on board (e.g. number of openings from the different ventilation inlets and outlets, number of cooling containers/reefers on board)

o) Total container capacity in TEU

p) Maximum possible number of plugged in reefers

q) Typical average number of reefers at berth

r) Maximum combined electric load of all pumps/heaters/lights/reefers etc. installed that could be used while moored

s) Average electric load that normally occurs while moored

General information on the measurements

t) Number of each sound source on board that was in operation during the measurements

u) Electrical load of each auxiliary engine during the measurements, preferably documented over time.

v) Number of plugged in reefers during the measurements

w) Sketch of the measurement positions at a certain distance from the ship with respect to the ship contour and orientation of the ship (bow and stern), including the position of the funnel outlet

x) Height of the funnel above quay ground

y) Height of the microphone at the measurement positions at a certain distance from the ship above quay ground (h_m)

z) Soil texture (especially percentage of absorbing and reflecting ground) between ship and measurement positions at a certain distance

aa) If different from the instructions given in section 6.3.2, sketch of the alternatively chosen measuring surfaces for the sound emission measurements on board including the surface area in m² for each sound source

bb) If possible, a picture of each measured sound source

cc) If possible, a picture of each measurement position for the measurements at a certain distance of the ship

dd) Further deviations from the measuring instructions

ee) Short explanation of unexpected observations (e.g. rattling sounds, pronounced tones etc.).

ff) Short explanation about the presence of high sound emissions that are radiated from the ship's hull (e.g. pumps under deck)

Acoustic information

gg) Acoustic measuring equipment used during the measurements (including type, serial numbers and documentation of calibration before and after measurements)

hh) All recorded time signals (.wav files) shall be sent to the central project team upon request. The title of the .wav files shall be named so that it can easily be linked to the respective measurements stated in the report. This includes e.g. the ship name, the date of measurements and the measurement position. The time signals shall at least have a sampling rate of 16 bit and a sampling frequency of 24 kHz.

ii) For each measured sound source (i, j), (sound emission measurements on board of the ship, see section 0):

I) L_{Aeq}: equivalent A-weighted continuous sound pressure level

II) $L_{AF,max}$* maximum sound pressure level during the measurement interval

III) L_{WA} *or* $L_{WA,corr}$ calculated (corrected) A-weighted sound power level; each correction needs to be documented, including the chosen correction factor K

Note: All data shall be recorded as 1/3 octave band levels from at least 25 Hz to 10 kHz (if possible from 10 Hz to 10 kHz) and broadband level including those 1/3 octave bands; the $L_{AF,max}$ only needs to be recorded as total level.

IV) Type (and recorded level) of background noise/residual noise disturbing the measurements.

jj) For each measurement position at a certain distance from the ship and each measurement position (*k*), (complementary measurements at a certain distance, see section 6.4.4):

I) L_{Aeq}: equivalent A-weighted continuous sound pressure level

II) L_{Ceq}: equivalent C-weighted continuous sound pressure level

III) L_{AF95}: 95 % percentile sound pressure level

IV) L_{AF10}: 10 % percentile sound pressure level

V) $L_{AF,max}$: maximum sound pressure level during the measurement interval

Note: All data shall be recorded as 1/3 octave band levels from at least 25 Hz to 10 kHz (if possible from 10 Hz to 10 kHz) and broadband level including those 1/3 octave bands; the $L_{AF,max}$ only needs to be recorded as total level.

The measurement time needs to be documented.

VI) Type (and recorded level) of residual noise/background noise (e.g. what kind of sources causing residual noise were present during measurements and at which time; for example passing ships and air planes, port noise etc.).

kk) The total broadband sound power level $L_{WA,total}$ of the ship (including all 1/3 octave frequency bands from 25 Hz to 10 kHz).

ll) The low frequent sound power level $L_{WA,total,\leq 160Hz}$ of the ship (including all 1/3 octave frequency bands from 25 Hz to 160 Hz).

Additional information

Additionally, each deviation from the measurement instruction needs to be documented; if possible, including sketches.

Any comment and information that is relevant for adapting the outcome of the measurement protocol or for its reproducibility shall be documented at the end of the report. This includes any difficulties occurring during the measurements and that is of relevance for the report.

8 Contributors

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CMP COPENHAGEN MALMÖ PORT

PORT OF GOTHENBURG The Port of Scandinavia

PORT of CORK DEEPWATER MULTI-MODAL PORT

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This measuring report was produced with the assistance and consultancy of:

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Appendix

Exemplary calculation of the measurement position MP 1

In the following the horizontal distance d_h from the funnel outlet to the measurement position MP 1 is calculated for an exemplary measurement setup.

The height of the funnel will most likely be taken from ship drawings. In the following the height is assumed to be h_c = 66 m above quay ground. The microphone height will be chosen with h_m = 6 m above quay ground. The horizontal distance d_h will then be calculated by the angular function

$$d_h = \frac{h_c - h_m}{\tan(\alpha)} \quad \text{in dB} \qquad (11)$$

For the given condition $5° \leq \alpha \leq 20°$ this will result in a rounded distance of 165 m ≤ d_h ≤ 690 m.

Note: The horizontal distance d_h is not similar to the horizontal distance to the ship contour. For the height of the funnel *outlet h_c the distance from the quay ground is important. The distance from the ship keel to the quay therefore needs to be taken into account when taking the height h_c from ship drawings.*