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A MEASUREMENT PROTOCOL FOR SOUND POWER OF MOVING SHIPS

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Residents living nearby large waterways are exposed to environmental noise from seagoing and inland shipping. The exposure level and the associated degree of noise annoyance are in most cases fairly low and therefore this type environmental noise is generally not covered by legal regulations. However, assessing the noise from moving ships on (large) waterways may still be necessary, for example for environmental impact studies and for planning residential development along waterways. For these purposes, as with other motorized means of transport, calculation models may be used in which average sound power data and traffic intensity estimates are used as input parameters. The first step is to perform measurements to determine reliable and representative average source data of the noise sources: for each ship category, the average sound power depending on speed and also the average source height is required. The measurement protocol that is presented in this paper has been drawn up to perform such measurements in a verifiable and repeatable manner. The protocol is based on existing standards and protocols (for example ISO 2922, NEPTUNES 2019, ISO 1996-2).

Keywords: environmental noise, moving ships, sound power measurement

1. Introduction

This measurement protocol is aimed at determining noise and other data from a (large) number of commercial vessels sailing at one or more measurement locations, in such a way that the source data can ultimately – after statistical analysis and categorization – be used in a noise computation model for the purpose of noise mapping, EIA studies and housing developments. The statistical analysis and categorization are not part of this measurement protocol.

This measurement protocol is not intended for enforcement of legal limit values and/or control of noise emissions from individual ships.

The measurements can be carried out manned or unmanned.

2. Requirements

2.1 Measurement location

The measurement method is suitable for ships sailing at a distance D [m] from the measuring position, where D is between 20 m and $15(h_s + h_m)$. Here h_s is the source height and h_m is the measurement height, both relative to the water level[1].

The measuring height h_m is at least 4 m above the water level and also at least 2 m above ground level (under the microphone stand).

For the purpose of determining a suitable measurement location along a wide waterway using the above requirements for D, a provisional source height $h_s = 2$ m for inland shipping and $h_s = 5$ m for sea shipping may be used. (The determination of the actual source height of ships is part of the measurement protocol.)

At greater measurement distances than $15(h_s + h_m)$, the effect of meteorology on the source powers to be determined becomes too great. If larger measurement distances are unavoidable, measurements are only valid during periods with homogeneous atmosphere. As a rule of thumb[2], it can be assumed that this requirement is only met during daytime and only when the vector component of the wind speed parallel to the direction of sound propagation is between +1.0 and +3.0 m/s. Such conditions occur in the Netherlands only during approximately 15 to 20% of all daytime hours.

The microphone is preferably placed within a distance of 5 m from the water's edge[3]. If a greater distance than 5 m from the water's edge is unavoidable, the ground surface between the microphone and the water's edge must be flat (<1 m) and acoustically hard within the source angle of view ϑ. This source angle of view is either 90° or 120°. Its choice[4] is clarified in Section 3.4.

Within this angle of view there must be an unblocked view of the sailing line (or ship path) of the ship to be measured.

The measurement location is chosen in such a way that the influence of residual noise (from non-relevant sources) and reflections is negligible. There may be no reflective objects within 50 m of the measuring position.

The measurement location shall not be chosen near a bend in the waterway.

2.2 Measuring equipment

The measuring microphone must be of IEC class 1 or 2. The higher uncertainty of the measurement chain associated with class 2 microphones leads to a higher total uncertainty, see Section 4. The outdoor microphone shall be equipped with a windscreen.

The equivalent-continuous A-weighted sound pressure level $L_{Aeq}(t)$ [dB re 20 µPa] is measured as a function of time, in one-third octave bands from 25 Hz to 10 kHz, measurement mode Slow. At least 1 spectrum per second must be recorded from each ship pass-by.

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[1] The condition $D \geq 20$ m is required to avoid proximity effects. The condition $D \leq 15(h_s + h_m)$ is loosely based on the ISO 1996:2:2017 condition for soft ground, being $D \leq 10(h_s + h_m)$. According to that measurement standard 'larger distances may be acceptable' for hard ground. In this protocol this latter exception is quantified as $D \leq 15(h_s + h_m)$.

[2] See table 4 of ISO 1996:2:2017.

[3] In ISO 2922:2020, the microphone is placed only 0.5 m away from the water's edge. That condition is considered too impractical for (unmanned) long-term measurements in this protocol.

[4] Ships cannot be assumed to be monopole noise sources. Therefore the sound power is not simply based on L_{Amax}, but evaluated over a reasonable part of the pass-by duration.

The measuring microphone must be suitable for application within the source angle of view. The means that the variation in measurement sensitivity of the microphone within this angle should be less than ±1 dB. If this is not the case, the sound spectra must be corrected in an angle-dependent manner.

The wind speed [m/s] is measured at the measuring position.

2.3 Meteorology

The wind speed above which measurements are rejected is 5.0 m/s. No measurements are taken if precipitation exceeds 1.0 mm per hour[5]. As a large temperature difference between the water of the waterway and the air above it may affect sound propagation, measurements at extremely low and high air temperatures are disregarded (for the Netherlands: below 0° C or above 30° C).

3. Measurement procedure

3.1 Data acquisition

A usable measurement is a ship pass-by of which:

- The aforementioned requirements are met;
- The residual noise level during the pass-by is at least 7 dB below the noise level of the ship[6]. Short noise peaks in the time-history of the pass-by which are not caused by the ship are removed prior to this test;
- Only 1 vessel contributes to the time-history of the pass-by $L_{\mathrm{Aeq}}(t)$. For this purpose, multiple ships and/or barges lashed together count as 1 vessel;
- The measurement distance D [m] and vessel speed V [km/h] are each determined with an accuracy of better than 10% (if the measured distance refers to the vessel's side, half the width of the vessel should be taken into account when calculating D);
- A photograph or video was taken of the vessel;
- The ENI or IMO (inland or maritime shipping) number has been identified;
- The average or dominant source height has h_s been estimated (e.g. visually) or measured (e.g. with an acoustic camera).

3.2 Additional data

The following data are also recorded per pass-by, as far as possible:

- Sailing direction upstream/downstream;
- The measured side (starboard or port);
- Actual current velocity [km/h]
- Draught [m];
- The presence of reefers (on seagoing container ships)[7].

[5] Soft rain (small drops, low wind speed) will generally have a negligible effect.

[6] This 7 dB requirement means that it is considered acceptable that due to residual noise the measured level might be 1,0 dB higher than the actual level. A more stringent requirement for residual noise could be problematic on busy waterways.

[7] The noise power from cooling engines depends on the air temperature and the number of reefers being in operation. The exact number is generally not available (and hard to estimate from the shore).

3.3 Sample size

The sample size required to determine the average source power of a ship class or ship fleet with sufficient accuracy depends on the total number of individual ships in that class or fleet as well as the variance of source powers within that ship class of ship fleet. As an estimate for the Netherlands, the required sample size would be roughly about 500 to 1,000 individual ships[8]. This estimate applies to both inland shipping (Rhine fleet) and sea shipping (Port of Rotterdam).

To determine the speed dependence of the source power within a ship class, it is necessary to collect measurements at various speeds within that class.

3.4 Determination of source power

For a monopole sound source, it would be sufficient to determine the $L_{A,max}$ and calculate the sound power in a straightforward manner using distance D. In general, ships may have a certain directivity pattern of the source radiation in the horizontal plane, which may depend on which sides the (various) ventilation outlets are located. With a view to the ultimate application of the source power in a simple calculation model for environmental noise assessment, in which monopole sources are used, it is necessary to determine the equivalent monopole source power of each ship pass-by on the basis of the time history L_{Aeq}(t). First the angle of view ϑ is chosen, see Fig. 1. If $\vartheta = 90°$ is not sufficient because certain noise sources would not be take into account, for example in long tows, $\vartheta = 120°$ can be used. For short and medium-sized ships, an angle of view of 120° may increase the effect of residual noise and if there is another ship nearby, it may also increase the risk of the measurement being rejected.

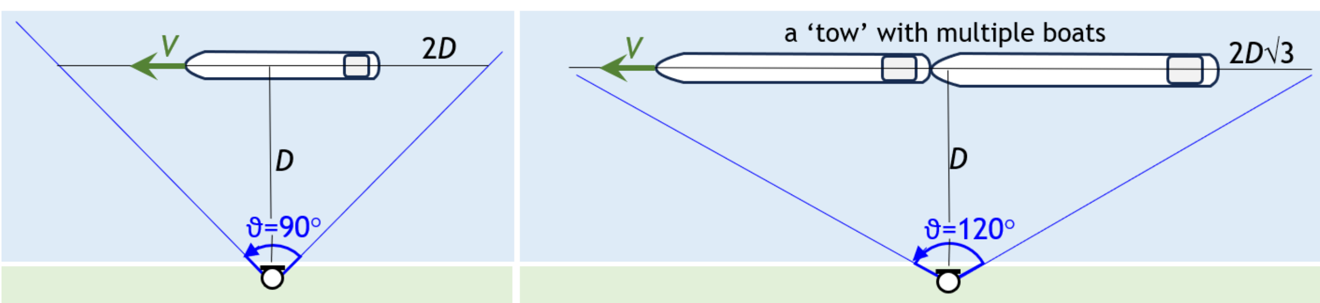

Figure 1: Choice of the angle of view.

Based on the values for the distance D [m], the ship's speed V [km/h] and the angle ϑ, the pass-by duration T_ϑ [s] is calculated as follows: $T_{90°} = 2D / (V/3.6)$ or $T_{120°} = 2D\sqrt{3} / (V/3.6)$.

A time window with length T_ϑ is then moved along the A-weighted signal $L_{Aeq}(t)$ in order to find the highest sound energy average within this window, see Fig. 2. The right graph shows the highest energy average in this example.

For each one third-octave band separately, the energy average is evaluated within this time window. A value $\Delta L_{90°} = 1.15$ dB or $\Delta L_{120°} = 2.35$ dB is added to this in order to find the pass-by maximum of a monopole source that has the same source power as the ship[9]. This pass-by maximum is further referred to as L'_{Amax} spectrum.

[8] It has been assessed that a sample of roughly 10% of a certain ship population should be measured to keep the bias of the average sound power for that population below 0.5 dB, if the standard deviation within that sample equals 3.6 dB. (3.6 dB is the standard deviation assessed by measurement in 2004 for the largest class of Rhine motorships.)

[9] These values for ΔL result from calculating the propagation attenuation according to $20 \log(r) + 0.005r + 9.1$ [dB] where r is the distance and the 3 terms represent the effects of geometric expansion, air damping and ground attenuation, respectively.

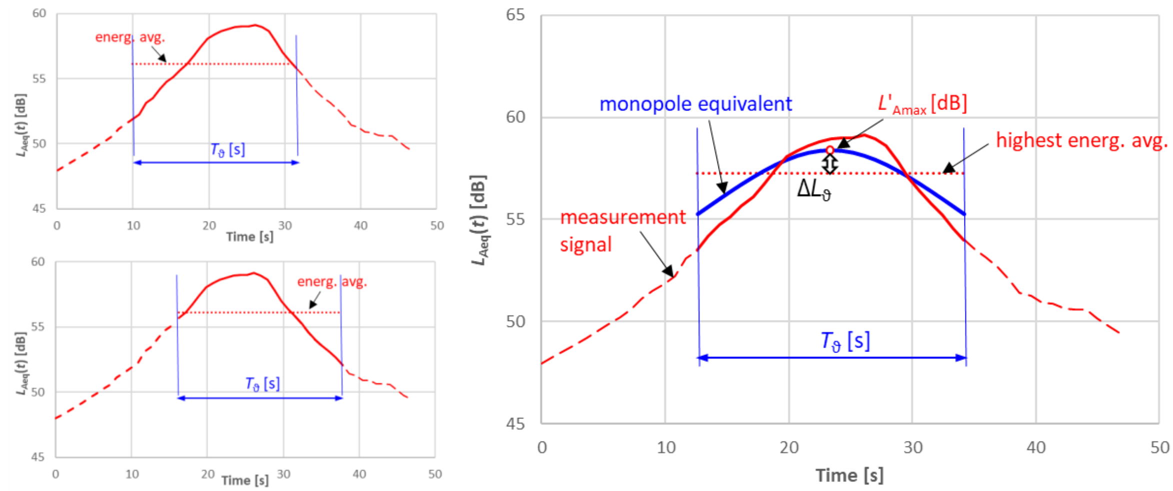

Figure 2: Determination of L'_{Amax} of a ship based on the passage level profile

If desired, an assessment of tonal noise can be made on the L'_{Amax} spectrum of a ship in accordance with ISO 1996-2:2017 Annex K.

After this, the L'_{Amax} spectrum is converted to an octave band spectrum by energy summation of the values of the three contributing one third-octave bands for each octave band (31.5 Hz to 8 kHz). The equivalent source power L'_{WA} [dB re 1 pW] is found per octave band number *i* by:

$$L'_{\mathrm{WA},i} = L'_{\mathrm{Amax},i} + 20\log D + \delta_{\mathrm{air},i} D + 9.1 \qquad (1)$$

where the value for $\delta_{\mathrm{air},i}$ is given in Table 1.

Table 1: The air damping coefficient $\delta_{\mathrm{air},i}$ as a function of frequency.

Octave band number *i*	1	2	3	4	5	6	7	8	9
Centre frequency [Hz]	31.5	63	125	250	500	1000	2000	4000	8000
$\delta_{\mathrm{air},i}$ [dB/m]	0	0	0	0.001	0.002	0.004	0.010	0.023	0.058

4. Measurement uncertainty

The uncertainty in the source power of a pass-by is estimated using the following formula:

$$\sigma = \sqrt{\sigma_{\mathrm{meteo}}^2 + \sigma_{\mathrm{wet}}^2 + \sigma_{\mathrm{res}}^2 + \sigma_{\mathrm{slm}}^2} \qquad (2)$$

In which:

σ_{meteo}: the uncertainty due to meteorological effects (wind, temperature, air damping). The estimated value for this is $D/10$, where D is the measurement distance. E.g. at $D = 80$ m, $\sigma_{\mathrm{meteo}} \approx 0.8$ dB applies.

σ_{wet}: the uncertainty resulting from measuring during periods with a wet windscreen. After a rain shower it may take several hours for the windscreen to dry out. A wet windscreen leads to a significant increase of the measured sound level. For the climate in the Netherlands, where precipitation falls evenly over all seasons, for long-term measurements the uncertainty may be estimated as $\sigma_{wet} \approx 0.3$ dB.

σ_{res}: the uncertainty resulting from unnoticed residual noise may be estimated as $\sigma_{res} \approx 0.5$ dB.

σ_{slm}: the uncertainty in the measurement chain equals 0.5 dB for IEC class 1 and 1.5 dB for IEC class 2. If deviations greater than 0.5 dB occur between calibration prior to the measurements and after the measurements, higher uncertainties can be taken into account.

5. Reporting requirements

The report shall include at least the following items:

1. The purpose of the measurements, name and address of the affiliation and name of the persons who carried out the measurement and analysis, description of the waterway (width [m], average current velocity [km/h], CEMT class (for European fairways), overview map with indication of measurement location).
2. A description of the measurement period, measurement height h_m [m], measuring equipment (with date of last calibration). Photos showing the (surroundings of the) measurement location are also included.
3. Description of the method of: source power analysis, ship speed determination, source height determination and ship identification.
4. For each usable measurement the following quantities are reported (in a table): energy-averaged L_{Aeq} spectrum in one third-octave bands, angle of view ϑ [°], L'_{Amax} spectrum (octaves and overall level), L'_{WA} spectrum (octaves and overall level), measurement uncertainty σ, measurement distance D [m], speed V [km/h], date and time* of pass-by, ENI or IMO number* (and on that basis vessel length [m], year built, gross tonnage and deadweight tonnage), air temperature [°C], wind speed [m/s], wind direction (and parallel wind component if relevant).
5. If available, the following is also recorded for each usable measurement: source height h_s [m], sailing direction upstream/downstream, side (starboard/port), actual current velocity [km/h], draught [m], the presence of reefers (on seagoing container ships).

* The inclusion of timestamp and identification number in the measurement report may be subject to restrictions from applicable regulations, if the report is to be distributed in the public domain.

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