IEC 61400-11

Edition 3.0 2012-11

INTERNATIONAL STANDARD

Wind turbines –
Part 11: Acoustic noise measurement techniques

[..................]

3 Terms and definitions

For the purposes of this standard, the following terms and definitions apply.

3.1
apparent sound power level
L_{WA}
A-weighted sound power level re. 1 pW of a point source at the rotor centre with the same emission in the downwind direction as the wind turbine being measured, L_{WA} is determined at bin centre wind speeds at hub height

Note 1 to entry: Apparent sound power level is expressed in dB re. 1 pW.

3.2
apparent sound power level with reference to wind speed at 10 m height
$L_{WA,10m}$
A-weighted sound power level re. 1 pW of a point source at the rotor centre with the same emission in the downwind direction as the wind turbine being measured, $L_{WA,10m}$ are determined at bin centre wind speeds at 10 m height within the measured wind speed range

Note 1 to entry: Apparent sound power level with reference to wind speed at 10 m height is expressed in dB re. 1 pW.

3.3
audibility criterion
L_a
frequency dependent criterion curve determined from listening tests, and reflecting the subjective response of a “typical” listener to tones of different frequencies

Note 1 to entry: Audibility criterion is expressed in dB re. 20 μPa.

3.4 sound pressure levels

3.4.1 A-weighted sound pressure levels
L_A
sound pressure levels measured with the A frequency weighting networks specified in IEC 61672

Note 1 to entry: A-weighted sound pressure levels are expressed in dB re. 20 μPa.

3.4.2 C-weighted sound pressure levels
L_C
sound pressure levels measured with the C frequency weighting networks specified in IEC 61672

Note 1 to entry: C-weighted sound pressure levels are expressed in dB re. 20 μPa.

3.5
bin centre
centre value of a wind speed bin

3.6
inclination angle
ϕ
angle between the plane of the measurement board and a line from the microphone to the rotor centre

Note 1 to entry: Inclination angle is expressed in °.

3.7
maximum power
maximum value of the binned power curve for the power optimised mode of operation

Note 1 to entry: Maximum power is expressed in kW.

3.8
measured wind speed at height *Z*
$V_{Z,\mathrm{m}}$
wind speed measured at height Z with a mast mounted anemometer

Note 1 to entry: Measured wind speed at height Z is expressed in m/s.

3.9
measured nacelle wind speed at hub height
$V_{\mathrm{nac,m}}$
wind speed measured at hub height with a nacelle anemometer

Note 1 to entry: Measured nacelle wind speed at hub height is expressed in m/s.

3.10
normalised nacelle wind speed at hub height
$V_{\mathrm{nac,n}}$
normalised wind speed measured at hub height with a nacelle anemometer corrected to standard meteorological conditions

Note 1 to entry: Normalised nacelle wind speed at hub height is expressed in m/s.

3.11
normalised wind speed derived from power curve
$V_{\mathrm{P,n}}$
normalised wind speed derived from power curve under standard meteorological conditions

Note 1 to entry: Normalised wind speed derived from power curve is expressed in m/s.

3.12
normalised wind speed at hub height during background noise measurements
$V_{\mathrm{B,n}}$
normalised wind speed at hub height from anemometer

Note 1 to entry: Normalised wind speed at hub height during background noise measurements is expressed in m/s.

3.13
normalised wind speed at hub height
$V_{\mathrm{H,n}}$
normalised wind speed at hub height

Note 1 to entry: Normalised wind speed at hub height is expressed in m/s.

3.14
normalised wind speed at height *Z*
$V_{Z,\mathrm{n}}$
normalised wind speed at height Z from mast mounted anemometer

Note 1 to entry: Normalised wind speed at height Z is expressed in m/s.

3.15
reference distance
R_0
nominal horizontal distance from the centre of the base of the wind turbine to each of the prescribed microphone positions

Note 1 to entry: Reference distance is expressed in m.

3.16
reference roughness length
z_{0ref}
roughness length of 0,05 m used for converting wind speed to meteorological reference conditions

Note 1 to entry: Reference roughness length is expressed in m.

3.17
sound pressure level
L_p
10 times the $\log_{10}$ of the ratio of the square mean sound pressure to the square of the reference sound pressure of 20 µPa

Note 1 to entry: Sound pressure level is expressed in dB re. 20 µPa.

3.18
tonal audibility
$\Delta L_{a,k}$
difference between the tonality and the audibility criterion in each wind speed bin, where k is the centre value of the wind speed bin

Note 1 to entry: Tonal audibility is expressed in dB.

3.19
tonality
ΔL_k
difference between the tone level and the level of the masking noise in the critical band around the tone in each wind speed bin where k is the centre value of the wind speed bin

Note 1 to entry: Tonality is expressed in dB.

3.20
wind speed bin
wind speed interval, 0,5 m/s wide, centred around integer and half-integer wind speeds open at the low end, and closed at the high end

3.21
wind speed at 10 m height
V_{10}
wind speed at 10 m height for reporting apparent sound power levels and spectra with reference to 10 m height

Note 1 to entry: Wind speed at 10 m height is expressed in m/s.

[………………]

5 Outline of method

This part of IEC 61400 defines the procedures to be used in the measurement, analysis and reporting of acoustic emissions of a wind turbine. Instrumentation and calibration requirements are specified to ensure accuracy and consistency of acoustic and non-acoustic measurements. Non-acoustic measurements required defining the atmospheric conditions relevant to determining the acoustic emissions are also specified. All parameters to be measured and reported are identified, as are the data reduction methods required for obtaining these parameters.

Application of the method described in this International Standard provides the apparent A-weighted sound power levels, spectra, and tonal audibility at bin centre wind speeds at hub height and 10 m height of an individual wind turbine. The tonal audibility is included to give information on the presence of tones in the noise. The tonality determined is not giving information on the tonality at other distances. Optionally, measurements can be made in supplementary positions to give information on the directional characteristics.

The method applies to all wind speeds. The wind speed range for documentation is related to the specific wind turbine. As a minimum it is defined as the hub height wind speed from 0,8 to 1,3 times the wind speed at 85 % of maximum power rounded to bin centres. Indicatively, this is a wind speed range of approximately 6 to 10 m/s at 10 m height, depending on the turbine type. The wind speed range may be expanded for instance to comply with national requirements.

The measurements are made at locations close to the turbine in order to minimise the influence of terrain effects, atmospheric conditions or wind-induced noise. To account for the size of the wind turbine under test, a reference distance R_0 based on the wind turbine dimensions is used.

Measurements are taken with a microphone positioned on a measurement board placed on the ground to reduce the wind noise generated at the microphone and to minimise the influence of different ground types.

Measurements are taken with a microphone positioned on a measurement board placed on the ground to reduce the wind noise generated at the microphone and to minimise the influence of different ground types.

Measurements of sound pressure levels, sound pressure spectra, wind speeds, electrical power, rotor rotational speed and, if measured, pitch angle are made simultaneously over short periods of time and over a wide range of hub height wind speeds. The sound pressure levels and spectra at bin centre wind speeds are determined and used for calculating the apparent A-weighted sound power spectra and levels.

Annexes are included that cover:

- other possible characteristics of wind turbine noise emission and their quantification (Annex A informative);
- assessment of turbulence intensity (Annex B informative);
- assessment of measurement uncertainty (Annex C informative);
- apparent roughness length (Annex D informative);
- classification of a secondary wind screen (Annex E informative);
- small wind turbines (Annex F normative);
- air absorption (Annex G informative).

[..................]

6.1 Acoustic instruments

6.1.1 General

The following equipment is necessary to perform the acoustic measurements as set forth in this standard.

6.1.2 Equipment for the determination of the equivalent continuous A-weighted sound pressure level

The equipment shall meet the requirements of an IEC 61672 class 1 sound level meter. The diameter of the microphone diaphragm shall be no greater than 13 mm.

6.1.3 Equipment for the determination of A-weighted 1/3-octave band spectra

In addition to the requirements given for class 1 sound level meters, the equipment shall have a constant frequency response over at least the frequency range given by the 1/3-octave bands with centre frequencies from 20 Hz to 10 kHz. The filters shall meet the requirements of IEC 61260 for class 1 filters.

The equivalent A-weighted continuous sound pressure levels in 1/3-octave bands with centre frequencies from 20 Hz to 10 kHz shall be determined simultaneously.

6.1.4 Equipment for the determination of narrow band spectra

The equipment shall fulfil the relevant requirements for IEC 61672 series class 1 instrumentation in the 20 Hz to 11 200 Hz frequency range.

6.1.5 Microphone with measurement board and windscreen

The microphone shall be mounted at the centre of a flat hard board with the diaphragm of the microphone in a plane normal to the board and with the axis of the microphone pointing towards the wind turbine, as in Figure 1 and Figure 2. The measurement board shall be circular with a diameter of at least 1,0 m and made from material that is acoustically hard, such as plywood or hard chip-board with a thickness of at least 12,0 mm or metal with a thickness of at least 2,5 mm. In the exceptional case that the board is split (i.e. not in one piece) there are considerations; the pieces shall be level within the same plane, the gap less than 1 mm, and the split shall be off the centre line and parallel with the microphone axis as shown in Figure 1a.

The windscreen to be used with the ground-mounted microphone shall consist of a primary and, where necessary, a secondary windscreen. The primary windscreen shall consist of one half of an open cell foam sphere with a diameter of approximately 90 mm, which is centred around the diaphragm of the microphone, as in Figure 2.

The secondary windscreen may be used when it is necessary to obtain an adequate signal-to-noise ratio at low frequencies in high winds.

If the secondary windscreen is used, the influence of the secondary windscreen on the frequency response shall be documented and corrected for in 1/3-octave bands. A procedure for calibration of the secondary windscreen can be found in Annex E together with suggestions for design and demands on the insertion loss.

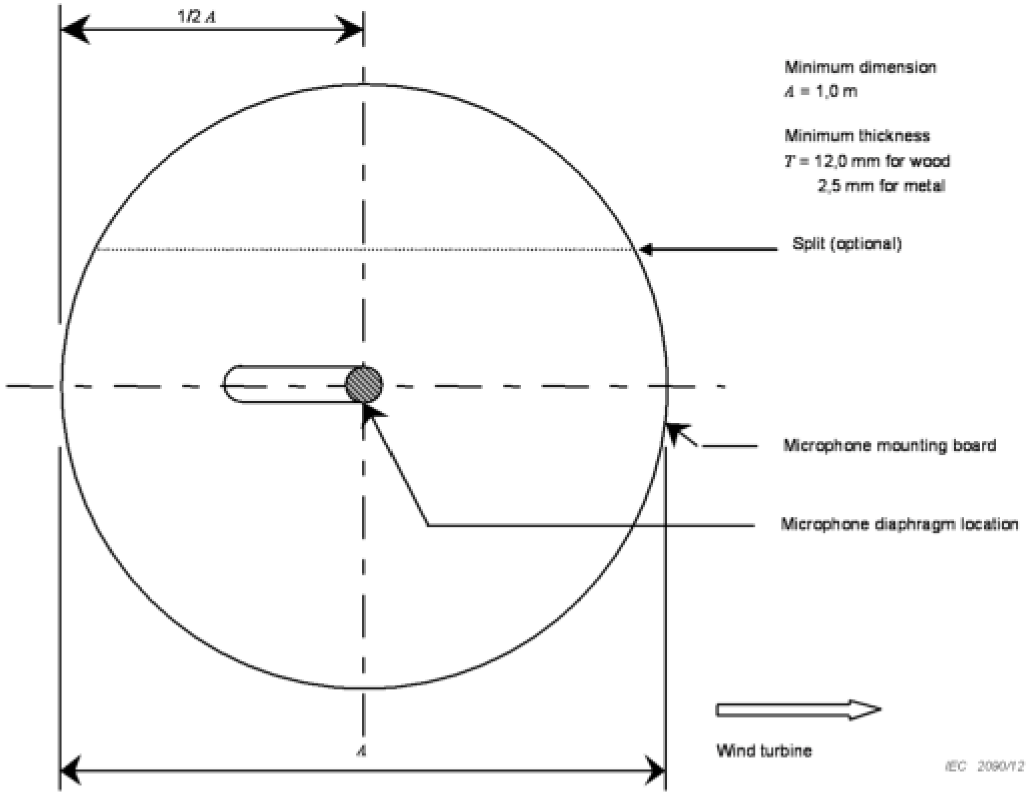

Figure 1a – Mounting of the microphone – Plan view

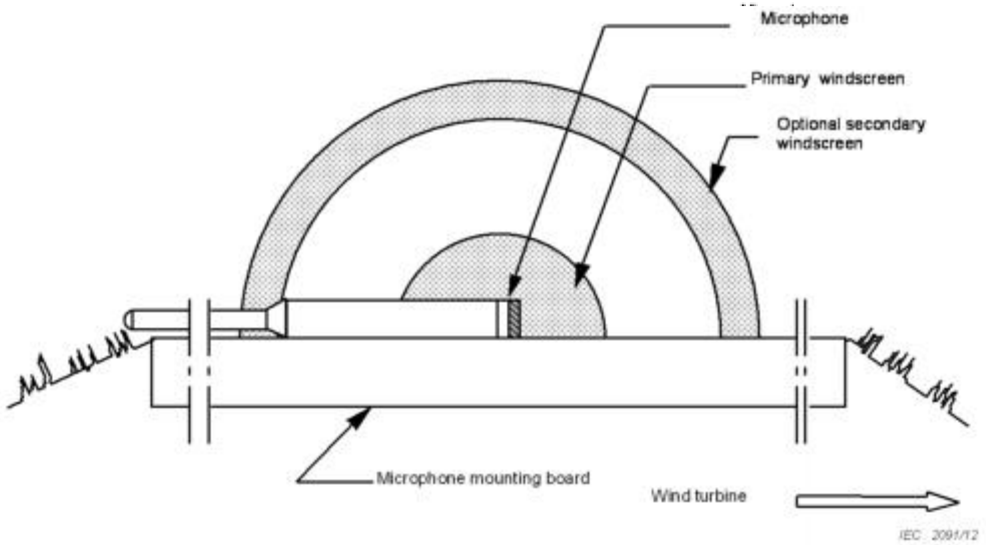

Figure 1b – Mounting of the microphone – Vertical cross-section

Figure 1 – Mounting of the microphone

[………………]

7 Acoustic measurements and measurement procedures

7.1 Acoustic measurement positions

To fully characterize the noise emission of a wind turbine, the following measurement positions are required.

One, and optionally another three, microphone positions are to be used. The positions shall be laid out in a pattern around the vertical centreline of the wind turbine tower as indicated in the plan view shown in Figure 3. The required downwind measurement position is identified as the reference position, as shown in Figure 3. The direction of the positions shall be within ±15° relative to the downwind direction of the wind turbine at the time of measurement. The downwind direction can be derived from the yaw position. The horizontal distance R_0 from the wind turbine tower vertical centreline to each microphone position shall be as shown in Figure 3, with a tolerance of ±20 %, maximum ±30 m, and shall be measured with an accuracy of ±2 %.

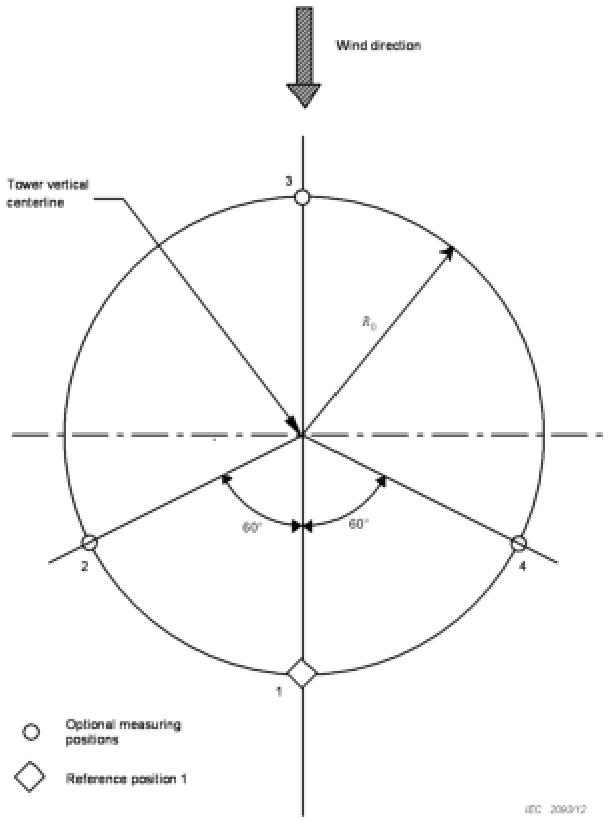

Figure 3 – Standard pattern for microphone measurement positions (plan view)

[..................]

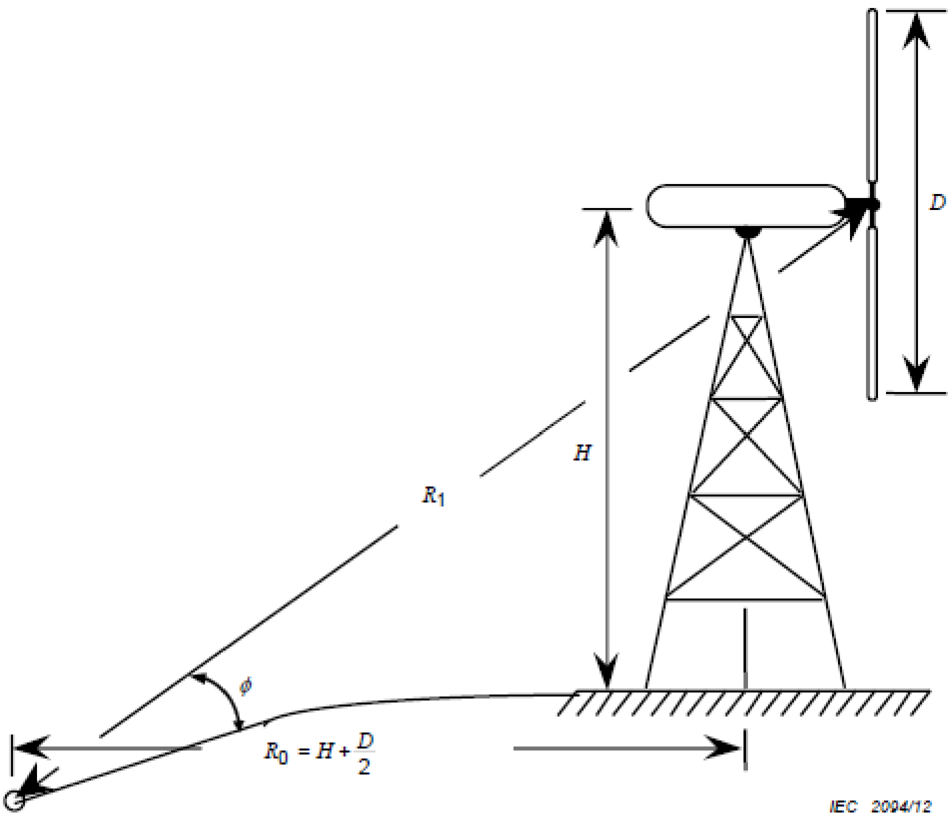

Figure 4a – Horizontal axis turbine

As shown in Figure 4a, the reference distance R_0 for horizontal axis turbines is given by:

$$R_0 = H + \frac{D}{2} \quad (1)$$

where

H is the vertical distance from the ground to the rotor centre; and

D is the diameter of the rotor.

To minimize influence due to the edges of the measurement board on the measurement results, it shall be ensured that the board is positioned flat on the ground. Any edges or gaps under the board should be levelled out by means of soil. The inclination angle ϕ, as shown in Figure 4, shall be between 25° and 40°. This may require adjustment of the measurement position within the tolerances stated above. Additional considerations shall be made for measurements in complex terrain to avoid influence such as screening or reflections from obstructions or terrain.

The measurement position shall be chosen so that the calculated influence from any reflecting structures, such as buildings or walls, shall be less than 0,2 dB.

7.2 Acoustic measurements

7.2.1 General

The acoustic measurements shall permit the following information to be determined about the noise emission from the wind turbine at bin centre wind speeds:

– the A-weighted apparent sound power level;
– the A-weighted 1/3-octave band levels;
– the tonal audibility.

Optional measurements may include directivity, infrasound, low-frequency noise and impulsivity.

7.2.2 Acoustic measurement requirements

For all acoustic measurements, the following requirements are valid:

- The complete measurement chain shall be calibrated at least at one frequency before and after the measurements, or if the microphones are dis- and reconnected during the measurements.
- All acoustical signals shall be recorded and stored for later inspection.
- Periods with intruding intermittent background noise (as from aircraft) shall be omitted.
- The wind speed range is related to the specific wind turbine. As a minimum it is defined as the hub height wind speed from 0,8 to 1,3 times the wind speed at 85 % of maximum power rounded to wind speed bin centres.
- With the wind turbine stopped, and using the same measurement set-up, the background noise shall be measured immediately before or after each measurement series of wind turbine noise and during similar wind conditions. When measuring background noise, every effort shall be made to ensure that the background sound measurements are representative of the background noise that occurred during the wind turbine noise emission measurements. It is recommended to measure the background noise several times during the measurement period to cover the same wind speed range as for the total noise.
- The measurements shall cover as broad a range of wind speeds as practically possible. To obtain a sufficient range of wind speeds it may be necessary to take the measurements in several measurement series.
- At least 180 measurements shall be made overall for both total noise and background noise covering corresponding wind speed ranges.
- At least 10 measurements shall be made in each wind speed bin for both total noise and background noise.

Additionally, the following requirements are valid for the individual acoustic measurements.

7.2.3 A-weighted sound pressure level

The equivalent continuous A-weighted sound pressure level of the noise from the wind turbine shall be measured at the reference position. Each measurement shall be integrated over a period of 10 s.

7.2.4 A-weighted 1/3-octave band measurements

A-weighted 1/3-octave spectra are measured synchronously with the overall sound pressure levels as the energy average over 10 s periods. As a minimum, 1/3-octave bands with centre frequencies from 20 Hz to 10 kHz, inclusive, shall be measured. A-weighting shall be applied in the time domain i.e. before the frequency analysis.

Background measurements with the wind turbine stopped shall satisfy the same requirements.

7.2.5 A-weighted narrow band measurements

Narrowband spectra are measured synchronously with the sound pressure levels as the energy average over 10 s periods. Narrow band spectra shall be A-weighted. A Hanning window with an overlap of at least 50 % shall be used. The frequency resolution shall be between 1 and 2 Hz.

Additional noise measurements may be needed to determine the audibility of an identified tone as stated in 9.5.8.

Background noise measurements shall be used to determine that tones do not originate from background noise.

7.2.6 Optional acoustic measurements at positions 2, 3 and 4

Measurements in the non-reference positions shall fulfil the requirements for the reference position.

The measurements in the non-reference positions should be made simultaneously with corresponding measurements in the reference position. The measurements in the three non-reference positions can be made individually, but each one shall be made simultaneously with measurement in the reference position.

[.....]

8.2 Wind speed measurements

The wind speed is to be measured from the produced power through a power curve.

For sections of the power curve where the requirements in Equation (3) are not met, the wind speed cannot be determined from the power readings and the nacelle anemometer shall be used. If no nacelle anemometer is available an anemometer shall be mounted on the nacelle. Guidance for mounting the nacelle anemometer is given in IEC 61400-12-2.

The wind speed measured by the nacelle anemometer shall be representative of the wind speed hitting the rotor.

For measurements of background noise an anemometer mounted on a met mast of at least 10 m height shall be used. The position of the met mast should be relatively undisturbed and represent the free wind at the turbine position. In order to ensure a correlation between the measured wind speeds at the met mast, at hub height, and the wind at the microphone position, guidance on the met mast position is given in Figure 5.

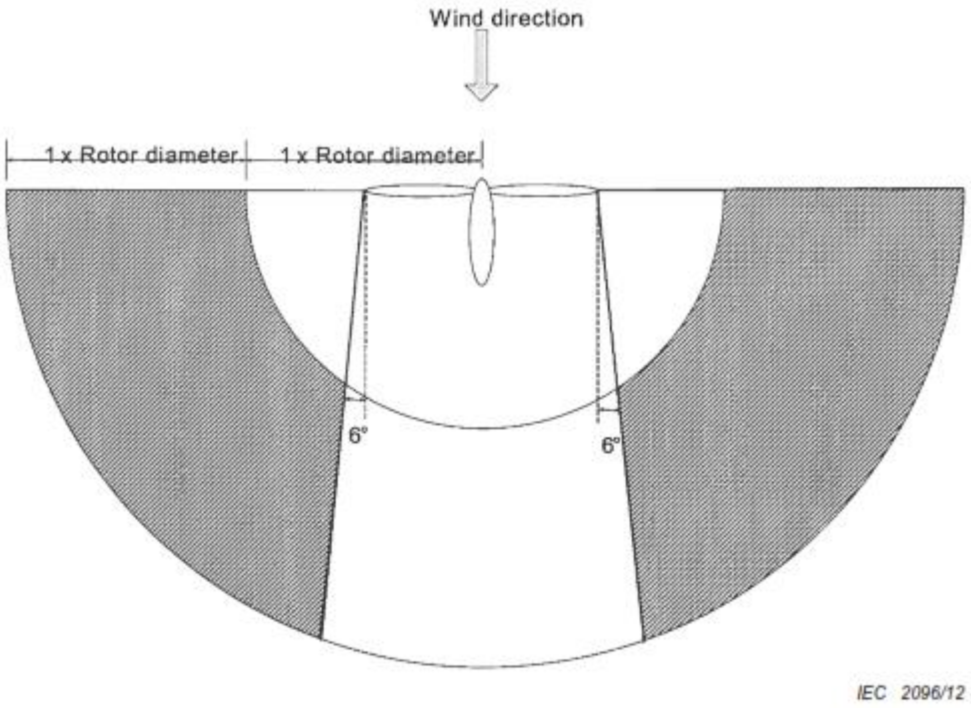

Figure 5 – Acceptable meteorological mast position (hatched area)

8.2.2 Wind speed measurements during background noise measurements

For background noise measurements, the wind speed shall be measured with a met mast mounted anemometer at a height of at least 10 m. For in-situ calibration purposes the wind speed from the met mast shall be measured during the entire measurement.

[..................]

9 Data reduction procedures

9.1 General methodology for sound power levels and 1/3-octave band levels

The aim of this procedure is to produce sound power spectra in 1/3-octave bands and overall sound power levels using statistical methods. It should be noted there are two types of averaging used in the analysis: arithmetic averaging for non-acoustic data and energy averaging for acoustic data.

The uncertainty is also determined in this subclause and determined along with the sound power spectra in 1/3-octave bands and overall sound power levels. For most instruments the accuracy is given. Before using this in the text below, the accuracy shall be converted into an uncertainty. Guidelines are given in Annex C.

Noise and wind speed are measured and averaged over 10 s periods. Noise is measured both as the A-weighted sound pressure level L_{Aeq} and A-weighted 1/3-octave spectrum $L_{Aeq,o}$. Each 1/3-octave spectrum is normalized to the measured value for the L_{Aeq}.

The data points are sorted into wind speed bins and averaged giving:

- average wind speed;
- average A-weighted 1/3-octave spectrum;

- corresponding standard uncertainties.

The average wind speed may not be at the bin centre.

For each 1/3-octave band the value of the noise at the bin centre is found by linear interpolation between the adjacent bin average values. This results in a 1/3-octave spectrum at the centre of each bin.

The procedure described above applies to both the total noise and the background noise to determine bin centre spectra.

At each wind speed bin centre the wind turbine noise 1/3-octave spectrum is found by correcting the total noise spectrum with the background noise spectrum for the same wind speed bin centre. If the difference between the sum of the 1/3-octave bands of the total noise and the sum of the 1/3-octave bands of background noise is between 3 and 6 dB the result shall be marked with an asterisk when reported. If the difference is 3 dB or less, the result for that wind speed bin shall not be reported.

In the description below following subscripts and indexes are used:

i 1/3 octave band number (e.g. i = 1 for 20 Hz centre frequency, i = 2 for 25 Hz centre frequency, ... , i = 28 for 10 kHz centre frequency);

j 10 s measurement period number (each bin should have the minimum of 10 points per bin therefore j = 1 to 10 or greater);

k wind speed bin (i.e. k = 6 m/s bin, k = 6,5 m/s bin, k = 7 m/s bin, etc.);

V bin centre value;

o measured 1/3 octave spectrum;

n normalized spectrum;

T total noise;

B background noise;

C background corrected total noise.

9.2 Calculation of sound pressure levels

9.2.1 General

The noise is measured as an equivalent noise level L_{Aeq} and a 1/3-octave band spectrum with centre frequencies from 20 Hz to 10 kHz. The equivalent noise level $L_{\mathrm{Aeq,o}}$ is determined from the energy sum of the 1/3-octave bands. The difference L_{Aeq}-$L_{\mathrm{Aeq,o}}$ is determined.

$$L_{\mathrm{Aeq,o},j} = 10 \cdot \log \sum_{i=1}^{28} 10^{\left(\frac{L_{\mathrm{Aeq},i,j}}{10}\right)} \tag{6}$$

$$\Delta_j = L_{\mathrm{Aeq},j} - L_{\mathrm{Aeq,o},j} \tag{7}$$

This difference is added to each individual band in the 1/3-octave band spectrum to give the normalized 1/3-octave band spectrum for each measurement period j.

$$L_{\mathrm{Aeq,n},i,j} = L_{\mathrm{Aeq},i,j} + \Delta_j \tag{8}$$

where

$L_{\mathrm{Aeq,o},j}$ is the A-weighted sound pressure level calculated from the 1/3-octave spectrum in the measurement period j;

$L_{\mathrm{Aeq},i,j}$ is the A-weighted sound pressure level at 1/3-octave band i in the measurement period j;

$L_{\mathrm{Aeq},j}$ is the measured A-weighted sound pressure level in the measurement period j;

Δ_j is the difference between the calculated A-weighted sound pressure level from the 1/3-octave spectrum and the measured A-weighted sound pressure level;

$L_{\mathrm{Aeq,n},i,j}$ is the normalized 1/3-octave band i in the measurement period j.

If a secondary wind screen is used, the normalized spectra shall be corrected for the influence of the secondary wind screen in 1/3-octave bands.

All the following analyses are made using the normalized 1/3-octave band spectra. The 1/3-octave band spectra are sorted into wind speed bins k. Average value and uncertainties for both sound pressure level and wind speed for each bin are calculated using the following expressions within each wind speed bin k.

The total noise and background noise are analysed using the same principles.

[..................]

9.3 Apparent sound power levels

Within each bin, the apparent sound power level for each 1/3-octave band $L_{WA,i,k}$ is calculated from the corresponding background corrected sound pressure level for the same 1/3-octave band, $L_{V,c,i,k}$, at the bin centre wind speeds as follows:

$$L_{WA,i,k} = L_{V,c,i,k} - 6 + 10\log\left[\frac{4\pi R_1^2}{S_0}\right] \tag{26}$$

where

$L_{V,c,i,k}$ is the background corrected A-weighted sound pressure level in 1/3-octave band i at the bin centre wind speed k under meteorological reference conditions;

R_1 is the slant distance in meters from the rotor centre to the microphone as shown in Figure 4; and

S_0 is a reference area, S_0 = 1 m^2.

The 6 dB constant in Equation (26) accounts for the approximate pressure doubling that occurs for the sound level measurements on a measurement board.

The estimate for the A-weighted sound power level in bin k is calculated by energy summing of all 1/3-octave band sound power values.

$$L_{WA,k} = 10 \cdot \log \sum_{i=1}^{28} 10^{\left(\frac{L_{WA,i,k}}{10}\right)} \qquad (27)$$

If the difference between the sum of the 1/3-octave bands of the total noise and the sum of the 1/3-octave bands of the background noise is between 3 and 6 dB the result shall be marked with an asterisk when reported. If the difference is 3 dB or less, the result for that wind speed bin shall not be reported.

$$u_{L_{WA,k}} = \frac{\sum_{i=1}^{28}\left(u_{c,i,k} 10^{\left(\frac{L_{WA,i,k}}{10}\right)}\right)}{\sum_{i=1}^{28} 10^{\left(\frac{L_{WA,i,k}}{10}\right)}} \qquad (28)$$

Equation (28) is valid for correlated uncertainties. The uncertainties of the sound power levels of the 1/3 octave bands are assumed to be correlated.

Guidance for Type B uncertainties are given in Annex C.

9.4 Apparent sound power levels with reference to wind speed in 10 m height

To calculate the apparent sound power level with reference to wind speed in 10 m height, $L_{\text{WA},10\text{ m},k}$, at integer wind speeds within the measurement range, the following procedure is used:

Calculate the corresponding wind speed at hub height, $V_{H,\text{n}}$ by using Equation (29). Then use linear interpolation and the background noise correction as described in Equations (20) to (26).

$$V_H = V_{10} \cdot \left(\frac{\ln\left(\frac{H}{z_{0\,\text{ref}}}\right)}{\ln\left(\frac{10}{z_{0\,\text{ref}}}\right)}\right) \qquad (29)$$

$L_{\text{WA},10\text{ m},k}$ for integer wind speeds k within the measurement range with corresponding uncertainty, $u_{L_{\text{WA},10\text{m},k}}$ is calculated by using Equations (27) and (28).

[..................]

10 Information to be reported

10.1 General

The configuration of the wind turbine and its operating conditions shall be reported as follows.

10.2 Characterisation of the wind turbine

The wind turbine configuration shall include the following information:

- Wind turbine details:
  - manufacturer;
  - model number;
  - serial number.
- Operating details:
  - vertical or horizontal axis wind turbine;
  - upwind or downwind rotor;
  - hub height;
  - horizontal distance from rotor centre to tower axis;
  - diameter of rotor;
  - tower type (lattice or tube);
  - passive stall, active stall, or pitch controlled turbine;
  - constant or variable speed;
  - power curve;
  - rotational speed at wind bins;
  - rated power output;
  - control software version.
- Rotor details:
  - rotor control devices;
  - presence of vortex generators, stall strips, serrated trailing edges;
  - blade type;
  - serial number;
  - number of blades.
- Gearbox details:
  - manufacturer;
  - model number;
  - serial number.
- Generator details:
  - manufacturer;
  - model number;
  - serial number.

10.3 Physical environment

The following information on the physical environment at and near the site of the wind turbine and the measuring positions shall be reported:

- details of the site including location, site map and other relevant information;
- type of topography/terrain (hilly, flat, cliffs, mountains, etc.) in surrounding area (nearest 1 km);
- surface characteristics (such as grass, sand, trees, bushes, water surfaces);
- nearby reflecting structures such as buildings or other structures, cliffs, trees, water surfaces;
- other nearby sound sources possibly affecting background noise level, such as other wind turbines, highways, industrial complexes, airports;
- two photos, one taken in the direction of the turbine from the reference microphone position, and one taken from the wind mast toward the turbine;
- a photo of the microphone on the measurement board positioned on the ground and immediate surroundings, see Figure 2.

10.4 Instrumentation

The following information on the measurement instrumentation shall be reported:

- manufacturer(s);
- instrument name and type;
- serial number(s);
- other relevant information (such as last calibration date);
- met mast anemometer position and height for each measurement series;
- influence of secondary wind screen, if used;
- measurement position of each microphone for each measurement series.

10.5 Acoustic data

The following acoustic data shall be reported:

- measurement position of each microphone for each measurement series;
- time and date of each measurement series;
- apparent sound power level $L_{\mathrm{WA},k}$ at bin centre wind speeds at hub height;
- apparent sound power level $L_{\mathrm{WA,10\ m},k}$ at integer wind speeds at 10 m height;
- a plot showing all measured data pairs at reference position 1 of the measured total noise and background noise (with different symbols). Differentiate in the plot if the wind speed was derived from different methods. On the plot, the axes of L_{Aeq} and $V_{H,n}$ shall be linear, and scaled so that 1 m/s corresponds to 2 dB;
- a plot showing all measured total noise versus electrical power data;
- table and plot of sound power spectrum in 1/3-octaves for each bin centre wind speed; coordinates plotted at 1 octave = 10 dB, and levels bracketed as appropriate;
- table showing total noise and background noise. The values shall be calculated as the energy sum of the average 1/3-octave band spectra for each bin. The corrected L_{Aeq} at bin centre values calculated from the corrected 1/3-octave band spectrum at the bin centre can be included in the table. If the difference between total noise and background noise is between 3 and 6 dB the result shall be marked with an asterisk. If the difference is 3 dB or less the result shall not be used.

[..................]

10.6 Non-acoustic data

The following non-acoustic data shall be reported:

- wind speed determination method(s);
- plots of wind speed from the power curve relative to measured nacelle wind speed and met mast measured wind speed;
- rotor rotational speed;
- air temperature;
- atmospheric pressure;
- roughness length (estimated);
- range of the downwind direction during the measurement including the method used to ensure the yaw direction was within ±15° of the microphone position.

Optional non-acoustic data that may be reported include:

- estimates or measurements of the turbulence intensity during acoustic measurements;
- whether the turbulence intensity data were determined by measurement or by inference from meteorological conditions.

Annex D
(informative)

Apparent roughness length

D.1 General

Roughness length is the parameter used for calculation of the wind speed at different heights based only on the terrain conditions. In Table D.1 guidance on how to estimate the roughness length is given. Since this is crude estimate, valid only for cloudy conditions, this annex gives some guidance on how to determine an apparent roughness length either from wind speed measurements or from typical wind shear data measured during site evaluation.

Table D.1 – Roughness length

Type of terrain	Roughness length z_0 m
Water, snow or sand surfaces	0,000 1
Open, flat land, mown grass, bare soil	0,01
Farmland with some vegetation	0,05
Suburbs, towns, forests, many trees and bushes	0,3

D.2 Method for determination of roughness length.

Roughness length is a parameter in the equation for the logarithmic wind profile. The equation for the logarithmic wind profile is given in Equation (D.1).

$$V_z = V_{z,\mathrm{ref}} \cdot \left(\frac{\ln\left(\frac{z}{z_0}\right)}{\ln\left(\frac{z_{\mathrm{ref}}}{z_0}\right)} \right) \tag{D.1}$$

where,

V_z is the wind speed at height z above ground level;

$V_{z,\mathrm{ref}}$ is the wind speed at height z_{ref} above ground level (typical hub height);

z is the height above ground for the desired wind speed;

z_{ref} is the height above ground where the wind speed is known;

z_0 is the roughness length in the wind direction under consideration.

Equation (D.1) can be rearranged to

$$z_0 = e^{\left(\frac{V_z \cdot \ln(z_{\mathrm{ref}}) - V_{z,\mathrm{ref}} \cdot \ln(z)}{V_z - V_{z,\mathrm{ref}}} \right)} \tag{D.2}$$

By measuring the wind velocity in two different heights above ground we are able to determine the roughness length in the wind direction under consideration. The roughness length is determined by averaging all the calculated 10 s roughness length during the

complete noise measurement. Preferable z_{ref} is chosen to be hub height, and z is chosen to be tip low height, in order to minimise local ground effects.

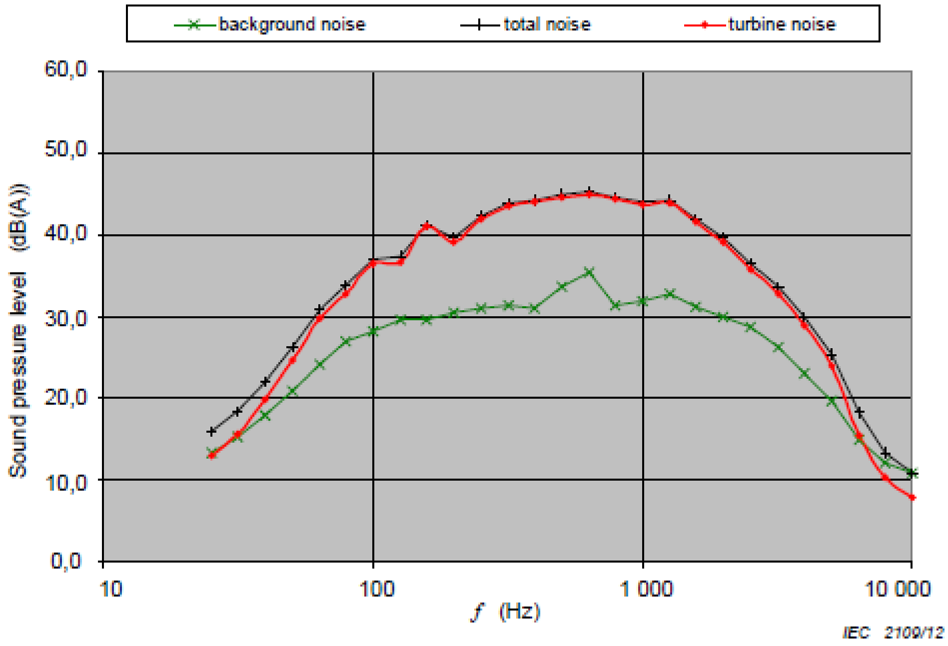

Figure G.1 – Example of 1/3-octave spectrum