# TEST REPORT

DANAK TEST Reg.nr. 134



**Acoustic Noise Emission, IEC 61400-11 ed.2**
Viking 25 Wind Turbine



Report no.: P6.001.11
Århus 10. February 2011
Project: 35.6349.01

Client:

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Ver. 2007.11.30 PHe

**Summary:**

For the HSWind wind turbine type Viking 25, the following acoustic data has been determined according to IEC 61400-11 Edition 2.1:

| Standardized wind speed, $V_s$ [m/s] | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|
| Power [kW], from power curve | 9.9 | 14.5 | 18.6 | 22.1 | 25.4 |
| Apparent sound power level, $L_{WA}$ [dB re 1 pW] | 93.9 | 94.9 | 95.8 | 96.4 | 97.2 |
| Tonality [dB] | 0.1 | 1.0 | 0.3 | 0.1 | -0.2 |
| Uncertainty [dB] | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 |

Third octave band spectra are shown in figure 11.

The measurements were carried out on 11. January 2011, at Randers, Denmark.

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# 1 INTRODUCTION

HS Wind A/S has requested Grontmij | Carl Bro A/S. Acoustica, to carry out acoustic noise measurements for a Viking 25 wind turbine erected near Randers, Denmark.

Grontmij | Carl Bro A/S, Acoustica, is accredited by DANAK (Danish Accreditation) under EN ISO/IEC 17025 to perform testing using the relevant standards.

# 2 METHODOLOGY

## 2.1 Standard

The measurements, data reduction, and calculations were carried out according to the standard IEC 61400 –11, edition 2.1 “Wind turbine generator systems – Part 11: Acoustic noise measurement techniques”, 2006-11.

## 2.2 Deviations from IEC 61400-11 Ed. 2.1

No data for electrical power, nacelle wind speed, RPM and yaw were registered during the measurements. In order to reduce the background noise from traffic on Clausholmvej a small barrier of bales of straw was set up around the microphone as shown in photos 2 and 4. The bales of straw is considered to be highly absorptive thus not influencing measuring the noise from the wind turbine.

## 2.3 Options used from IEC 61400-11 Ed. 2.1

As the hub height is only 18 m for the wind turbine it was decided to determine the wind speed according to method 2, through direct measurements at 10 m height. This is in agreement with the suggestions in 88/384/CDV dated 2010-11-26 for revision of 61400-11 for small wind turbines.

## 3 CHARACTERIZATION OF THE WIND TURBINE

**Table 2. Information about the wind turbine as provided by the manufacturer.**

| | |
|---|---|
| Manufacturer | HS Wind Aps |
| Model number | Viking 25 |
| Serial number | N/A |
| Further identification | Prototype |
| Configuration | Horizontal axis, upwind rotor |
| Rotor center height | 18 m |
| Horizontal distance from rotor center to tower axis | ~ 1 m |
| Diameter of rotor | 6.5 m |
| Tower type | Tubular HSWind Tilt |
| Power control | Stall |
| Rotational speed | 65 RPM |
| Power curve | See table 3 |
| Rated power output | 25 kW |
| Control software version | Mita-Teknik IC 1100 |
| Rotor control devices | Aerodynamic brakes |
| Vortex generators, stall strips, serrated trailing edges | N/A |
| Blade type | OLW 620 Passive |
| Number of blades | 3 |
| Gear manufacturer | N/A |
| Gear model number | STM-EX1501/804 23.25 PAM200D M1s |
| Gear serial number | N/A |
| Gear configuration | Planetary + helical |
| Gear ratio | 1:23.25 |
| Generator manufacturer | VEM Motors GmbH |
| Generator model number | G21R 200 L4 HW |
| Generator serial number | N/A |
| Rated RPM / Rated Slip | 1525/- |

The power curve below is provided by the manufacturer. The power curve has not been used in connection with the noise measurements.

**Table 3. Power output at sea level air density (1,225 kg/m$^3$ )**

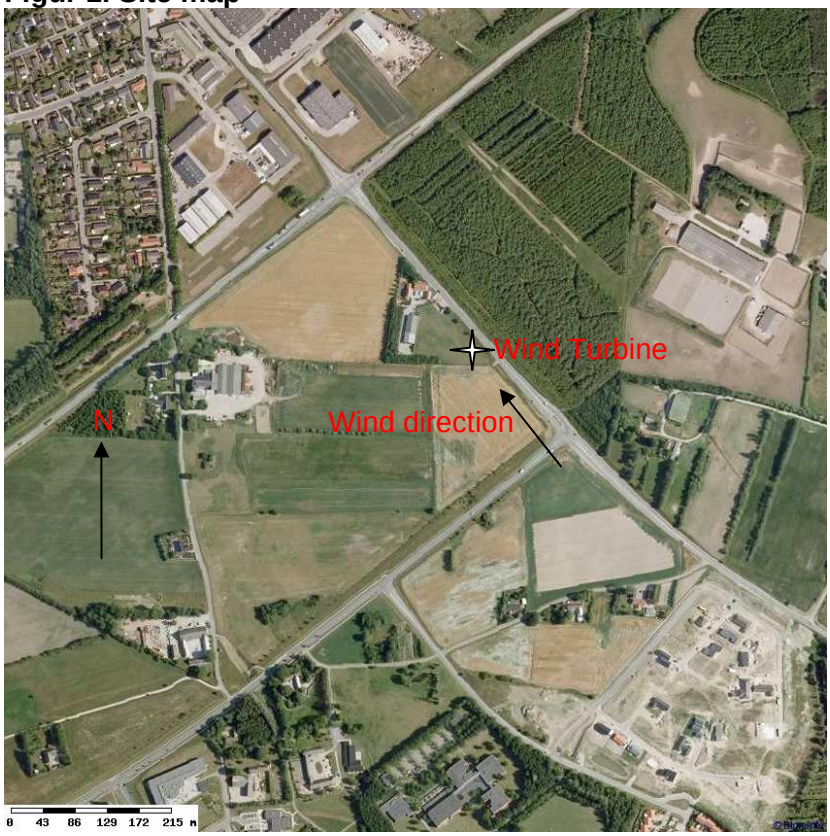
| Normalized Hub Height Wind Speed [m/s] | Power Output [kW] |
|---|---|
| 3.75 | 0.19 |
| 4.25 | 0.78 |
| 4.75 | 0.26 |
| 5.25 | 4.21 |
| 5.75 | 6.21 |
| 6.25 | 8.14 |
| 6.75 | 10.20 |
| 7.25 | 12.36 |
| 7.75 | 14.35 |
| 8.25 | 16.27 |
| 8.75 | 18.11 |
| 9.25 | 19.73 |
| 9.75 | 21.33 |
| 10.25 | 22.78 |
| 10.75 | 24.67 |
| 11.25 | 25.69 |
| 11.75 | 26.00 |

## 4 PHYSICAL ENVIRONMENT

**Table 4. The physical environment at and near the site of the wind turbine and the measuring positions**

| | |
|---|---|
| Site location | North 56 26 16, East 10 04 34.<br>Clausholmvej 24, 8960 Randers, Denmark |
| Topography within 1 km from turbine | Almost flat, agricultural land. Altitude at turbine: 40 m above sea level. Relative altitudes within a 1 km radius: +10 m to -10 m. East of the wind turbine the terrain have a steep rise of several meters to an area with small trees. |
| Surface characteristics | Grass, Crop. |
| Nearby reflecting structures | None |
| Other nearby sound sources | Road traffic noise from Clausholmvej and Paderup Boulevard |

**Figur 1. Site map**




**Figur 2. Photo taken in the direction of the turbine from the reference microphone position. Note the reference microphone is behind the bales of straw.**

**Figur 3. Photo taken in the direction of the wind mast from the turbine**

**Figur 4. Photo of the microphone on the measurement board from the wind turbine.**

## 5 INSTRUMENTATION

**Table 5. Instrumentation used for measurements and analysis**

| Description | Manufacturer | Type | ACA no. | Calibrated | Next calibration |
|---|---|---|---|---|---|
| Microphone 1/2" | BSWA Tech | MPA261 | 146 | 28-04-10 | 28-04-11 |
| Calibrator | Brüel & Kjær | 4200 | 378 | 16-06-10 | 16-12-10 |
| Anemometer | Autohelm | ZC80 | 644 | 27-08-10 | 27-08-12 |
| Data acq.-software | Acoustica | Windturbine 4.0.4 | 864 | 10-01-11 | 10-01-13 |
| Data acquisition | National Instr. | PXI-4462 | 626 | 10-01-11 | 10-01-13 |
| Data acquisition t | National Instr. | PXI-6220 | 626 | 10-01-11 | 10-01-13 |

The anemometer and the wind direction transducer were placed at a height of 10 meters above the ground. The distance to the wind turbine was 20 m. The compass bearing from the tower towards the anemometer was 200°.

No secondary wind screen was used.

**Table 6. Microphone positions**

| Position | Horizontal distance from tower centerline | Vertical distance from tower foundation |
|---|---|---|
| 1 (ref. pos.) | 20 m | 0 m |

No measurements were carried out in the positions 2, 3, and 4.

## 6 ACOUSTIC DATA

The measurements were carried out during the following period:
2011-11-01 from 13.35 to 16.30 local time.

The wind speed was determined by direct measurement at 10 m height.

From the power curve it appears that 95% of the maximum output (95% of 25 kW) is produced at a normalized hub height wind speed of 10.5 m/s. This corresponds to a standardized wind speed of 9.5 m/s at 10 meters height. The cut-in appears at 3 m/s.

Measured data pairs (1 minute periods) of total noise were excluded from the analysis and calculations if:

- The nacelle azimuth deviates more the than ±15°fr om a true downwind direction in the reference microphone position.
- The sound pressure is influenced by loud background noise.

Measured data pairs (1 minute periods) of background noise were excluded from the analysis and calculations if:

- The nacelle azimuth deviates more the than ±15°fr om a true downwind direction in the reference microphone position.
- The sound pressure is influenced by loud background noise.

**Figure 5. Measured data pairs at the reference microphone position used in analysis and calculations. Red circles: Total noise. Blue squares: Background noise.**

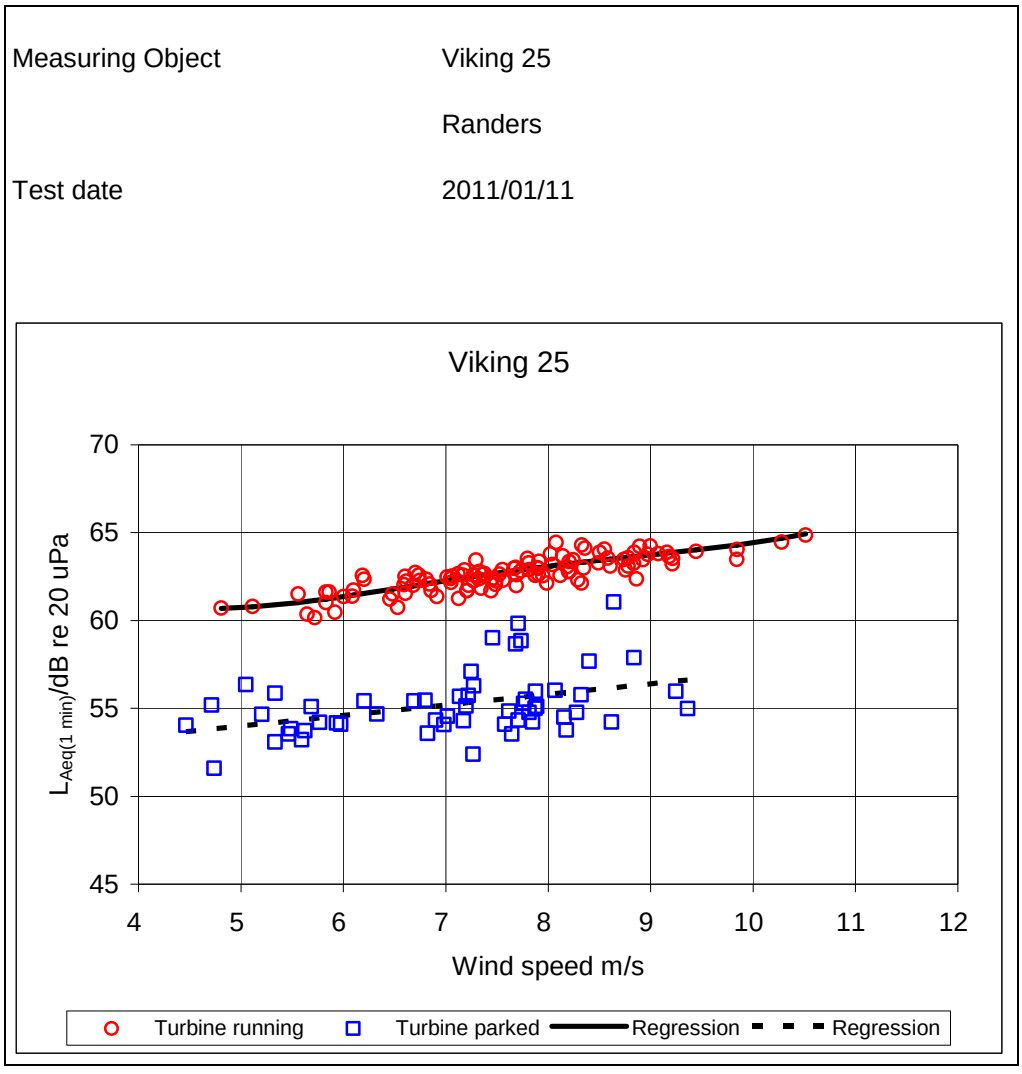



Table 1 shows the BIN-analysis of the measured noise levels with the turbine in operation.

**Table 1 BIN-analysis of noise levels with wind turbine in operation**

| BIN Class [m/s] | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|
| Number of measurements | 14 | 36 | 34 | 21 | 4 |
| Average wind speed [m/s] | 6.0 | 7.1 | 8.0 | 8.9 | 10.1 |
| Avg. $L_{Aeq,Total}$ [dB re 20µPa] | 61.4 | 62.2 | 63.0 | 63.6 | 64.2 |

Table 2 shows the BIN-analysis of the measured noise levels with the wind turbine parked.

**Table 2 BIN-analysis of noise levels with the wind turbine parked.**

| BIN Class [m/s] | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|
| Number of measurements | 10 | 11 | 26 | 13 | 9 |
| Average wind speed [m/s] | 6.0 | 7.1 | 8.0 | 9.1 | 10,0 |
| Avg. $L_{Aeq,Back.}$ [dB re 20µPa] | 47.8 | 48.2 | 50.8 | 51.6 | 54.2 |

The results corrected for background noise are shown in Table 3.

**Table 3 Measurement results corrected for background noise.**

| BIN Class [m/s] | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|
| $L_{Aeq,c\ Polynomia}$ [dB re 20µPa] | 60.3 | 61.3 | 62.2 | 62.9 | 63.6 |

Regression analysis of 4$^{th}$ order of the measured data pairs gives correlation a coefficient of $R^2 = 0.91$.

The regression coefficients are shown in Table 5.

**Table 4. Coefficient of regression for total noise and background noise.**

| Order | 4 | 3 | 2 | 1 | 0 |
|---|---|---|---|---|---|
| Total Noise | 0.0114 | -0.3556 | 4.0641 | -19.367 | 93.29 |
| Background noise | | | | 0.60 | 50.99 |

## 6.1 Apparent sound power levels

The measured wind speeds $V_Z$ are corrected to wind speeds at reference conditions $V_S$ using formula (7) in the standard with a roughness length of 0.05 m.

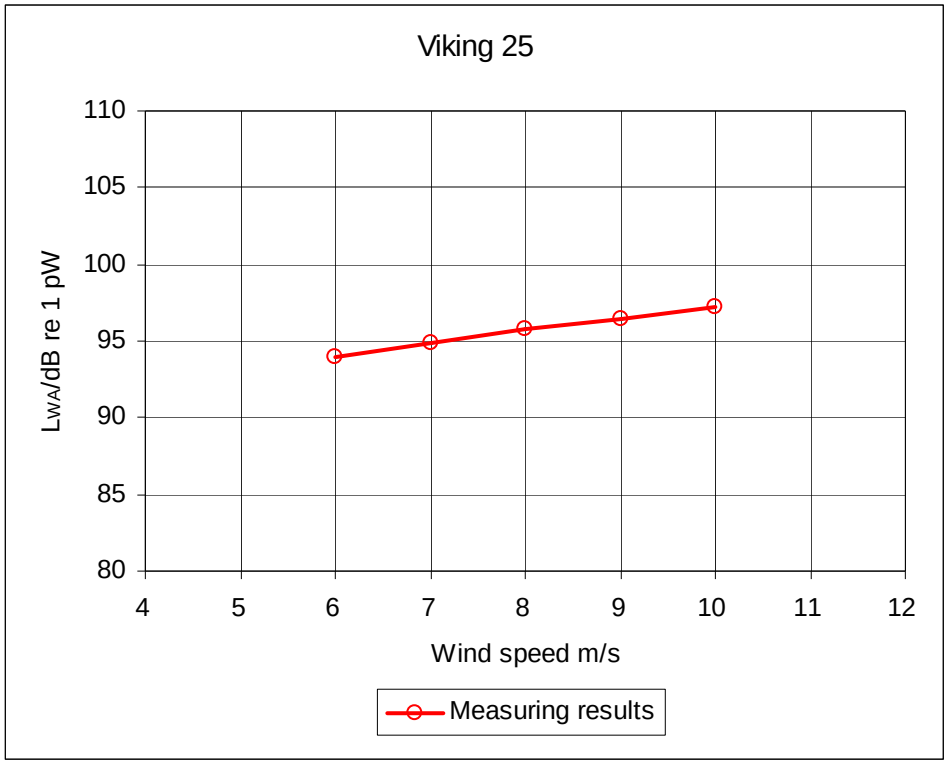
The apparent sound power levels $L_{WA,k}$ are calculated using 4$^{th}$ order regression analysis of data pairs for total noise and linear regression for background noise.

**Table 6. Apparent sound power levels at integer wind speeds**

| Standardized wind speed $V_s$ [m/s] | 6 | 7 | 8 | 9 | 10* |
|---|---|---|---|---|---|
| Power from Power Curve [kW] | 9.9 | 14.5 | 18.6 | 22.1 | 25.4 |
| Apparent sound power level $L_{WA,k}$ [dB] | 93.9 | 94.9 | 95.8 | 96.4 | 97.2 |

* 10 m/s corresponds to more than 95% of rated power

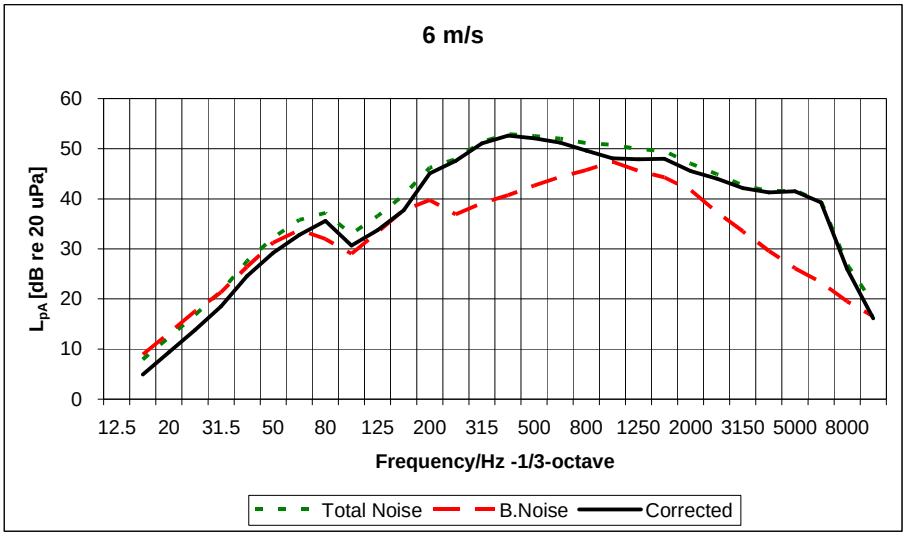
**Figure 5. Apparent sound power levels at integer wind speeds**



## 6.2 Third octave spectra

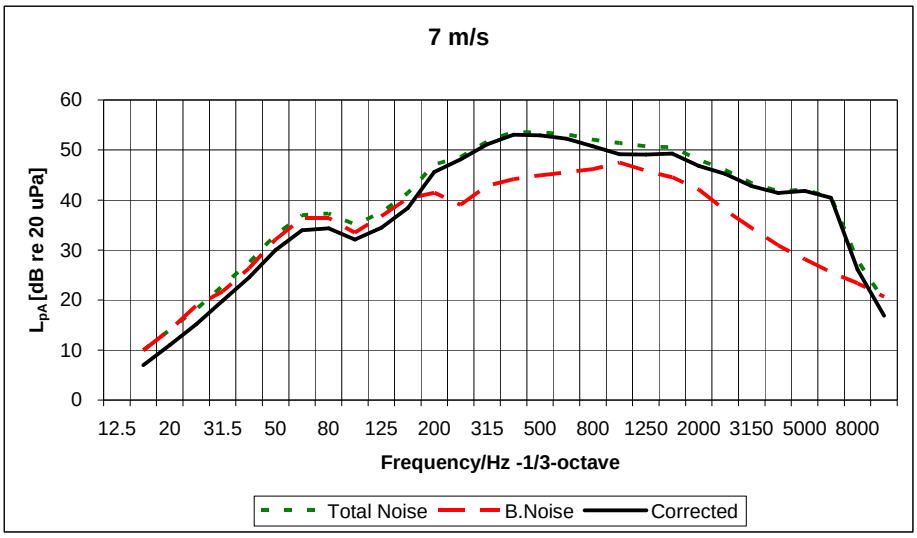
All sound power levels are A-weighted and corrected for the influence of the background noise. An * indicates that the difference between total noise and background noise is less than 6 dB. For numbers in Italic the difference is less than 3 dB. For this situation the numbers are given as the level of the total noise minus 3 dB. This is in accordance with 88/384/CDV dated 2010-11-26 for revision of 61400-11

**Figure 6. Third octave spectrum at the standardised wind speed 6 m/s.**



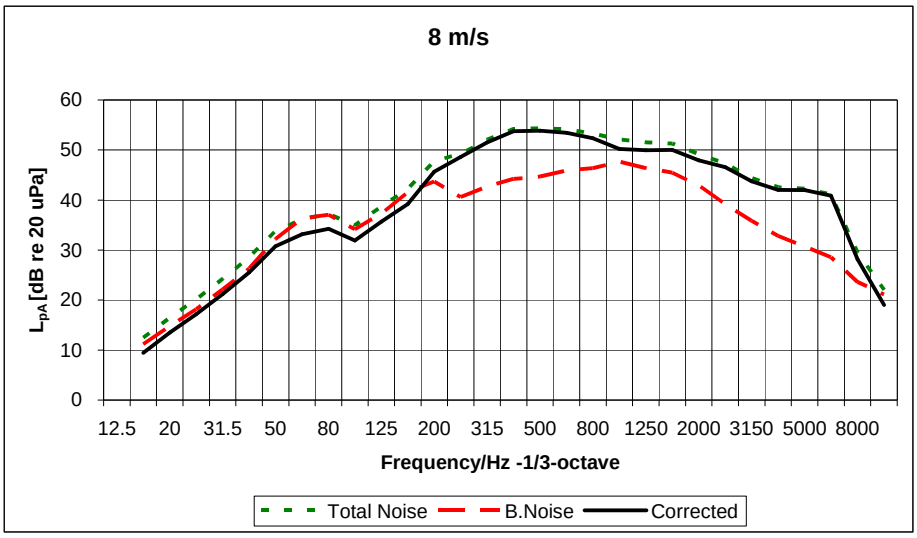

| Frequency | LpA pr 1/3-octave [dB] Total Noise | B.Noise | Corrected | LpA pr 1/1-octave [dB] Frequency | Corrected |
|---|---|---|---|---|---|
| 12.5 | | | | | |
| 16 | 7.9 | 8.9 | *4.9* * | 16 | |
| 20 | 12.4 | 13.2 | *9.4* * | | |
| 25 | 16.8 | 17.5 | *13.8* * | | |
| 31.5 | 21.6 | 21.3 | *18.6* * | 31.5 | *25.8* |
| 40 | 27.5 | 26.4 | *24.5* * | | |
| 50 | 32.2 | 31.2 | *29.2* * | | |
| 63 | 35.8 | 33.8 | *32.8* * | 63 | 37.3 |
| 80 | 37.1 | 32.0 | 35.6 * | | |
| 100 | 32.9 | 29.0 | 30.7 * | | |
| 125 | 36.5 | 33.3 | 33.7 * | 125 | 39.7 |
| 160 | 40.7 | 37.7 | *37.7* * | | |
| 200 | 46.2 | 39.7 | 45.1 | | |
| 250 | 47.9 | 36.9 | 47.6 | 250 | 53.4 |
| 315 | 51.3 | 39.1 | 51.1 | | |
| 400 | 52.9 | 40.7 | 52.6 | | |
| 500 | 52.5 | 42.6 | 52.1 | 500 | 56.8 |
| 630 | 52.0 | 44.4 | 51.2 | | |
| 800 | 51.1 | 45.7 | 49.6 * | | |
| 1000 | 50.8 | 47.4 | 48.1 * | 1000 | 53.4 |
| 1250 | 49.9 | 45.6 | 47.9 * | | |
| 1600 | 49.5 | 44.3 | 48.0 * | | |
| 2000 | 47.0 | 41.7 | 45.5 * | 2000 | 50.9 |
| 2500 | 44.9 | 37.3 | 44.1 | | |
| 3150 | 42.7 | 33.5 | 42.1 | | |
| 4000 | 41.6 | 29.6 | 41.3 | 4000 | 46.4 |
| 5000 | 41.7 | 26.2 | 41.5 | | |
| 6300 | 39.4 | 23.3 | 39.3 | | |
| 8000 | 26.9 | 19.5 | 26.0 | 8000 | 39.5 |
| 10000 | 19.2 | 16.5 | *16.2* * | | |

**Figure 7. Third octave spectrum at the standardised wind speed 7 m/s.**



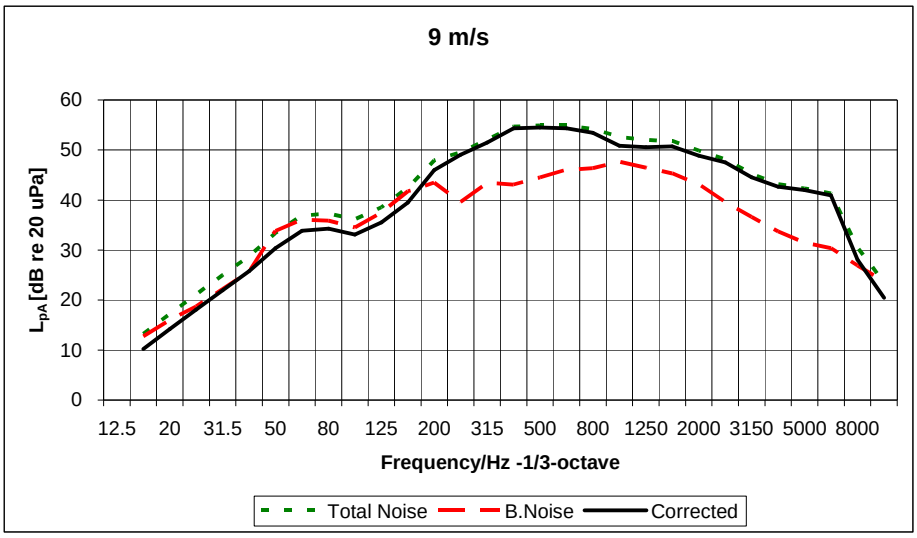

| Frequency | LpA pr 1/3-octave [dB] Total Noise | B.Noise | Corrected | | LpA pr 1/1-octave [dB] Frequency | Corrected |
|---|---|---|---|---|---|---|
| 12.5 | | | | | | |
| 16 | 10.0 | 9.9 | *7.0* | * | 16 | |
| 20 | 14.1 | 14.0 | *11.1* | * | | |
| 25 | 18.1 | 18.9 | *15.1* | * | | |
| 31.5 | 22.9 | 21.7 | *19.9* | * | 31.5 | *26.2* |
| 40 | 27.5 | 26.4 | *24.5* | * | | |
| 50 | 33.0 | 32.1 | *30.0* | * | | |
| 63 | 37.0 | 36.4 | *34.0* | * | 63 | *37.9* |
| 80 | 37.3 | 36.4 | *34.3* | * | | |
| 100 | 35.1 | 33.5 | *32.1* | * | | |
| 125 | 37.5 | 36.7 | *34.5* | * | 125 | *40.6* |
| 160 | 41.4 | 40.3 | *38.4* | * | | |
| 200 | 47.0 | 41.5 | 45.6 | * | | |
| 250 | 48.6 | 39.0 | 48.1 | | 250 | 53.7 |
| 315 | 51.7 | 42.9 | 51.1 | | | |
| 400 | 53.6 | 44.2 | 53.1 | | | |
| 500 | 53.6 | 44.9 | 52.9 | | 500 | 57.5 |
| 630 | 53.1 | 45.6 | 52.3 | | | |
| 800 | 52.1 | 46.2 | 50.8 | * | | |
| 1000 | 51.4 | 47.5 | 49.1 | * | 1000 | 54.5 |
| 1250 | 50.8 | 45.9 | 49.1 | * | | |
| 1600 | 50.6 | 44.6 | 49.3 | * | | |
| 2000 | 48.1 | 42.1 | 46.8 | * | 2000 | 52.2 |
| 2500 | 46.0 | 37.9 | 45.3 | | | |
| 3150 | 43.4 | 34.4 | 42.8 | | | |
| 4000 | 41.8 | 31.0 | 41.4 | | 4000 | 46.8 |
| 5000 | 42.1 | 28.2 | 41.9 | | | |
| 6300 | 40.6 | 25.6 | 40.4 | | | |
| 8000 | 28.0 | 23.4 | 26.1 | * | 8000 | 40.6 |
| 10000 | 19.8 | 20.7 | *16.8* | * | | |

**Figure 8. Third octave spectrum at the standardised wind speed 8 m/s.**



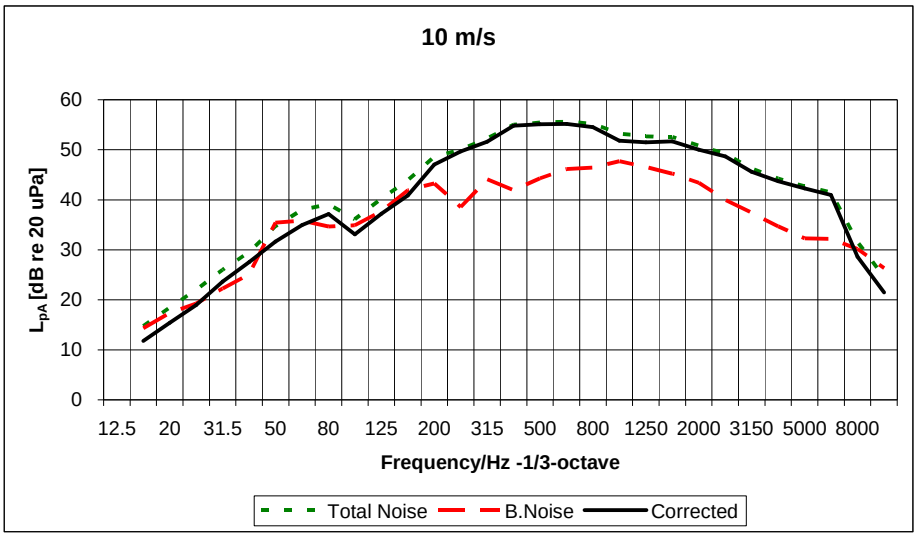

| Frequency | LpA pr 1/3-octave [dB] Total Noise | B.Noise | Corrected | | LpA pr 1/1-octave [dB] Frequency | Corrected |
|---|---|---|---|---|---|---|
| 12.5 | | | | | | |
| 16 | 12.5 | 11.2 | *9.5* | * | 16 | |
| 20 | 16.5 | 14.7 | *13.5* | * | | |
| 25 | 20.2 | 18.2 | *17.2* | * | | |
| 31.5 | 24.2 | 22.1 | *21.2* | * | 31.5 | *27.4* |
| 40 | 28.6 | 26.3 | *25.6* | * | | |
| 50 | 33.8 | 32.2 | *30.8* | * | | |
| 63 | 36.1 | 36.3 | *33.1* | * | 63 | *37.7* |
| 80 | 37.2 | 37.1 | *34.2* | * | | |
| 100 | 34.9 | 34.2 | *31.9* | * | | |
| 125 | 38.7 | 37.3 | *35.7* | * | 125 | *41.4* |
| 160 | 42.2 | 41.6 | *39.2* | * | | |
| 200 | 47.8 | 43.7 | 45.7 | * | | |
| 250 | 49.3 | 40.6 | 48.6 | | 250 | 54.0 |
| 315 | 52.1 | 42.7 | 51.6 | | | |
| 400 | 54.2 | 44.2 | 53.8 | | | |
| 500 | 54.4 | 44.7 | 53.9 | | 500 | 58.5 |
| 630 | 54.2 | 45.9 | 53.5 | | | |
| 800 | 53.3 | 46.4 | 52.3 | | | |
| 1000 | 52.1 | 47.7 | 50.2 | * | 1000 | 55.7 |
| 1250 | 51.5 | 46.4 | 50.0 | * | | |
| 1600 | 51.3 | 45.5 | 50.0 | * | | |
| 2000 | 49.1 | 42.9 | 48.0 | | 2000 | 53.2 |
| 2500 | 47.3 | 39.1 | 46.6 | | | |
| 3150 | 44.4 | 35.9 | 43.8 | | | |
| 4000 | 42.5 | 32.8 | 42.1 | | 4000 | 47.5 |
| 5000 | 42.3 | 30.6 | 42.0 | | | |
| 6300 | 41.1 | 28.6 | 40.9 | | | |
| 8000 | 29.5 | 23.6 | 28.2 | * | 8000 | 41.1 |
| 10000 | 22.0 | 21.1 | *19.0* | * | | |

**Figure 9. Third octave spectrum at the standardised wind speed 9 m/s.**



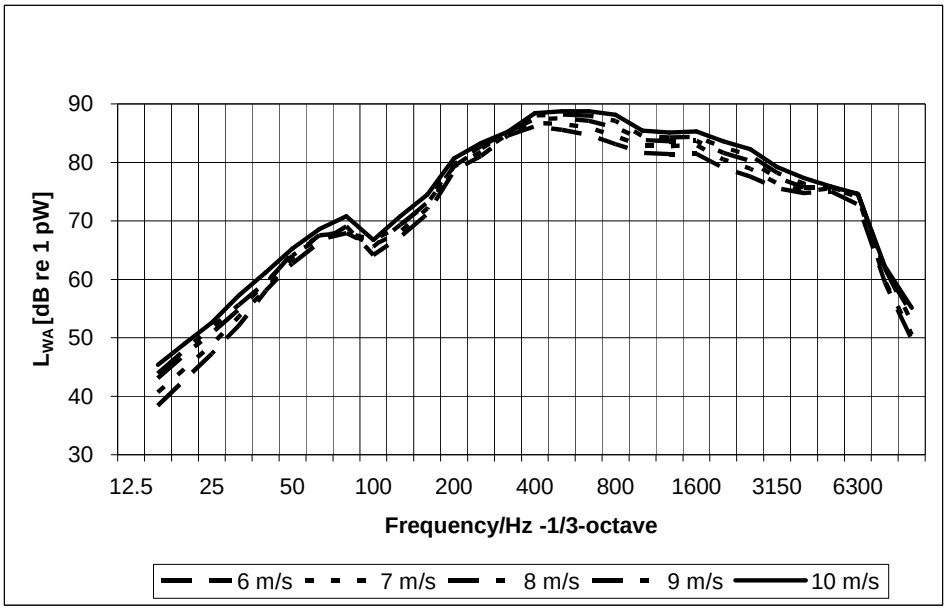

| Frequency | LpA pr 1/3-octave [dB] Total Noise | B.Noise | Corrected | | LpA pr 1/1-octave [dB] Frequency | Corrected |
|---|---|---|---|---|---|---|
| 12.5 | | | | | | |
| 16 | 13.2 | 12.8 | *10.2* | * | 16 | |
| 20 | 17.2 | 16.1 | *14.2* | * | | |
| 25 | 21.1 | 18.7 | *18.1* | * | | |
| 31.5 | 25.0 | 22.2 | *22.0* | * | 31.5 | *27.8* |
| 40 | 28.8 | 25.7 | 25.8 | * | | |
| 50 | 33.4 | 33.8 | *30.4* | * | | |
| 63 | 36.9 | 36.1 | *33.9* | * | 63 | *37.9* |
| 80 | 37.3 | 35.9 | *34.3* | * | | |
| 100 | 36.1 | 34.5 | *33.1* | * | | |
| 125 | 38.5 | 37.5 | *35.5* | * | 125 | *41.6* |
| 160 | 42.5 | 41.7 | *39.5* | * | | |
| 200 | 47.9 | 43.5 | 46.0 | * | | |
| 250 | 49.5 | 39.6 | 49.1 | | 250 | 54.2 |
| 315 | 52.1 | 43.4 | 51.5 | | | |
| 400 | 54.7 | 43.1 | 54.4 | | | |
| 500 | 54.9 | 44.5 | 54.5 | | 500 | 59.2 |
| 630 | 54.9 | 46.0 | 54.3 | | | |
| 800 | 54.2 | 46.4 | 53.5 | | | |
| 1000 | 52.6 | 47.7 | 50.9 | * | 1000 | 56.6 |
| 1250 | 52.0 | 46.5 | 50.6 | * | | |
| 1600 | 51.9 | 45.4 | 50.8 | | | |
| 2000 | 49.9 | 43.1 | 48.9 | | 2000 | 54.0 |
| 2500 | 48.2 | 39.6 | 47.5 | | | |
| 3150 | 45.2 | 36.7 | 44.6 | | | |
| 4000 | 43.2 | 33.7 | 42.7 | | 4000 | 48.0 |
| 5000 | 42.3 | 31.5 | 42.0 | | | |
| 6300 | 41.3 | 30.4 | 40.9 | | | |
| 8000 | 30.5 | 26.9 | 28.1 | * | 8000 | 41.2 |
| 10000 | 23.4 | 23.7 | *20.4* | * | | |

**Figure 10. Third octave spectrum at the standardised wind speed 10 m/s. 10 m/s corresponds to more than 95% of rated power.**




| Frequency | LpA pr 1/3-octave [dB] Total Noise | B.Noise | Corrected | | LpA pr 1/1-octave [dB] Frequency | Corrected |
|---|---|---|---|---|---|---|
| 12.5 | | | | | | |
| 16 | 14.8 | 14.3 | *11.8* | * | 16 | |
| 20 | 18.4 | 17.4 | *15.4* | * | | |
| 25 | 22.0 | 19.2 | *19.0* | * | | |
| 31.5 | 26.0 | 22.2 | 23.6 | * | 31.5 | 29.4 |
| 40 | 29.5 | 25.1 | 27.6 | * | | |
| 50 | 34.7 | 35.5 | *31.7* | * | | |
| 63 | 38.0 | 35.9 | *35.0* | * | 63 | *39.4* |
| 80 | 39.1 | 34.7 | 37.2 | * | | |
| 100 | 36.1 | 34.9 | *33.1* | * | | |
| 125 | 40.2 | 37.7 | *37.2* | * | 125 | *42.9* |
| 160 | 43.9 | 41.9 | *40.9* | * | | |
| 200 | 48.6 | 43.3 | 47.1 | * | | |
| 250 | 50.0 | 38.5 | 49.7 | | 250 | 54.6 |
| 315 | 52.3 | 44.1 | 51.6 | | | |
| 400 | 55.1 | 42.0 | 54.8 | | | |
| 500 | 55.5 | 44.3 | 55.1 | | 500 | 59.8 |
| 630 | 55.7 | 46.1 | 55.2 | | | |
| 800 | 55.2 | 46.4 | 54.5 | | | |
| 1000 | 53.3 | 47.7 | 51.8 | * | 1000 | 57.6 |
| 1250 | 52.7 | 46.6 | 51.5 | | | |
| 1600 | 52.6 | 45.2 | 51.7 | | | |
| 2000 | 50.8 | 43.4 | 50.0 | | 2000 | 55.1 |
| 2500 | 49.2 | 40.0 | 48.7 | | | |
| 3150 | 46.2 | 37.4 | 45.6 | | | |
| 4000 | 44.2 | 34.7 | 43.7 | | 4000 | 48.9 |
| 5000 | 42.7 | 32.3 | 42.3 | | | |
| 6300 | 41.5 | 32.2 | 41.0 | | | |
| 8000 | 31.6 | 30.1 | *28.6* | * | 8000 | 41.1 |
| 10000 | 24.5 | 26.3 | *21.5* | * | | |

**Figure 11. Third octave sound power spectra at standardised wind speeds from 6 m/s to 10 m/s. 10 m/s corresponds to more than 95% of rated power.**




| | LWA pr 1/3-octave [dB] | | | | | LWA pr 1/1-octave [dB] | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Frequency | 6 m/s | 7 m/s | 8 m/s | 9 m/s | 10 m/s | 6 m/s | 7 m/s | 8 m/s | 9 m/s | 10 m/s |
| 12.5 | | | | | | | | | | |
| 16 | 38.4 | 40.7 | 43.1 | 43.9 | 45.4 | | | | | |
| 20 | 42.8 | 44.7 | 47.1 | 47.9 | 49.0 | | | | | |
| 25 | 47.3 | 48.8 | 50.8 | 51.8 | 52.6 | | | | | |
| 31.5 | 52.0 | 53.6 | 54.9 | 55.6 | 57.2 | 59.3 | 59.8 | 61.0 | 61.5 | 63.1 |
| 40 | 58.0 | 58.2 | 59.2 | 59.5 | 61.2 | | | | | |
| 50 | 62.7 | 63.7 | 64.4 | 64.0 | 65.3 | | | | | |
| 63 | 66.3 | 67.6 | 66.8 | 67.5 | 68.6 | 71.5 | 71.6 | 71.4 | 71.6 | 73.5 |
| 80 | 69.1 | 68.0 | 67.9 | 67.9 | 70.8 | | | | | |
| 100 | 64.1 | 65.8 | 65.6 | 66.8 | 66.7 | | | | | |
| 125 | 67.2 | 68.2 | 69.3 | 69.2 | 70.8 | 73.2 | 74.2 | 75.0 | 75.3 | 76.5 |
| 160 | 71.2 | 72.1 | 72.9 | 73.2 | 74.5 | | | | | |
| 200 | 78.6 | 79.3 | 79.3 | 79.7 | 80.7 | | | | | |
| 250 | 81.0 | 81.8 | 82.3 | 82.7 | 83.3 | 86.9 | 87.3 | 87.7 | 87.9 | 88.2 |
| 315 | 84.5 | 84.8 | 85.2 | 85.2 | 85.2 | | | | | |
| 400 | 86.1 | 86.8 | 87.4 | 88.0 | 88.4 | | | | | |
| 500 | 85.6 | 86.6 | 87.5 | 88.2 | 88.7 | 90.3 | 91.2 | 92.1 | 92.8 | 93.4 |
| 630 | 84.7 | 85.9 | 87.1 | 88.0 | 88.8 | | | | | |
| 800 | 83.1 | 84.5 | 86.0 | 87.1 | 88.1 | | | | | |
| 1000 | 81.6 | 82.8 | 83.9 | 84.5 | 85.4 | 86.9 | 88.2 | 89.4 | 90.3 | 91.2 |
| 1250 | 81.4 | 82.8 | 83.6 | 84.3 | 85.1 | | | | | |
| 1600 | 81.5 | 83.0 | 83.7 | 84.4 | 85.3 | | | | | |
| 2000 | 79.0 | 80.5 | 81.6 | 82.5 | 83.6 | 84.4 | 85.9 | 86.8 | 87.7 | 88.7 |
| 2500 | 77.5 | 78.9 | 80.2 | 81.2 | 82.3 | | | | | |
| 3150 | 75.6 | 76.5 | 77.4 | 78.2 | 79.2 | | | | | |
| 4000 | 74.8 | 75.1 | 75.7 | 76.3 | 77.3 | 79.9 | 80.5 | 81.1 | 81.6 | 82.5 |
| 5000 | 75.0 | 75.5 | 75.6 | 75.6 | 75.9 | | | | | |
| 6300 | 72.8 | 74.1 | 74.5 | 74.6 | 74.6 | | | | | |
| 8000 | 59.5 | 59.8 | 61.8 | 61.8 | 62.2 | 73.0 | 74.3 | 74.8 | 74.9 | 74.9 |
| 10000 | 49.6 | 50.5 | 52.7 | 54.1 | 55.1 | | | | | |
| $L_{WA}$ | 93.9 | 94.9 | 95.8 | 96.4 | 97.2 | 93.9 | 94.9 | 95.8 | 96.4 | 97.2 |

## 6.3 Tonality

The tonality analysis was carried out using A-weighting with the analysis software WT-Tonality programmed at Acoustica.

The level of the background noise in the critical bands was more than 6 dB below the total noise.

Only tones with $\Delta L_{a,k} \geq$ -3,0 dB are shown.

FFT-spectra and the tonality analysis are shown in figures 12 – 16. The resulting tonality is shown in table 7. The purple curve in the figures represent the background noise.

Tones below 200 Hz are from the background noise from the traffic on nearby roads.

**Table 7. Tonality**

| BIN Class [m/s] | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|
| Tone frequency | 441.2 | 442.8 | 443.2 | 443.7 | 443.7 |
| Tonal Audibility ΔLa [dB] | 0.1 | 1.0 | 0.3 | 0.1 | -0.2 |

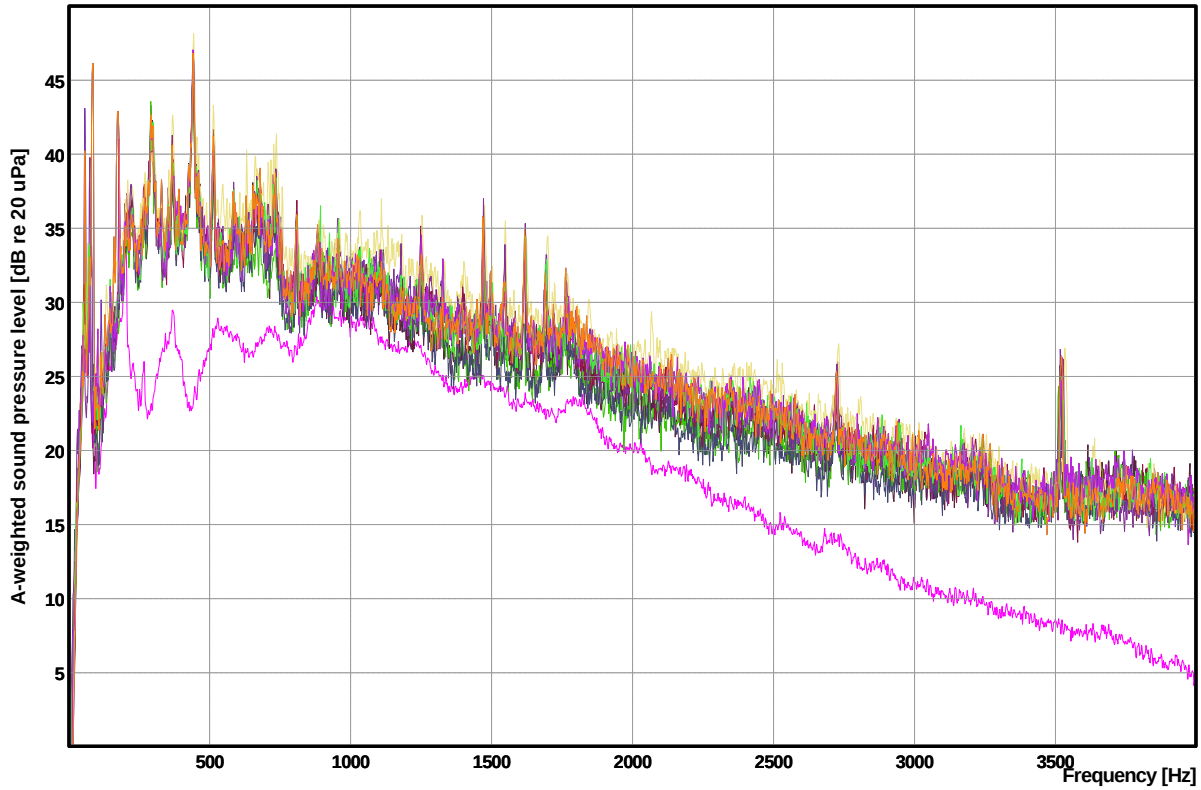
Supplementary, a tonality analysis according to Danish regulations is made. This is reported in figure 17.

## Figure 12. FFT- spectra and determination of tonality at 6 m/s

## Tonality: IEC 61400, 2. ed., 2002-12

| Spectrum no. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No. in file | 717 | 718 | 719 | 720 | 721 | 722 | 713 | 714 | 715 | 716 | 717 | 718 |
| Tone frequency [Hz] | 441.0 | 441.0 | 441.0 | 441.0 | 441.0 | 441.0 | 441.0 | 443.0 | 441.0 | 441.0 | 441.0 | 441.0 |
| LpA,tone [dB re 20 uPa] | 50.5 | 49.5 | 50.3 | 50.5 | 47.7 | 49.5 | 49.4 | 51.6 | 50.5 | 50.8 | 50.5 | 49.5 |
| Critical bandwidth [Hz] | 114.0 | 114.0 | 114.0 | 114.0 | 114.0 | 114.0 | 114.0 | 114.0 | 114.0 | 114.0 | 114.0 | 114.0 |
| Lower limit [Hz] | 385.0 | 385.0 | 385.0 | 385.0 | 385.0 | 385.0 | 385.0 | 387.0 | 385.0 | 385.0 | 385.0 | 385.0 |
| Upper limit [Hz] | 499.0 | 499.0 | 499.0 | 499.0 | 499.0 | 499.0 | 499.0 | 501.0 | 499.0 | 499.0 | 499.0 | 499.0 |
| LpA,noise,avg. [dB] | 36.2 | 36.2 | 35.9 | 35.9 | 35.7 | 35.6 | 36.3 | 37.4 | 35.9 | 35.7 | 36.2 | 36.2 |
| 10*log(crit. BW/eff. noise BW) [dB] | 15.8 | 15.8 | 15.8 | 15.8 | 15.8 | 15.8 | 15.8 | 15.8 | 15.8 | 15.8 | 15.8 | 15.8 |
| LpnA [dB re 20 uPa] | 52.0 | 52.0 | 51.7 | 51.7 | 51.5 | 51.4 | 52.1 | 53.2 | 51.7 | 51.5 | 52.0 | 52.0 |
| dLtn [dB] | -1.5 | -2.5 | -1.4 | -1.3 | -3.7 | -1.8 | -2.7 | -1.5 | -1.1 | -0.7 | -1.5 | -2.5 |

| | |
|---|---|
| Avg. tone frequency [Hz] | 441.2 |
| dL (=dLtn,avg.) [dB] | -1.8 |
| dLa [dB] | 0.4 |



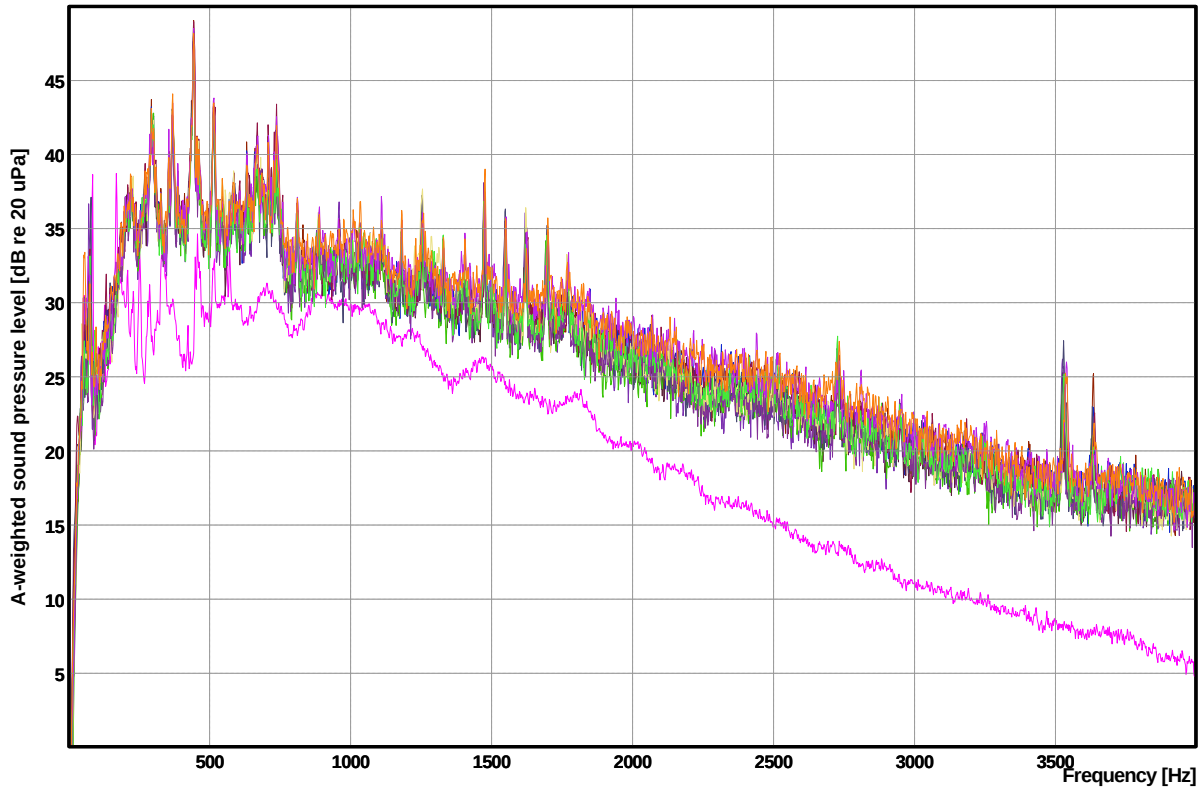

**Wind Class: 6 [m/s]**

## Figure 13. FFT- spectra and determination of tonality at 7 m/s

### Tonality: IEC 61400, 2. ed., 2002-12

| Spectrum no. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No. in file | 7 | 8 | 9 | 10 | 11 | 12 | 161 | 162 | 163 | 164 | 165 | 166 |
| Tone frequency [Hz] | 443.0 | 443.0 | 441.0 | 443.0 | 443.0 | 443.0 | 443.0 | 443.0 | 443.0 | 443.0 | 443.0 | 443.0 |
| LpA,tone [dB re 20 uPa] | 53.0 | 51.7 | 51.4 | 51.4 | 51.1 | 51.3 | 52.0 | 50.9 | 50.9 | 50.7 | 51.2 | 51.1 |
| Critical bandwidth [Hz] | 114.0 | 114.0 | 114.0 | 114.0 | 114.0 | 114.0 | 114.0 | 114.0 | 114.0 | 114.0 | 114.0 | 114.0 |
| Lower limit [Hz] | 387.0 | 387.0 | 385.0 | 387.0 | 387.0 | 387.0 | 387.0 | 387.0 | 387.0 | 387.0 | 387.0 | 387.0 |
| Upper limit [Hz] | 501.0 | 501.0 | 499.0 | 501.0 | 501.0 | 501.0 | 501.0 | 501.0 | 501.0 | 501.0 | 501.0 | 501.0 |
| LpA,noise,avg. [dB] | 37.2 | 37.0 | 36.5 | 36.7 | 36.6 | 36.5 | 37.3 | 37.0 | 36.3 | 36.1 | 37.3 | 37.4 |
| 10*log(crit. BW/eff. noise BW) [dB] | 15.8 | 15.8 | 15.8 | 15.8 | 15.8 | 15.8 | 15.8 | 15.8 | 15.8 | 15.8 | 15.8 | 15.8 |
| LpnA [dB re 20 uPa] | 53.0 | 52.8 | 52.3 | 52.5 | 52.4 | 52.3 | 53.1 | 52.8 | 52.1 | 51.9 | 53.1 | 53.2 |
| dLtn [dB] | -0.0 | -1.1 | -0.8 | -1.0 | -1.3 | -1.0 | -1.2 | -2.0 | -1.2 | -1.2 | -1.8 | -2.1 |

| | |
|---|---|
| Avg. tone frequency [Hz] | 442.8 |
| dL (=dLtn,avg.) [dB] | -1.2 |
| dLa [dB] | 1.0 |



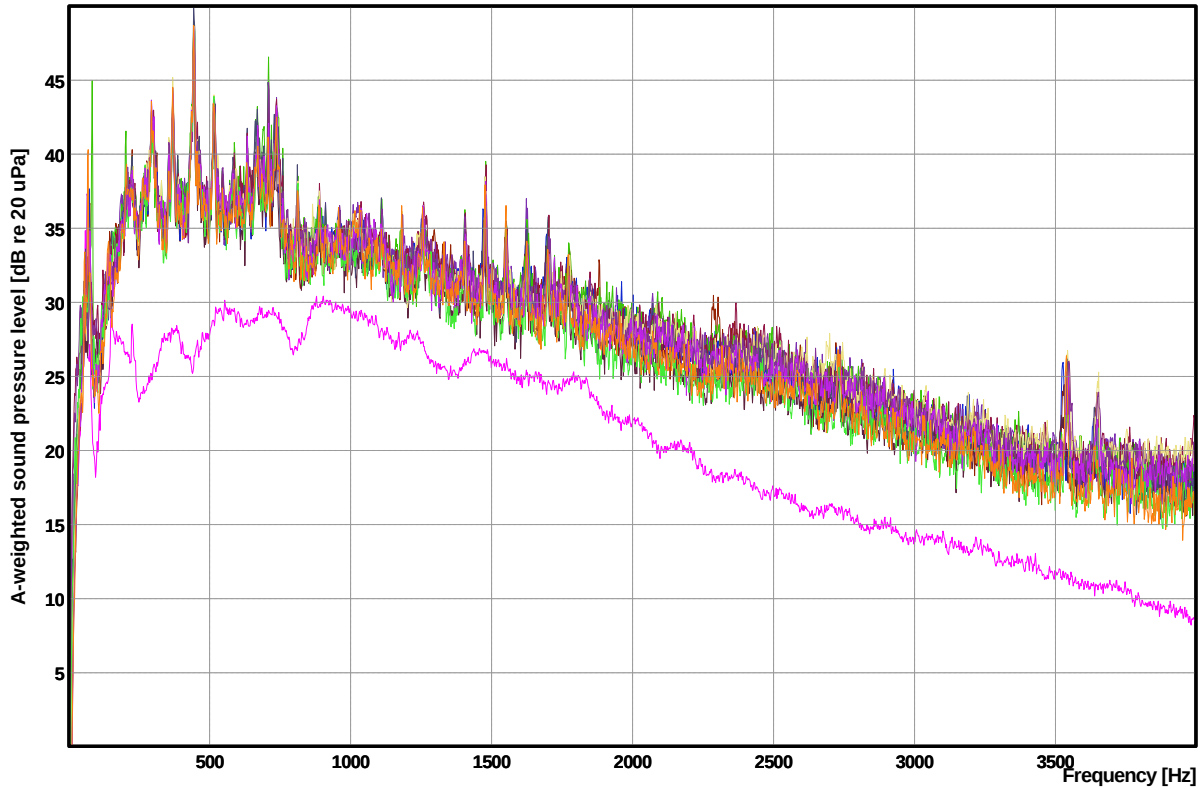

Wind Class: 7 [m/s]

## Figure 14. FFT- spectra and determination of tonality at 8 m/s

## Tonality: IEC 61400, 2. ed., 2002-12

| Spectrum no. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No. in file | 666 | 667 | 668 | 669 | 670 | 671 | 854 | 855 | 856 | 857 | 858 | 859 |
| Tone frequency [Hz] | 443.0 | 443.0 | 443.0 | 443.0 | 443.0 | 443.0 | 443.0 | 445.0 | 443.0 | 443.0 | 443.0 | 443.0 |
| LpA,tone [dB re 20 uPa] | 50.7 | 51.0 | 51.6 | 51.0 | 52.9 | 53.5 | 51.8 | 51.6 | 50.8 | 51.5 | 51.7 | 51.2 |
| Critical bandwidth [Hz] | 114.0 | 114.0 | 114.0 | 114.0 | 114.0 | 114.0 | 114.0 | 114.0 | 114.0 | 114.0 | 114.0 | 114.0 |
| Lower limit [Hz] | 387.0 | 387.0 | 387.0 | 387.0 | 387.0 | 387.0 | 387.0 | 389.0 | 387.0 | 387.0 | 387.0 | 387.0 |
| Upper limit [Hz] | 501.0 | 501.0 | 501.0 | 501.0 | 501.0 | 501.0 | 501.0 | 503.0 | 501.0 | 501.0 | 501.0 | 501.0 |
| LpA,noise,avg. [dB] | 37.4 | 37.4 | 38.4 | 37.1 | 38.4 | 38.1 | 38.3 | 37.9 | 38.0 | 37.5 | 37.8 | 36.9 |
| 10*log(crit. BW/eff. noise BW) [dB] | 15.8 | 15.8 | 15.8 | 15.8 | 15.8 | 15.8 | 15.8 | 15.8 | 15.8 | 15.8 | 15.8 | 15.8 |
| LpnA [dB re 20 uPa] | 53.2 | 53.2 | 54.2 | 52.9 | 54.2 | 53.9 | 54.1 | 53.7 | 53.8 | 53.3 | 53.6 | 52.7 |
| dLtn [dB] | -2.5 | -2.3 | -2.7 | -1.9 | -1.3 | -0.4 | -2.3 | -2.1 | -3.0 | -1.9 | -1.9 | -1.5 |

| | |
|---|---|
| Avg. tone frequency [Hz] | 443.2 |
| dL (=dLtn,avg.) [dB] | -1.9 |
| dLa [dB] | 0.3 |



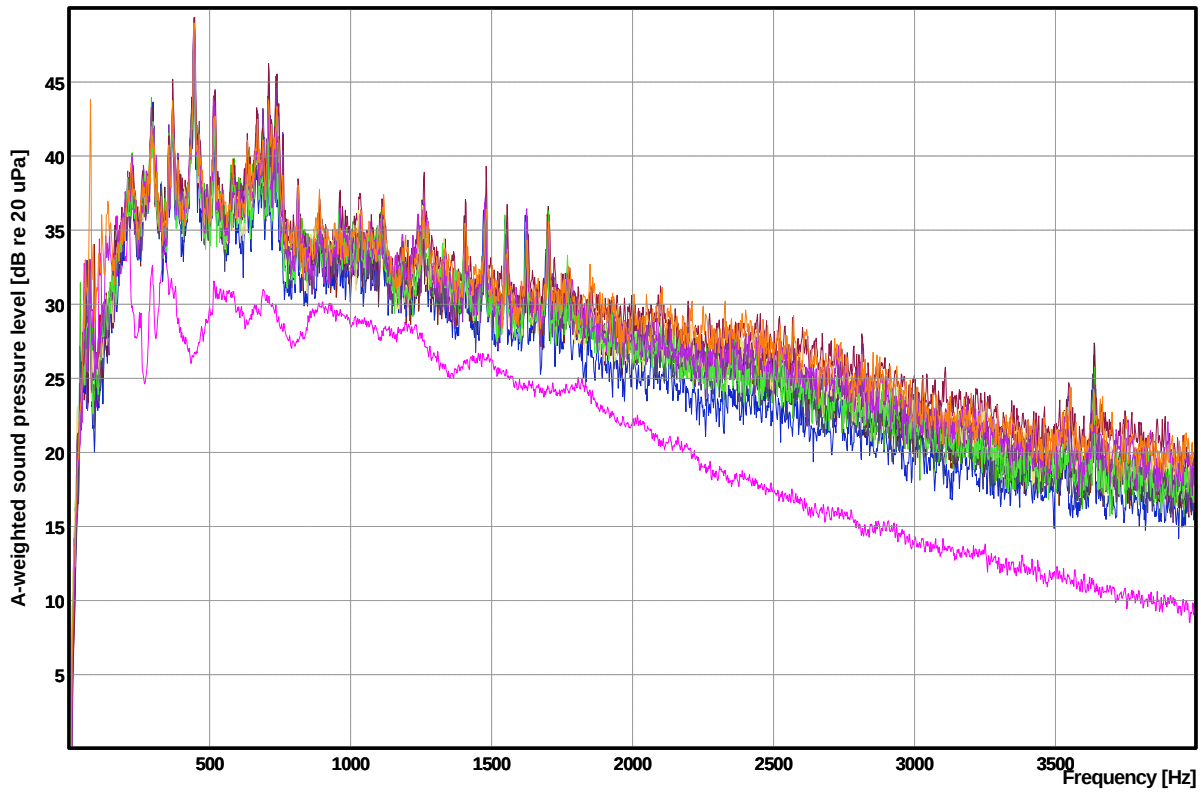

**Wind Class: 8 [m/s]**

## Figure 15. FFT- spectra and determination of tonality at 9 m/s

## Tonality: IEC 61400, 2. ed., 2002-12

| Spectrum no. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No. in file | 591 | 592 | 593 | 594 | 595 | 596 | 361 | 362 | 363 | 364 | 365 | 366 |
| Tone frequency [Hz] | 443.0 | 443.0 | 447.0 | 443.0 | 443.0 | 443.0 | 445.0 | 443.0 | 443.0 | 443.0 | 443.0 | 445.0 |
| LpA,tone [dB re 20 uPa] | 52.8 | 51.3 | 52.9 | 52.3 | 51.9 | 51.5 | 52.3 | 50.9 | 51.8 | 51.0 | 52.0 | 52.9 |
| Critical bandwidth [Hz] | 114.0 | 114.0 | 114.0 | 114.0 | 114.0 | 114.0 | 114.0 | 114.0 | 114.0 | 114.0 | 114.0 | 114.0 |
| Lower limit [Hz] | 387.0 | 387.0 | 391.0 | 387.0 | 387.0 | 387.0 | 389.0 | 387.0 | 387.0 | 387.0 | 387.0 | 389.0 |
| Upper limit [Hz] | 501.0 | 501.0 | 505.0 | 501.0 | 501.0 | 501.0 | 503.0 | 501.0 | 501.0 | 501.0 | 501.0 | 503.0 |
| LpA,noise,avg. [dB] | 38.6 | 37.0 | 38.4 | 38.7 | 38.9 | 38.2 | 38.7 | 38.0 | 38.5 | 37.6 | 38.6 | 38.4 |
| 10*log(crit. BW/eff. noise BW) [dB] | 15.8 | 15.8 | 15.8 | 15.8 | 15.8 | 15.8 | 15.8 | 15.8 | 15.8 | 15.8 | 15.8 | 15.8 |
| LpnA [dB re 20 uPa] | 54.4 | 52.8 | 54.2 | 54.5 | 54.7 | 54.0 | 54.5 | 53.8 | 54.3 | 53.4 | 54.4 | 54.2 |
| dLtn [dB] | -1.6 | -1.5 | -1.3 | -2.2 | -2.8 | -2.4 | -2.2 | -2.9 | -2.5 | -2.4 | -2.4 | -1.3 |

| | |
|---|---|
| Avg. tone frequency [Hz] | 443.7 |
| dL (=dLtn,avg.) [dB] | -2.1 |
| dLa [dB] | 0.1 |



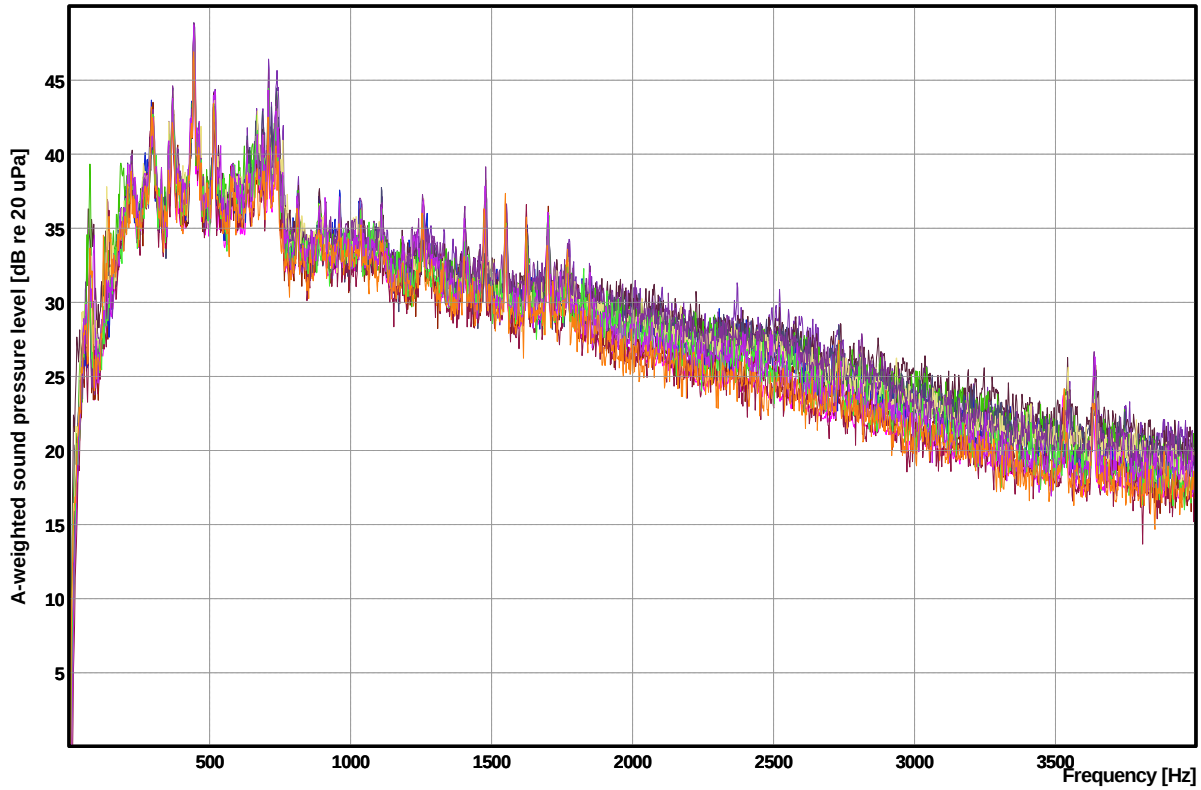

**Wind Class: 9 [m/s]**

## Figure 16. FFT- spectra and determination of tonality at 10 m/s

## Tonality: IEC 61400, 2. ed., 2002-12

| Spectrum no. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No. in file | 343 | 344 | 345 | 346 | 347 | 348 | 562 | 563 | 564 | 565 | 566 | 567 |
| Tone frequency [Hz] | 443.0 | 443.0 | 445.0 | 445.0 | 443.0 | 443.0 | 443.0 | 445.0 | 445.0 | 443.0 | 443.0 | 443.0 |
| LpA,tone [dB re 20 uPa] | 52.0 | 51.7 | 52.3 | 51.6 | 51.2 | 52.7 | 52.2 | 52.2 | 52.0 | 52.2 | 52.5 | 50.3 |
| Critical bandwidth [Hz] | 114.0 | 114.0 | 114.0 | 114.0 | 114.0 | 114.0 | 114.0 | 114.0 | 114.0 | 114.0 | 114.0 | 114.0 |
| Lower limit [Hz] | 387.0 | 387.0 | 389.0 | 389.0 | 387.0 | 387.0 | 387.0 | 389.0 | 389.0 | 387.0 | 387.0 | 387.0 |
| Upper limit [Hz] | 501.0 | 501.0 | 503.0 | 503.0 | 501.0 | 501.0 | 501.0 | 503.0 | 503.0 | 501.0 | 501.0 | 501.0 |
| LpA,noise,avg. [dB] | 38.4 | 38.5 | 38.7 | 38.5 | 39.3 | 38.7 | 37.8 | 39.2 | 38.9 | 38.5 | 38.9 | 38.3 |
| 10*log(crit. BW/eff. noise BW) [dB] | 15.8 | 15.8 | 15.8 | 15.8 | 15.8 | 15.8 | 15.8 | 15.8 | 15.8 | 15.8 | 15.8 | 15.8 |
| LpnA [dB re 20 uPa] | 54.2 | 54.3 | 54.5 | 54.3 | 55.1 | 54.5 | 53.6 | 54.9 | 54.7 | 54.3 | 54.7 | 54.1 |
| dLtn [dB] | -2.1 | -2.6 | -2.3 | -2.7 | -3.9 | -1.8 | -1.4 | -2.8 | -2.7 | -2.1 | -2.2 | -3.8 |

| | |
|---|---|
| Avg. tone frequency [Hz] | 443.7 |
| dL (=dLtn,avg.) [dB] | -2.5 |
| dLa [dB] | -0.2 |




**Wind Class: 10 [m/s]**

## 7 NON-ACOUSTIC DATA

**Table 8. Non-acoustic data**

| | |
|---|---|
| Wind speed determination method | Method 2, direct measurement at 10 m |
| Air temperature | 4℃ – 7℃ |
| Atmospheric pressure | 101 kPa – 102 kPa |
| Relative Humidity | 56 – 62 % |
| Roughness length | 0,05 m (estimated) |
| Wind direction | 170° |

## 8 UNCERTAINTY

The uncertainties are given as the expanded combined standard uncertainties with a coverage factor of k = 2, corresponding approximately to a 95% level of confidence

**Table 9. Calculated statistical type A uncertainty components**

| | Total noise $U_A$ | Background noise $U_A$ |
|---|---|---|
| Standardised wind speed, $V_s$ = 6 m/s | 0,7 dB | 0,7 dB |
| Standardised wind speed, $V_s$ = 7 m/s | 0,5 dB | 1,6 dB |
| Standardised wind speed, $V_s$ = 8 m/s | 0,3 dB | 1,8 dB |
| Standardised wind speed, $V_s$ = 9 m/s | 0,5 dB | 1,6 dB |
| Standardised wind speed, $V_s$ = 10 m/s | 0,6 dB | 2,0 dB* |

* Predicted from 9 m/s values.

**Table 10. Evaluated type B uncertainty components**

| **Component** | **Value** |
|---|---|
| Calibration, $U_{B1}$ | 0,2 dB |
| Instrument, $U_{B2}$ | 0,2 dB |
| Board, $U_{B3}$ ($L_{WA}$)<br>Board, $U_{B3}$ (third octave bands)<br>Board, $U_{B3}$ (tonality) | 0,3 dB<br>1,7 dB<br>1,7 dB |
| Distance, $U_{B4}$ | 0,1 dB |
| Impedance, $U_{B5}$ | 0,1 dB |
| Turbulence, $U_{B6}$ | 0,4 dB |
| Wind speed, measured, $U_{B7}$ | 0,9 dB |
| Direction, $U_{B8}$ | 0,3 dB |
| Background, $U_{B9}$ | 0,1 – 0,8 dB |

**Table 11. Combined and expanded uncertainty**

| **Acoustical quantity** | **Combined and expanded uncertainty, $U = k \cdot u_c$ (coverfactor, k=2)** |
|---|---|
| Apparent sound power level, $V_S$ = 6 m/s | 2,3 dB |
| Apparent sound power level, $V_S$ = 7 m/s | 2,3 dB |
| Apparent sound power level, $V_S$ = 8 m/s | 2,3 dB |
| Apparent sound power level, $V_S$ = 9 m/s | 2,3 dB |
| Apparent sound power level, $V_S$ = 10 m/s | 2,3 dB |
| Third octave band spectrum | 3,6 – 5,2 dB |
| Tonality | 2,5 – 3,2 dB |

**Figure 17. Tonality analysis according to danish regulations. The spectrum represents the 1 minute period with the highest tonality during measurements. The conclusion is that, as the $\Delta L_{tn}$ ($L_{pt}$-$L_{pn}$) =2.3 dB is less than the level of the criteria curve of 4.2 dB, the tones at 442 Hz and 512 Hz are not clearly audible.**

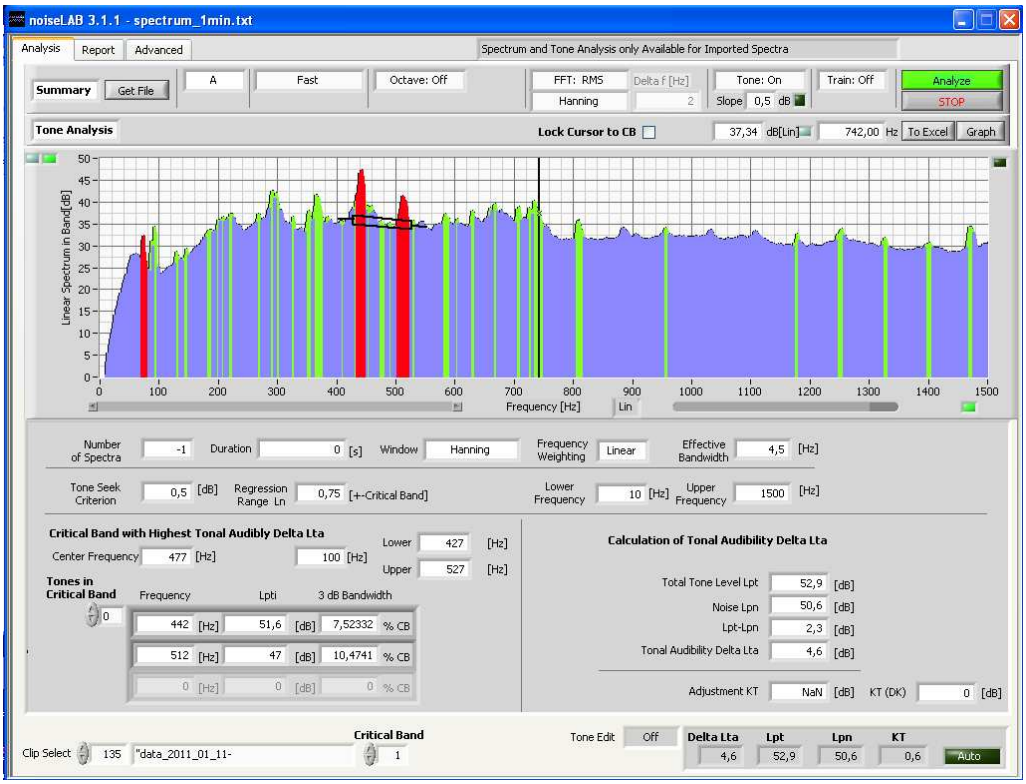


**Figure 18. Product sheet for Viking 25**

# Technical data Viking 25

**Operation Data**

| | |
|---|---|
| Rated power: | 25 kW |
| Hub height: | 18 m |
| Power regulation: | Stall |
| Cut-in wind speed: | 3,0 m/s |
| Rated wind speed: | 12 m/s |
| Cut-out wind speed: | >25m/s |
| Survival wind speed: | No limit |
| Yaw system: | Active UP Wind including cable untwist |
| Operational temperature: | -10 C° to + 40 C° |

**Rotor**

| | |
|---|---|
| Blade Type: | OLW 620 Passive Stall with tip brakes. |
| Rotation direction: | Clockwise |
| Number of blades: | 3 |
| Swept area: | 133 m2 |
| Blade material: | GRP |
| Rpm./min. | 65 |
| Tip speed: | 45 m/s |
| Blade producer: | Olsen Wings |

**Generator**

| | |
|---|---|
| Brand: | VEM Motors GmbH |
| Type: | G21R 200 L4 HW |
| Voltage: | 3*400 + N |
| Frequency: | 50/60 Hz |
| Rated Speed: | 1525 rpm |
| Grid connection: | yes + stand alone |

**Gearbox**

| | |
|---|---|
| Type: | STM-EX1501/804 23,25 PAM200D M1s |

**Safety system**

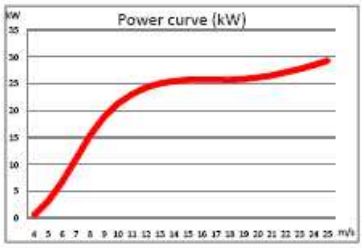
| | |
|---|---|
| Brakes: | Electro mechanical fail safe MAYR 9/800.410.3 |

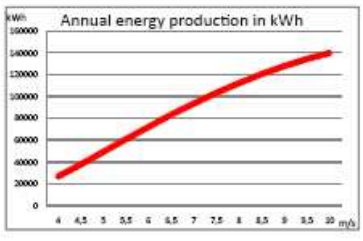
**Tower**

| | |
|---|---|
| Type: | HSWind tilt |

**Control system**

| | |
|---|---|
| Producer: | Mita-Teknik |




The curves are theoretical and may differ from reality

## Viking 25

**Development filosophy**
The Viking 25 is developed by the best designers and engineers in Denmark to deliver the best product.

To make sure all requirements are met, Viking 25 will comply with the IEC 61400 - 2 standard.

**Safety**
All service and maintenance is done while on the ground. No climbing of the tower is required.
The two independent brake systems are both fail safe.

**Tilt tower**
The Viking 25 is with tilt tower for easy installation and safety in case of hurricanes and other extremes.

HS Wind

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