NOISE FROM WIND TURBINES
STANDARDS AND NOISE REDUCTION PROCEDURES

H. Klug

Paper presented on the Forum Acusticum 2002,
16 - 20 September 2002, Sevilla, Spain

NOISE FROM WIND TURBINES
STANDARDS AND NOISE REDUCTION PROCEDURES

PACS Reference: 43.50.Rq

Helmut Klug
DEWI (German Windenergy Institute)
Ebertstrasse 96,26382 Wilhelmshaven, Germany; Tel.: ++49442148080,e-mail:h.klug@dewi.de

ABSTRACT

In many countries the noise radiation is still the major limitation in the tremendous development of wind energy over the last years. Within several European research projects, modifications of the rotor blade trailing edge (sharp or serrated) and the tip design (avoiding tip vortex-trailing edge interaction by ´trailing edge cutting´) resulted in considerable noise reductions in the range of several dB. Mechanical noise from gear box and generator was reduced significantly but tonal noise is still the crucial point concerning the acceptance of wind turbines. The measurement procedures have been improved significantly as well. The IEC standard 61400-11 Wind Turbines – Part 11 ‚Acoustic Noise Measurement Techniques' was revised recently in order to present a procedure expected to provide accurate results that can be replicated by others.

1. STANDARDS

1.1 IEC STANDARD ON MEASUREMENT TECHNIQUES

The IEC standard 61400-11 Wind Turbines – Part 11 ‚Acoustic Noise Measurement Techniques' provides a uniform methodology that will ensure consistency and accuracy in the measurement and analysis of acoustical emissions by wind turbine generator systems (WTGS). The sound power level is determined for an acoustic reference wind speed of 8 m/s at 10 m height. The revision of the standard focussed on a reproducible tonal assessment procedure and the determination of the sound power level at each integer wind speed from 6 to 10 m/s at 10 m height.

The presence of tones in the noise at different wind speeds shall be determined on the basis of a narrow band frequency analysis as follows:

- The sound pressure level L_{pt} of the tone shall be determined

- The sound pressure level of the masking noise L_{pn} in a critical band around the tone shall be determined
- The tonality ΔL_{tn}, the difference between the sound pressure level of the tone and the masking noise level shall be found

The tonal analysis shall cover the same wind speed range as the sound power level measurement. For each wind speed bin, the two one-minute periods with wind speeds closest to the integer wind speed value shall be analysed.
The narrow band frequency spectrum for the whole two-minutes period shall be determined. Then the two one-minute recordings shall be divided into twelve ten-second periods, from which twelve narrow band frequency spectra are obtained. From these twelve spectra all lines representing tones shall be identified.
Every spectral line is classified as a) 'tone', b) 'masking', or c) 'neither tone nor masking' as illustrated in the figure below.

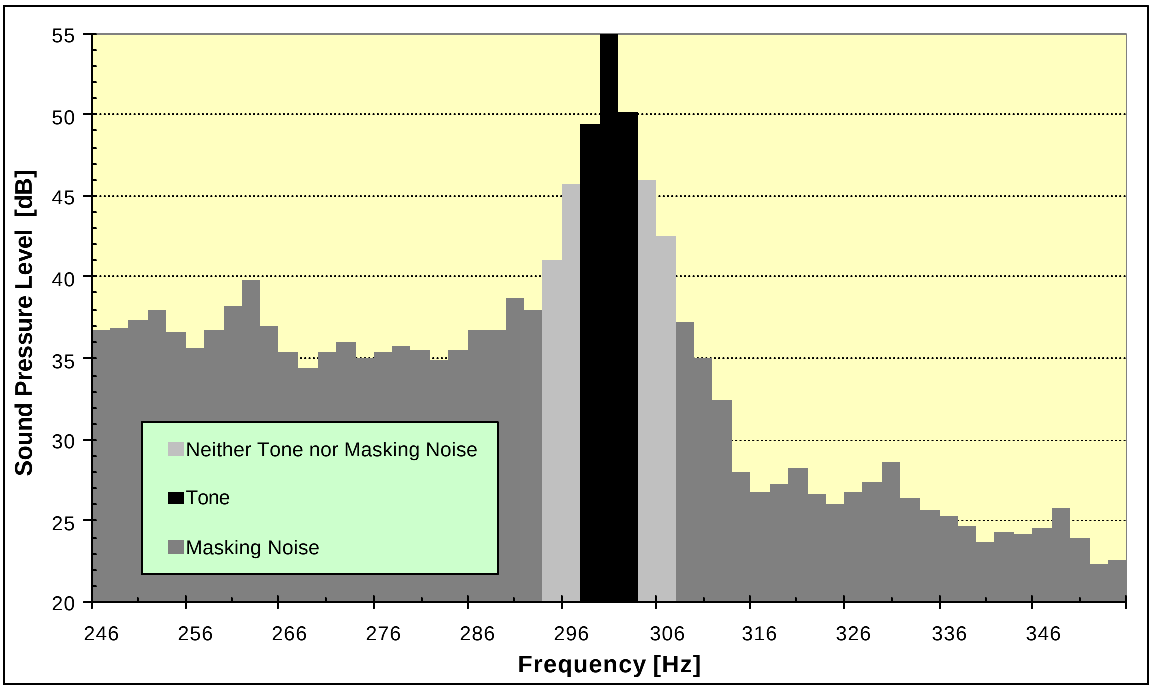


Figure 1 – Illustration of classifying all spectral lines

Determination of the tone levels $L_{pt,i}$

The sound pressure level of the tone, $L_{pt,i}$ is determined by energy summing all the spectral lines identified as tones from each 12 ten-second spectrum

Determination of the masking noise levels $L_{pn,i}$

The 12 sound pressure levels of the masking noise, $L_{pn,i}$, are defined as follows:

$$L_{pn} = L_{pn,avg} + 10 \ \lg\left[\frac{\text{critical bandwidth}}{\text{effective noise bandwidth}}\right]$$

Where $L_{pn,avg,i}$ is the energy average of the spectral lines identified as 'masking'.

Determination of the tonality DL_{tn}

The tonality $\Delta L_{tn,i}$ is the difference between the sound pressure level $L_{pt,i}$ and the level $L_{pn,i}$. The 12$\Delta L_{tn,i}$ are then energy averaged to one $\Delta L_{tn.}$

1.2 DECLARATION OF SOUND POWER LEVEL AND TONALITY VALUES OF WIND TURBINES

Information on the sound power level and tonality of wind turbines is needed by planners, manufacturers and authorities. At present wind turbine noise specifications tend to be based on measurement results from a single turbine of a particular make and model and these are then taken to be representative of these turbines as a whole. Clearly this is unlikely to be the case, as there will be individual variation between different turbines. The intention of this document is to determine declared noise emission values from a sample of turbines of the same type. The declaration will increase the reliability of wind farm planning and shall facilitate the comparison of sound power levels and tonality values of different types of wind turbines.

The documents IEC 61400-14 (IEC 88/161/CD) and prEN 50376 give guidelines for declaring the apparent sound power level and tonality of a batch of wind turbines.

The declared sound power level for a wind turbine can be determined from n measurement results $\{L_i\}$i=1,....n obtained by performing one measurement at each of n individual turbines of the same type.

The *n* measurements result in a mean value $\bar{L}_w$ and a standard deviation s defined as follows

$$\bar{L}_W = \sum_{i=1}^{n} \frac{L_i}{n}$$

$$s = \sqrt{\frac{1}{n-1} \sum_{i=1}^{n} (L_i - \bar{L}_w)^2}$$

The standard deviation of production σ_P can be estimated from:

$$\sqrt{s^2 - s_R^{\,2}} \leq s_P \leq s$$

An estimate of the standard deviation of reproducibility s_R is 0.9 dB, see typical uncertainties given in Annex D of the IEC 61400-11 standard. As long as only limited data on the real standard deviation of reproducibility is available and as for some cases very small values of s_R were found the relation s_P = s shall be used.
The standard deviation σ used for the declaration (including the standard deviation σ_R and σ_P from the n existing measurements and the standard deviation s_R and s_P of a verification measurement) is then determined by:

$$s = \sqrt{\frac{1}{n}(s_R^2 + s_P^2) + (s_R^2 + s_P^2)} = \sqrt{\frac{1+n}{n}(s_R^2 + s_P^2)}$$

with s_R = 0.9 dB and s_P = s
The declared sound power level is calculated from:

$$L_{WD} = \bar{L}_W + K = \bar{L}_W + 1.645\,s$$

The sound power level shall be declared by dual-number noise emission values reporting both $\bar{L}_w$ and *K*. *K* represents a certain confidence level and *K* =1.645 s reflects a probability of 5% that a sound power level measurement result made according to IEC 61400-11 performed at a turbine of the batch exceeds the declared value.

For the declaration procedure the influence of turbine characteristics on the acoustical performance is of great importance:

- Hub height : The sound power level is correlated to the acoustic reference wind speed and not to the wind speed at hub height. An increase of hub height will increase the sound power level and might have an unpredictable effect on tonality.

- Tip speed: the sound power level is very sensitive to the tip speed (L_W~50....60logV_{tip}). An increase in tip speed will cause an increase in sound power level, and may have an influence on aerodynamic tones.
- Pitch setting: Pitch settings affect the fundamental aero-acoustic processes on the blades, which may significantly change the overall sound power level and the tonality.
- Gear box: A major source of mechanical tones is the gear box. Small changes in the design (like ratio's, tooth shape, casing thickness) can have a significant effect on the frequency and level of the tones
- Blades: Changes to the blade geometry such as trailing edge thickness, tip shape, blade surface finish , internal structure, twist distribution, may all cause significant changes to the acoustical performance.
- In addition to the above mentioned items, there are a number of other items, generator, tower type, yaw motors, cooling fans, hydraulic pumps, etc., which may influence the acoustical performance.

1.3 MEASUREMENT OF NOISE IMMISSION FROM WIND TURBINES AT NOISE RECEPTOR LOCATIONS

The IEA recommendation **Measurement of Noise Immission from Wind Turbines at Noise Receptor Locations** recommends measurement techniques and methods which will enable a characterisation of the noise immission from wind turbines at a noise reception location. In several countries standards or guidelines from industrial sources have been implemented. However, it is not possible to apply these procedures to wind turbine acoustic measurements since they must be carried out in windy conditions outside the scope of the standards dealing with noise from industrial plants.

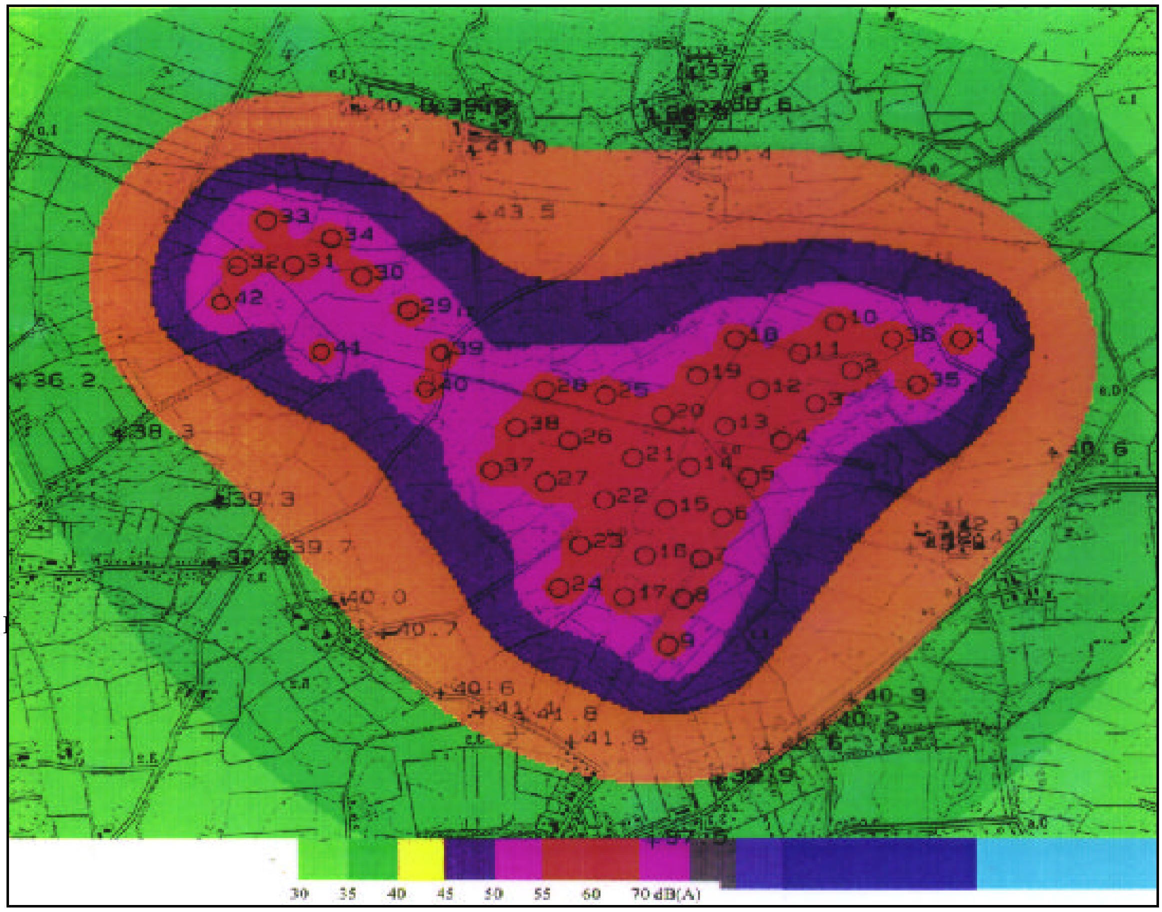


Fig. 2: Sound Pressure Levels around a Wind Farm

2. NOISE REDUCTION PROCEDURES

The choice of a wind turbine's blade pitch setting and its rotational speed is a compromise between noise radiation and energy production. The advantage of wind turbines with changed operational conditions (rotational speed/pitch setting) in noise-sensitive conditions (e.g. for specific wind directions or at night-time) are obvious: The acoustically affected area is smaller so that more wind turbines can be erected in a wind farm. The proposed noise-reduction-tool can also be used for subsequent noise reduction in cases of complaints.

As changes in the operating conditions of the wind turbines will influence their power curves, any resulting loss in energy production can be calculated, so that the cost effectiveness of the measures can be evaluated.

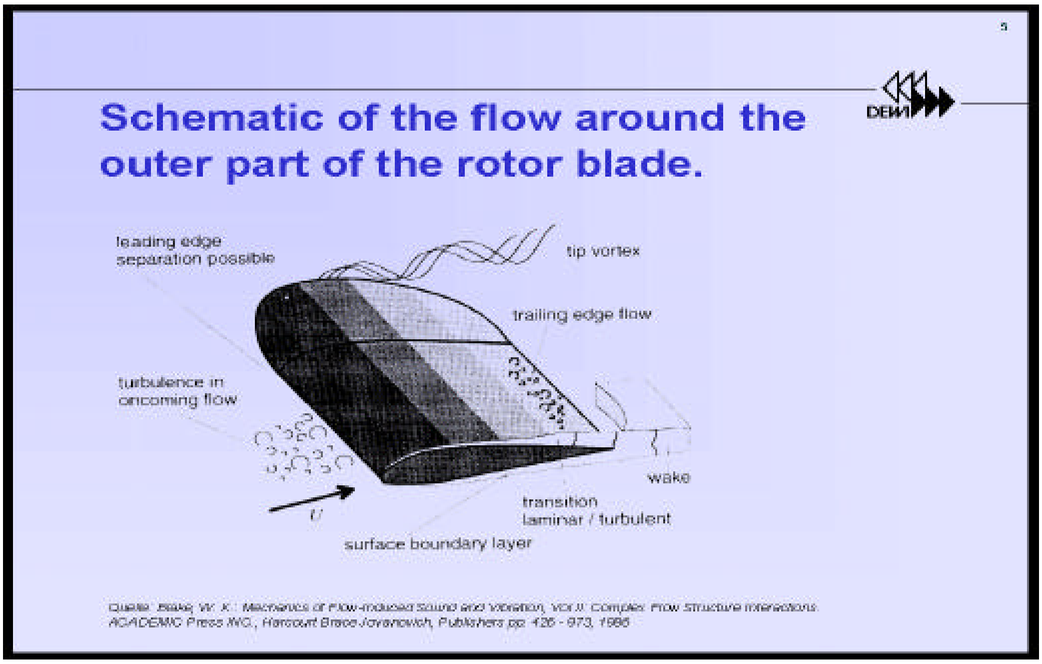
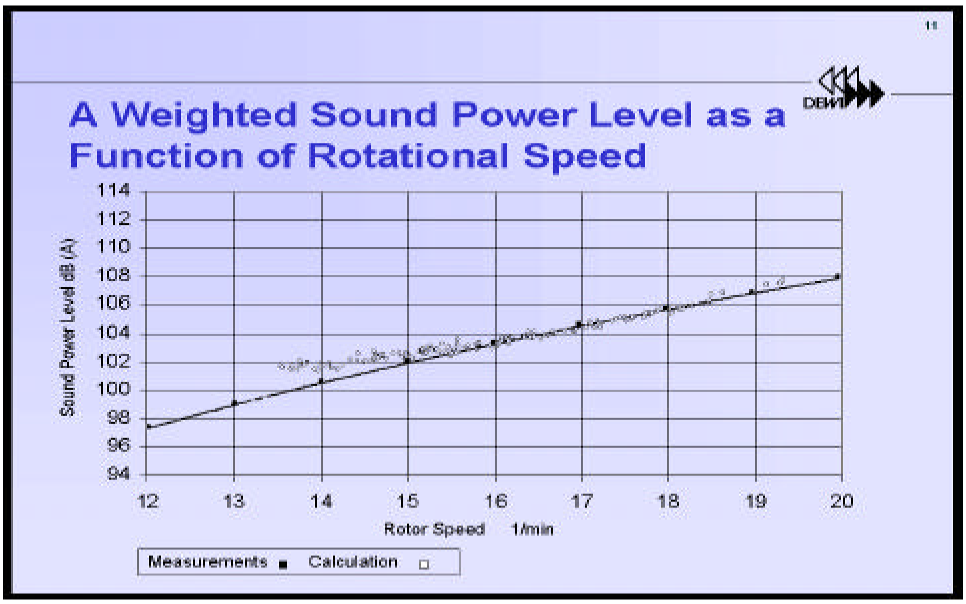


Fig.3: Schematic of the flow around the outer part of the rotor blade

Fig. 4: Sound Power Level of a 3 MW Turbine as a Function of Rotational Speed:



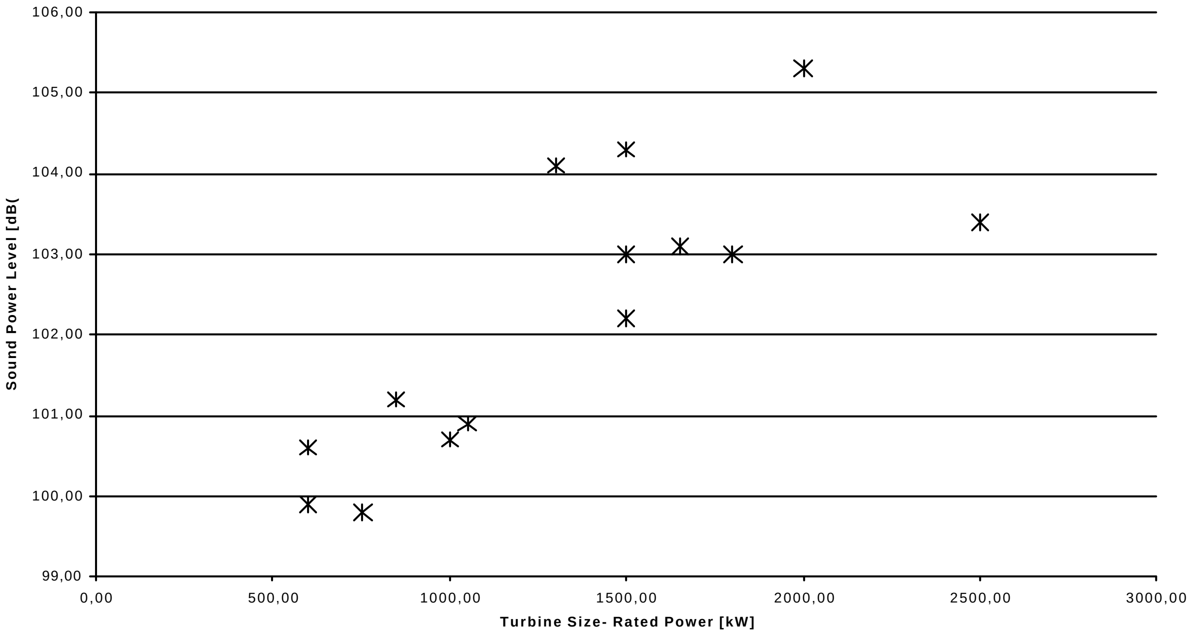


Fig: 5: Sound Power Levels (at 10 m/s at 10 m height) of different Wind Turbines as a function of Rated Power

References:

Klug, Osten, Lowson, Jakobsen, Andersen, van der Borg, Vink, Betke, Schultz-von Glahn, Larsen, 'Aerodynamic Noise from Wind Turbines and Rotor Blade Modification',

Final Report DEWI V-95 0006 (EU-Projekt JOU2-CT92-0233), Wilhelmshaven, 1995

.

H. Klug, 'Aerodynamic Noise from Wind Turbines and Rotor Blade Modification - Experimental Results', Forum Acusticum 1996, Acta Acustica, S.81.

Brooks, T.F., Pope, D.S., Marcolini, M.A.,'Airfoil Self Noise and Prediction', NASA Reference Publication 1218, 1989.

Howe, M.S., 'A Review of the Theory of Trailing edge noise', J. Sound Vib. 61, 3, 437-465 (1978).

Lowson, M.V.,'Assessment and Prediction of Wind Turbine Noise', ETSU W/13/00284/Rep1993.

Wagner, Bareiß, Guidati; Wind Turbine Noise, Springer Verlag , 1996.

Klug, Helmut; Osten, Tjado; Gabriel, Joachim: Noise from wind turbines or how many Megawatts can you get for a 100 dB(A). ?
Proceedings of the EWEC1997 in Dublin, Ireland, 6th to 9th October, 124-127.,1997

Recommended Practices for Wind Turbine Testing, 10. Acoustics - Measurement of Noise Immission from Wind Turbines at noise Receptor Locations, 1. edition, 1997 International Energy Agency. Edited by Sten Ljunggren, Sweden.