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by

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**brief communication**

# ***Low frequency noise from wind turbines: do the danish regulations have any impact? An analysis of noise measurements***

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## **ABSTRACT**

Previous analyses of low frequency noise from wind turbines and the development with wind turbine size have been interpreted differently [3], [4], [5], [6] and [7]. Based on an improved statistical basis with more than 200 measurement reports, these interpretations are tested again and conclusions that are more robust are achieved. Furthermore, the impact of the Danish regulation for low frequency noise is investigated. The development of low frequency noise with wind speed is indicated for different types of wind turbines.

## **1. INTRODUCTION**

From the beginning of 2012 the Danish regulations were revised [8] and a criteria for the amount of in-door low frequency noise were introduced. The impact of this has been tested by comparing the noise emission of new and older wind turbines. The development of low frequency noise with wind turbine size and wind speed is investigated as well. A more comprehensive presentation of the results can be found in [1] and [2]. The analysis follows the methods in previous analyses of the same type [3], [4], [5], [6] and [7]. At the moment Denmark is the only country with specific regulations for low frequency noise from wind turbines. Other countries are considering this type of regulations. These considerations involves definition of frequency range, choice of frequency weighting, in-door/out-door criteria and measurements contra predictions.

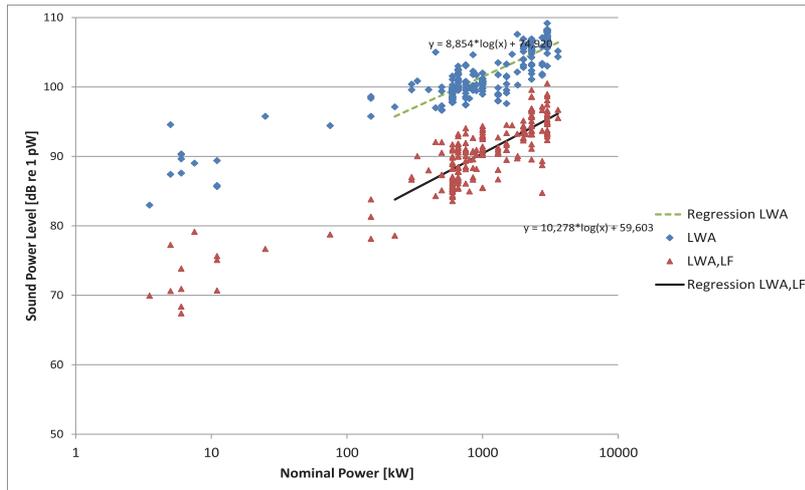
The following types of analysis are made:

The dependency of sound power level with wind turbine size (Rated Power)

The dependency of frequency distribution with wind turbine size (Rated Power)

## 2. SOUND POWER LEVEL

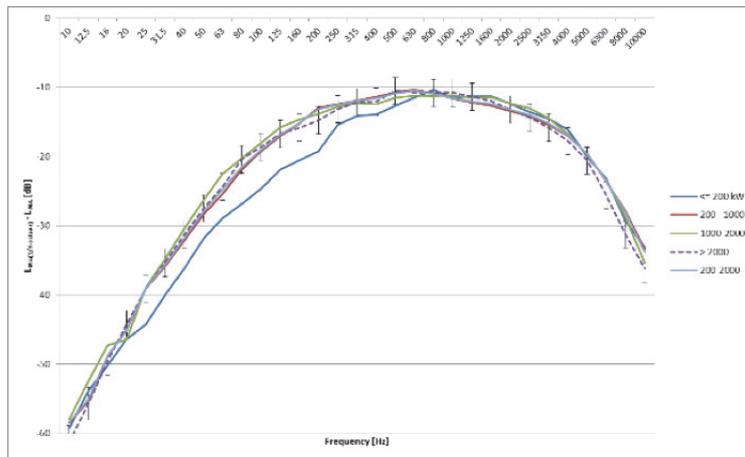
The apparent sound power level from the measurement reports is shown as a function of nominal power in Figure 1 both as the total level,  $L_{WA}$  and the low frequency part of the level, calculated as the sum of all 1/3-octave bands from 10 Hz to 160 Hz,  $L_{WA,LF}$ .



**Figure 1:**  $L_{WA}$  and  $L_{WA,LF}$  as a function of nominal power at 8 m/s. The figure shows that the low frequency part of the level increases at a higher rate than the total level. The slopes of the lines are not statistically significant different from each other [90 % confidence interval 7.2 to 10.5 for  $L_{WA}$  and 8.6 to 11.3 for  $L_{WA,LF}$ ], indicating that the noise and low frequency noise increases at approximately the same rate.

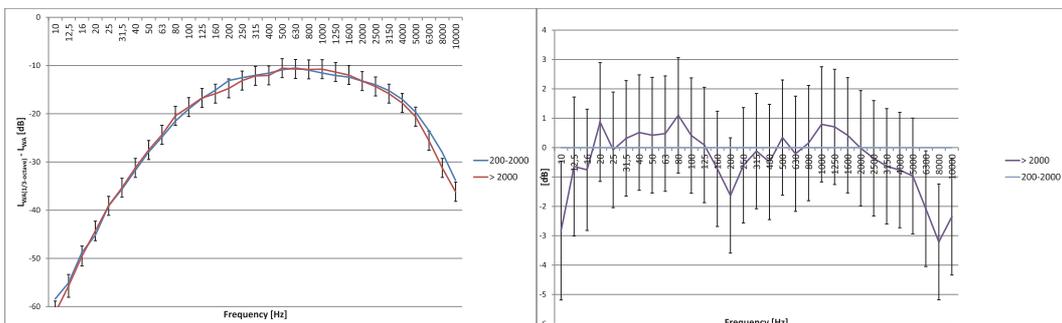
## 3. FREQUENCY DISTRIBUTION

Measurement data are sorted into 4 groups:  $\leq 200$  kW, ]200 kW – 1000 kW], ]1000 – 2000 kW], >2000 kW, >2000 kW old types and >2000 kW new types. This makes it possible to evaluate new large wind turbines compared to wind turbines designed and erected before the investigation in [3] and [4] was published. The spectra are normalised to  $L_{WA}$  of the individual wind turbine before averaging. A comparison of the averaged spectra for each class can be seen in Figure 2.



**Figure 2:** Normalized apparent sound power levels in one- third-octave bands. Mean of groups of wind turbines. Error bars show  $\pm 95\%$  confidence interval around the mean in every 1/3-octaveband for the group  $> 2000$  kW.

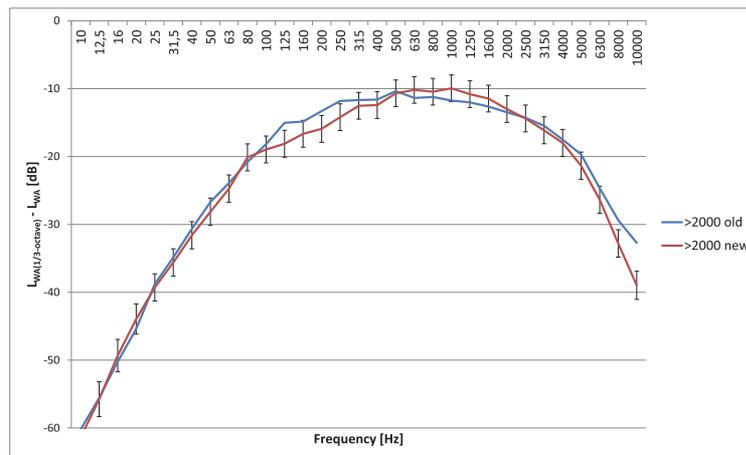
The spectra representing the different groups do not deviate much in the low frequency region from 10 Hz to 160 Hz, except for the group of wind turbines below 200 kW. These turbines are dominated by machinery noise and tonal noise. Small wind turbines are represented by the group [200 – 2000 kW] which is consistent with the previous analyses in [3] to [7]. In Figure 3, left a comparison of the group [200 – 2000 kW] and the group  $> 2000$  kW is shown. The differences in the low frequency range are small, which can be seen in more detail in Figure 3, right, where the spectrum for group  $> 2000$  kW is subtracted from the spectrum of group [200 – 2000 kW]. It is clear that the group of turbines above 2000 kW deviates very little from the group [200 – 2000 kW] wind turbine spectrum and positive deviations are less than 1 dB.



**Figure 3:** Normalized apparent sound power levels in one- third-octave bands. Mean for two groups of turbines: [200 kW- 2000 kW] and  $> 2\ 000$  kW- Left. Spectrum of the group  $> 2000$  kW wind turbines relative to the spectrum for the group [200 – 2000 kW] wind turbines - Right

Møller suggested [5], [6] that the development in low frequency noise with size corresponds to a shift by one 1/3-octave in the spectrum towards lower frequencies. It is obvious from Figure 3, that the assumption can be rejected as can the consequences of this assumption when extrapolated to 5 MW and 10 MW wind turbines.

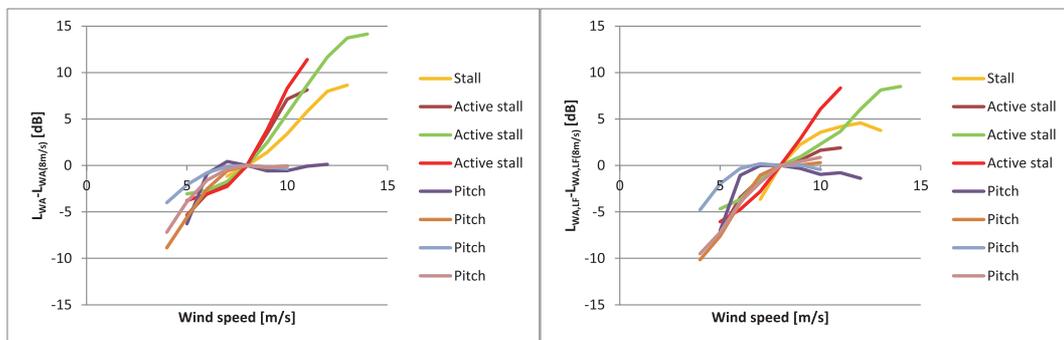
In order to investigate the results from Figure 3 further a comparison between new (after the regulation) and old (before the regulation) wind turbines from group >2000 kW is made in Figure 4. The definition of new and old is a little diffuse, but measurement reports from before 2010 are considered to be old and after 2010 as new. There is a statistically significant difference in the frequency range from 125 Hz to 400 Hz [ $p < 0,001$ ], where the relative amount of noise is lower for the new wind turbines than for the old wind turbines in this group. In the frequency range from 630 Hz to 1600 Hz [ $p < 0,01$ ], the relative amount of noise from the new wind turbines are higher than for the old wind turbines. This suggests that there is a development towards less low frequency noise, possibly because tonality in this frequency range is an area of focus for the developers. Also aerodynamic and aeroacoustic optimization of the blades tends to shift the aeroacoustically generated noise towards higher frequencies.



**Figure 4:** Normalized apparent sound power levels in one-third-octave bands. Comparison of new and old wind turbines > 2000 kW. Error bars show 95% confidence interval around the mean in every 1/3-octaveband for new wind turbines above 2000 kW

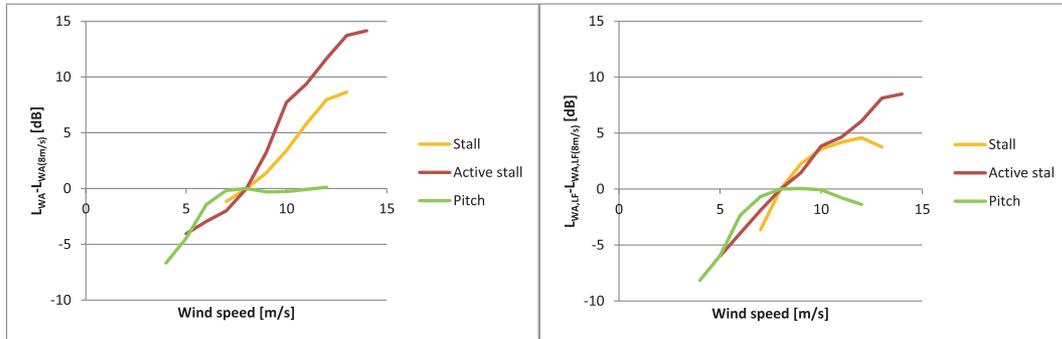
#### 4. NOISE AND LOW FREQUENCY NOISE AS A FUNCTION OF WIND SPEED

In this article as well as in most other reviews and presentations the basis has been the sound power level at 8 m/s. This wind speed has been the reference wind speed during the period where noise from wind turbines has been measured. In From the previous section it is clear that the type of regulation of the wind turbine is important for the emission of noise at different wind speeds. In this section an analysis of the development of noise and low frequency noise with wind speed for different types of wind turbines is made. Since almost all commercial measurements are designed to give the level and frequency distribution at 8 m/s or 10 m/s, only few measurements cover a wide range of wind speeds. A number of measurements have been analyzed in more detail. The measurements cover stall regulated wind turbines, active stall regulated wind turbines and modern pitch-RPM controlled wind turbines. In Figure 5 the wind speed dependency of the sound power levels  $L_{WA}$  and  $L_{WA,LF}$  is shown for different wind turbines. The sound power levels are shown relative to the level at 8 m/s. It is clear from the curves that the sound power level does not increase above 8 m/s for the pitch-RPM regulated wind turbines while there is a significant increase in the sound power level for the stall and active stall regulated wind turbines. What is interesting is that the curves for low frequency part of the noise are similar to the curves for  $L_{WA}$ . For pitch-RPM regulated wind turbines the low frequency noise does not increase above 8 m/s but a significant increase occurs for the other types of wind turbines. Note that for all the wind turbines 95% of rated power is reached around 8 m/s to 9 m/s.



**Figure 5:** Noise curves  $L_{WA}$  (left) and  $L_{WA,LF}$  (right) for different wind turbines. The curves are normalized to  $L_{WA} = 0$  dB at 8 m/s for comparison.

In Figure 6 the curves from Figure 5 are averaged according to type of regulation to make the comparison clearer. Note that the curve for stall regulated wind turbines is from a single measurement.



**Figure 6:** Noise curves  $L_{WA}$  and  $L_{WA,LF}$  for different wind turbines. Average of the curves in Figure 5.

It is clear from Figure 5 and Figure 6 that the development of low frequency noise with wind speed follows the development of the noise in general with wind speed.

## 5. CONCLUSIONS

Noise and low frequency noise increases with wind turbine size. The analysis show that on average the amount of low frequency noise is the same for large and small wind turbines, relative to the total noise level and that the amount of low frequency noise for new large wind turbines is less than for old large wind turbines, relative to the total noise level. The comparison between wind turbines with different types of regulation shows that the development with wind speed of the low frequency part of the sound power level  $L_{WA,LF}$  follows the general development of the sound power level  $L_{WA}$ . This means that for a modern pitch-RPM regulated wind turbine the low frequency noise does not increase above 8 m/s. For stall and active stall regulated wind turbines the low frequency part of the noise increases above 8 m/s but at a lower rate than, to get at a lower rate than the noise in general. These conclusions are expected to be valid when no significant tones are present in the low frequency part of the spectrum.

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