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Measurement of Swish Noise. A new method

Gunnar Lundmark, Lundmark Akustik & Vibration
Langelandsgatan 27, 16443 Kista, Sweden
gunnar.lundmark@swipnet.se

Abstract

Swish noise, amplitude modulated noise, is characteristic for wind turbines and by many considered to be extra annoying. Different turbine design, power regulation and meteorological conditions etc. can result in different modulation strengths. However, by standard measurement methods, it is not possible to distinguish the noise from a waterfall (constant, broad brand noise) from wind turbine swish noise (amplitude modulated noise). Standard measurement methods for wind turbines (and industrial noise), time averaged dB(A) levels, hides the swish noise very efficient.

The integration time, time constant, of the ear is about 20-200 milliseconds, and is approximated in sound level meters by the time constant Fast Response, 125 milliseconds. The main idea is to handle the time signal with the same integration time as the ear. Measurement of swish noise consists of two steps:

1) Registration of instantaneous sound pressure dB(A) levels. Sample the sound pressure level 8 times/second (time constant = 125 ms).

2) Calculate the Fast Fourier Transform (FFT) of the numeric time series to identify and quantify amplitude modulation, frequency and strength.

The measurements can be done with a hand held sound level meter, and the FFT calculation with standard functions in Excel Analysis ToolPak.

The difference between wind turbine noise and waterfall noise is obvious with this method, and I think it can be a good start for further investigations of amplitude modulated wind turbine noise.

Introduction

It is well known that the annoyance of noise depends both of the strength, the noise level, and the characteristics of the noise, audible tones, impulsive noise etc. Swish noise, amplitude modulated noise, is characteristic for wind turbines and by many considered to be extra annoying. Standard measurement methods on wind turbine noise, IEC 61400-11 (46 pages), gives detailed specification how the measurements should be done; wind speed, number of measurements, integration time (at least 30 measurements and an integration time not less than 1 minute), frequency analysis.....

But analysis of swish noise, amplitude modulated broad band noise, is only mentioned as Optional measurement, and in Appendix A5.”This modulation can be displayed by recording of the measured A-weighted sound pressure level with time weighting F (125 milliseconds, minimum 8 samples/s) for at least ten blade passes by the turbine.”

I have never seen modulation measurements in reports from wind turbine manufactures. Normal integrations times, at least 1 minute, hides the swish noise.

In Sweden there have been some serious complaints about bouncing swish / woosch noise (“sounds sometimes like a stone crusher at great distance”) from wind turbines of a specific type under some meteorological conditions. Sound measurements at sites has been done with long integrations times in accordance with IEC 61400 at reference conditions and have been compared to the sound data specification from the turbine manufacturer. The specific sound characteristic that some people have complained about was not analysed.

The problem with swish noise has been discussed by researchers in recent years. Time registration of instantaneous sound pressure levels are presented in some papers. The difference between max and min values has been presented as a measure of the modulation, but is not a good measure. The periodicity of the noise has not been analysed, only the level variation.

Time variation of instantaneous sound pressure level

Step1: Registration of instantaneous sound pressure dB(A) levels. Sample the sound pressure level 8 times/second (time constant = 125 ms).

Can be done with a modern hand held sound level meter. I have used Norsonic 118.

Example 1. Rhede wind park

A wind park at Rhede (Germany) has caused noise complains in a Dutch village near the park and the boarder. Residents living 500 m and more from the park have reacted strongly to the noise; residents up to 1900 m distance expressed annoyance. The noise from the Rhede wind park has been analysed by G.P. van den Berg. Results and conclusions are presented in [1] and [2]. van den Berg has sent me a recording of the noise taken 750 m from the nearest turbine. I have analysed the sound, made an registration of the instantaneous sound pressure level, dB(A).

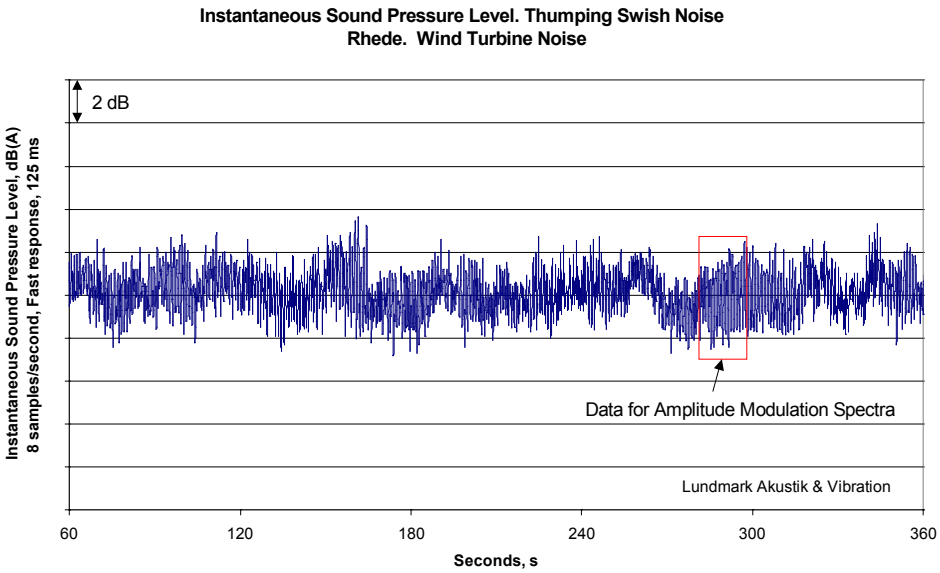

Figure 1. Time registration, Rhede wind park, 300 s.

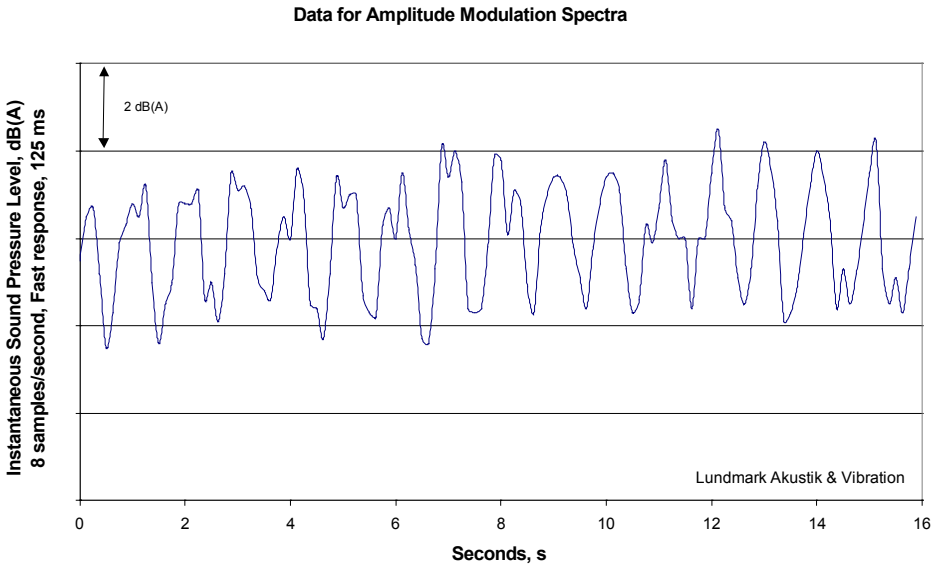

Figure 2. Time registration Rhede, 15.825 s. Clear modulation. The difference between max and min is approx. 4 dB(A). And the noise level is periodic.

Example 2. Wind park in the North of Sweden.

Measurement were taken near a house 1500-1700 m from five 2MW wind turbines. The noise limit 40 dB(A) was fulfilled. Measured sound pressure level 35 dB(A) at conditions for high levels. No serious noise complains, but the noise from the wind park could be heard some days. I have made the measurements and listened to the sound at the site a sunny and cold winter day.

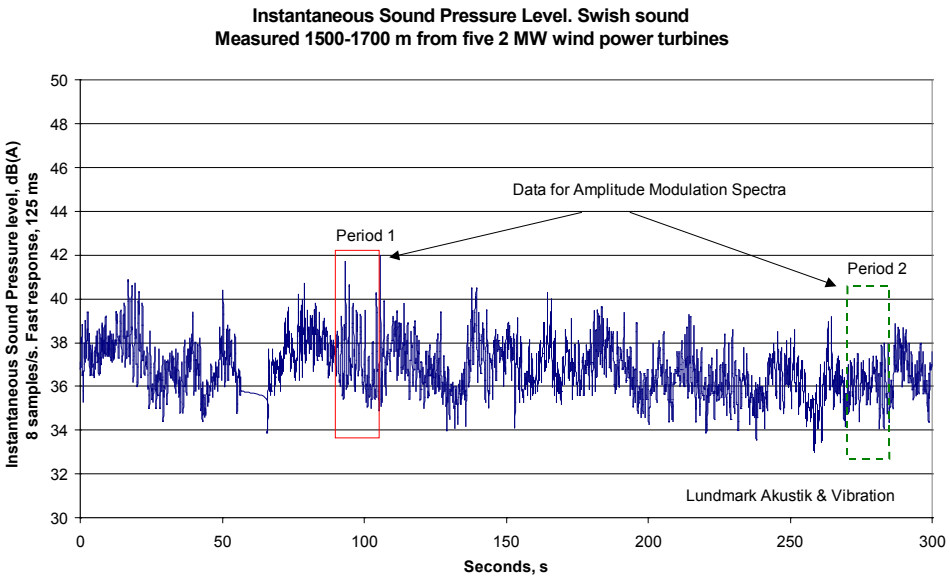

Figure 3. Time registration, Wind park in North of Sweden, 300 s.

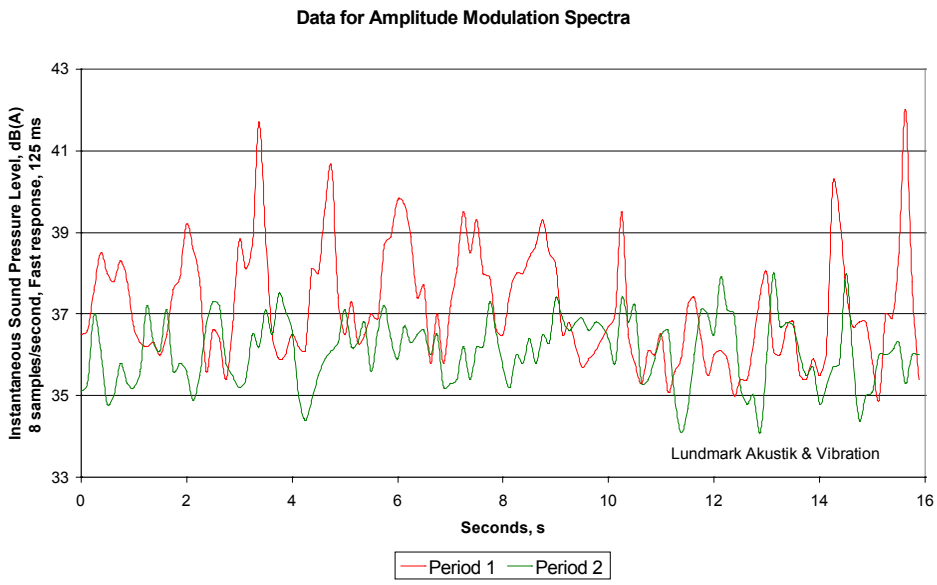

Figure 4. Time registration, North of Sweden, 15.825 s. Period 1: clear modulation; difference between max and min is approx. 6 dB(A). Period 2: weak modulation.

Example 3. Victoria Falls. Waterfall. No amplitude modulation

The sound from a waterfall is stochastic noise without modulation.

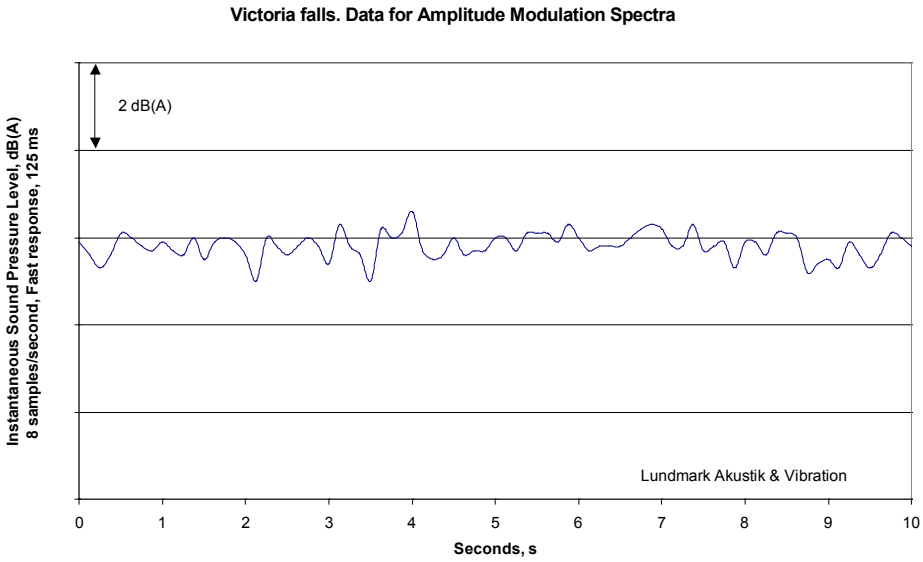

Figure 5. Time registration Victoria Falls, 10 s. No amplitude modulation, and almost constant noise level; difference between max and min approx. 1-2 dB(A).

Amplitude Modulation Spectra (AMS). FFT of level variation

Step2: The frequency and the strength of the amplitude modulation can be analysed by calculation of a FFT (Fast Fourier Transform) spectra of the instantaneous noise level, dB(A) level, in the time registrations. I have used the FFT algorithm in Excel Analysis ToolPac. (The FFT analysis can be improved.)

The sampling frequency, 8 samples/s (integration time 125 ms; comparable to the integration time of the ear) gives the maximum frequency range, 0 – 4 Hz, of the FFT spectra. In Excel the number of in data has to be a multiple of 2, e.g. 64,128, 256. I have chosen 128 values, which means that a time period of 15.825 second is analysed. Frequency resolution, 0.0625 Hz. I have discussed the scaling with prof. Kjell Ahlin [3] and follow his recommendations. A linear RMS-spectra is calculated from the time series of the sound levels adjusted to zero mean value. N=Number of samples.

Amplitude Modulation Spectra= Rot(2) x Abs(FFT(dB(A) levels,sampled 8/s))/N.

A normal sound spectra, FFT or 1/3 octave, is a spectra of the sound, and can be measured direct by instruments. The AMS is a spectra of the time variation of the sound level, and the function is not included in any instruments (as far as I know).

(Best title? Amplitude Modulation Spectra? Noise Modulations Spectra? Level Modulation Spectra? …)

Amplitude Modulation Spectra

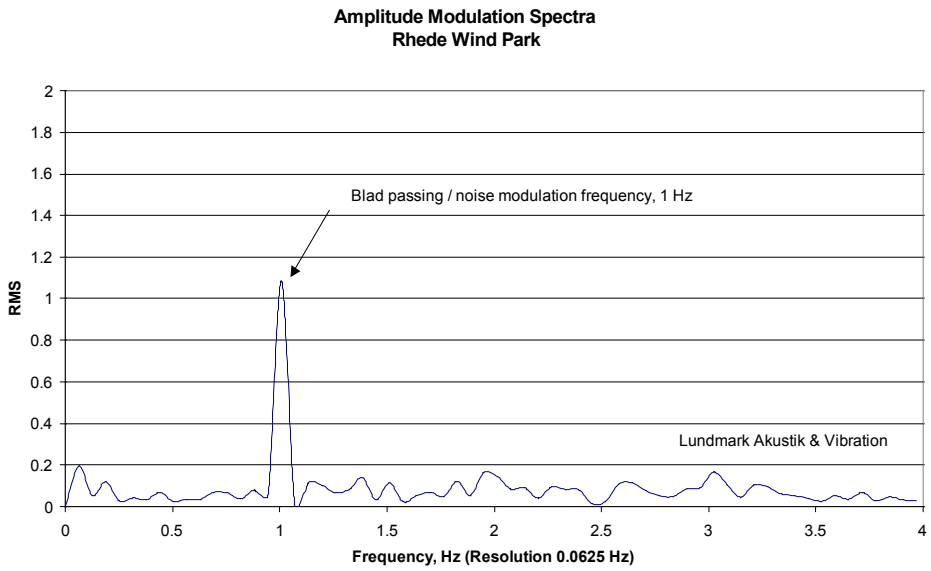

Figure 6. Rhede wind park. Clear amplitude modulation, 1 Hz. 3 blades, gives 20 RPM.

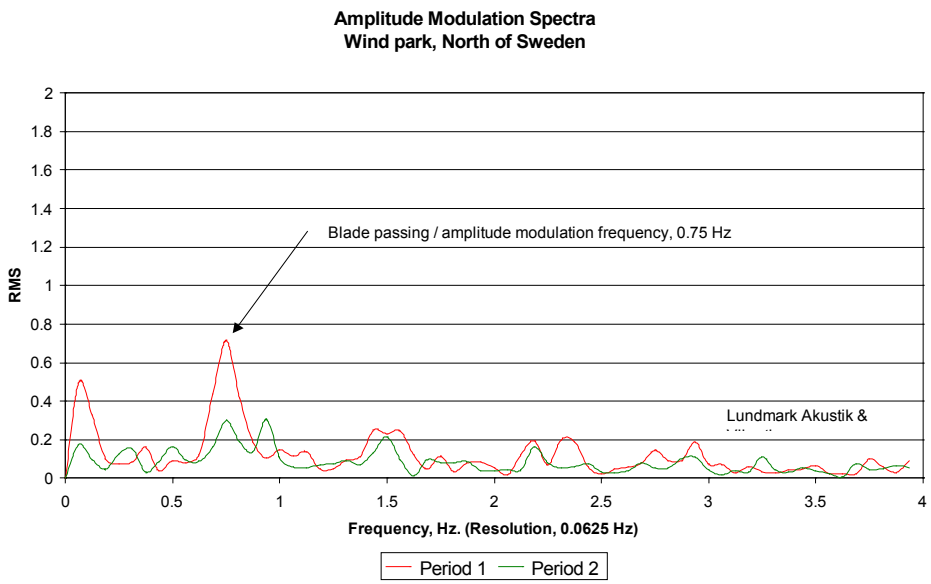

Figure 7. Wind park, North of Sweden. Period 1. Weak modulation, 0.75 Hz. 3 blades gives 15 RPM. Period 2, no modulation.

The amplitude modulation was stronger at Rhede, Figure 6 - 1.1 at 1 Hz, than at North of Sweden, Figure 7 - 0.7 at 0.75 Hz, but the difference between max and min was smaller at Rhede. The Amplitude Modulation Spectra is affected by both amplitude and periodicity.

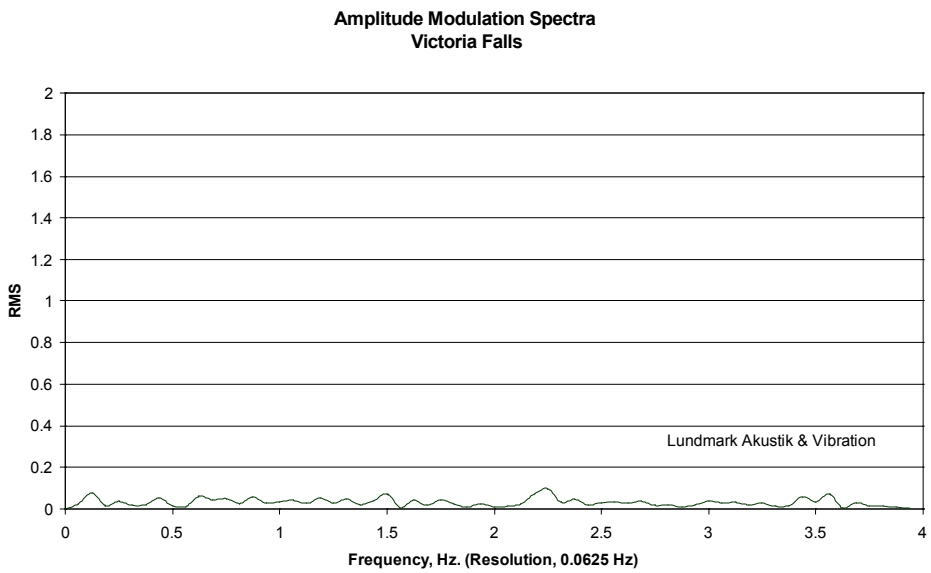

Figure 8. Victoria Falls. Stochastic noise, no modulation.

Conclusions

The suggested method for analysis of swish noise/ amplitude modulated noise seems to work well. It consists of two steps:

1) Registration of instantaneous sound pressure dB(A) levels. Sample the sound pressure level 8 times/second (time constant = 125 ms; comparable to the ear).

2) Calculation of Amplitude Modulation Spectra, FFT of the numeric time series, dB(A) levels to identify and quantify amplitude modulation, frequency and strength.

It is well known that the annoyance of noise depends both of the strength, the noise level, and the characteristics of the noise, audible tones, impulsive noise etc. The difference between amplitude modulated wind turbine noise and stochastic waterfall noise is obvious with my method. The method can be improved; FFT-calculation, averaging of Amplitude Modulation Spectra etc.

I think the method can be a good start for further investigations of amplitude modulated wind turbine noise; meteorological conditions with high risk of strong modulation, pitch regulation, basic turbine design, annoyance etc.

The relation between modulation strength, modulation frequency and annoyance is not known for wind turbine noise (as far as I know). It is a risk the the problem has been hidden with long time averages (1 minute or more) according to IEC 61400-11.

Measurement has to be carried out when people are complaining, not only at reference conditions. The risk for strong modulation is probably low a sunny summer day, when many noise measurements are done.

This measurement method, AMS, could perhaps good help in developing wind turbines with less annoying noise characteristics at the same dB(A) level and electric production.

References

[1] G.P. van den Berg, “The sound of high winds: the effect of atmospheric stability on wind turbine sound and microphone noise.”, Thesis, 2006.

[2] G.P. van den Berg, “Effects of the wind profile at night on wind turbine sound.”, JSV 2003.

[3] Discussions with prof. Kjell Ahlin, specialist in signal analysis, Blekinge Institute of Technology.