Features of Low Frequency Wind Turbine Sound

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1. INTRODUCTION

A lot has been written about low frequency (LF) noise emitted from wind turbines. It is relatively straight-forward to document physical parameters such as the sound pressure and its spectrum. Certain individuals experience or claim to experience adverse impacts from wind turbine sound ranging from annoyance to serious health effects [1,2]. There appears to be no supporting evidence for the latter [3,4].

Although low frequency sound emitted from wind turbines continues to be the subject of much speculation, objective descriptors of the sound are lacking. Aercoustics Engineering has tried to address this by examining several aspects of sound characteristics of large wind turbines. First, amplitude modulation was identified as being attributable to source motion and source directivity [5]. The phenomenon of amplitude modulation is not a low frequency phenomenon: the principal sound energy is well above 200 Hz, which is commonly used as an upper bound for LF sound. Some dynamic features of low frequency sound and possible means of their measurement have been discussed in reference [6]. Aspects of the cyclic signal, associated with the blade passage frequency are expanded upon herein.

2. WIND TURBINE CHARACTERISTICS

The rotating lift forces generated by the motion of the wind tunnel blades extract energy from the wind, some of which is converted to electric power. Large commercial wind turbines have rotor diameters of the order of 80 to 100 m and are mounted on 80m to 120m high towers. Rated power ranges from 1.2 MW to 6MW. The majority of wind turbines installed in Canada are 1.8 - 2 MW. The nominal sound power of such machines is of the order of 104 dBA.

Typical rotation rates (N) are 9 to 15 RPM, so that the tip speed of a 90m diameter rotor rotating at 12 RPM is ~ 56m/s. Thus the 'sonic' circle of the hydrodynamic pressure field is of the order of 270m. This is the extent of the acoustic near field of the wind turbine [$R_{NF}=60c/(\pi N)$].

There is a wealth of literature on the sound emitted by propellers and (helicopter) rotors. Tip speeds and disk loading are much greater than experienced by wind turbine rotors. Nevertheless, all of have similar low frequency spectra that are dominated by the blade passage tone (nB, n=N/60) and higher harmonics. The relative strengths are governed by the pressure distribution on the blade.

For a variety of reasons, the wind turbine blade passage tone and its harmonics have received little attention. From the perspective of conventional noise impact assessment, they make no sensible contribution to the ubiquitous A weighted Leq. or L90. Most measurement and analysis systems cannot cope with frequencies of the order of 0.6 Hz.

Even when low frequency spectra are measured, they may be masked by contributions from (broad-band) wind noise. For this reason we have elected to analyze low frequency wind turbine sound in the time domain.

3. AUTOCORRELATION:CYCLIC SOUND

The auto-correlation function is ideally suited to extract cyclic signals from a time series that has both periodic and random components:

$$p(t)=n(t)+\Sigma a_m\cos(2\pi mt/T)+b_m \sin(2\pi mt/T)$$

The autocorrelation $R_{pp}(\tau)=<p(t)p^*(t-\tau)>$ takes the form:

$$R_{pp}(\tau)=\Sigma\, c_m\cos(2\pi m(t-\tau)/T)+ R_{nn}(\tau),\ c_m=0.5(a_m^2+b_m^2)$$

The time scale of the random noise is typically short, so that $R_{nn}(\tau)$ vanish for τ large. The cyclic terms persist. The autocorrelation has a global maximum at zero time delay (t=0). It is customary to normalize autocorrelations by the $<p(t)p^*(t)>$ so that $R_{pp}(0)=1$.

4. MEASURED AUTOCORRELATIONS

In order to capture the essence of the low frequency sound the analysis window should be capture at least 100 blade passage events. A large number of files of wind turbine sound have been analyzed. Conventional 1/2 inch ICP microphones were used. The data was recorded on a Rion DA-20 digital data recorder. The frequency response of the data acquisition system was 'flat' to 10Hz. A typical LF spectrum is shown in figure 1. The first few harmonics can be readily identified. Higher harmonics are obscured by wind noise.

A measured autocorrelation of the wind turbine sound is shown in figure 2. The maximum is at zero time delay. This peak vanished rather quickly. Distinct pulses are also evident at time delays corresponding to the reciprocal of the blade passage frequency. These pulses form the auto-correlation signature of the cyclic portion of the wind turbine sound.

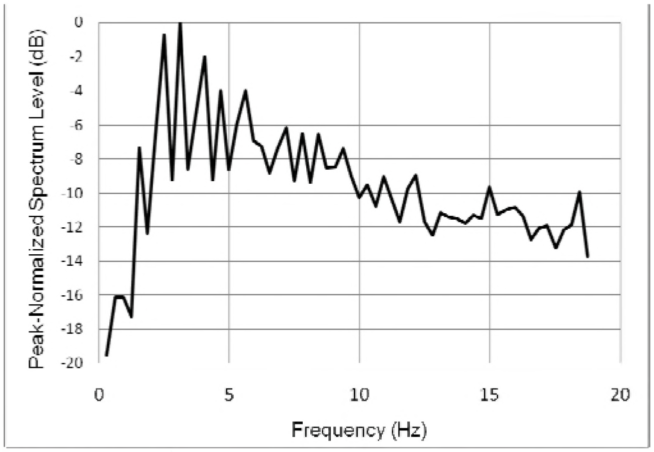

Figure 1. Low frequency wind-turbine spectrum

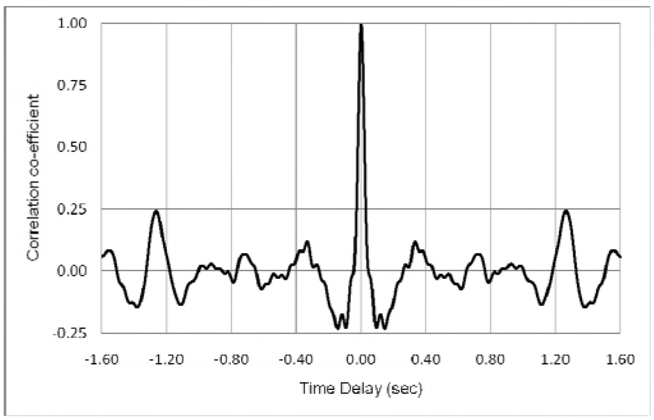

Figure 2. Measured autocorrelation of wind-turbine sound

The shape of the pulse can be image can be enhanced by time-shifting one of the records by $\Delta\tau=(nB)^{-1}$(Figure 3) This eliminates the error introduced by the so-called bow-tie correction that must be applied to FFT based autocorrelations.

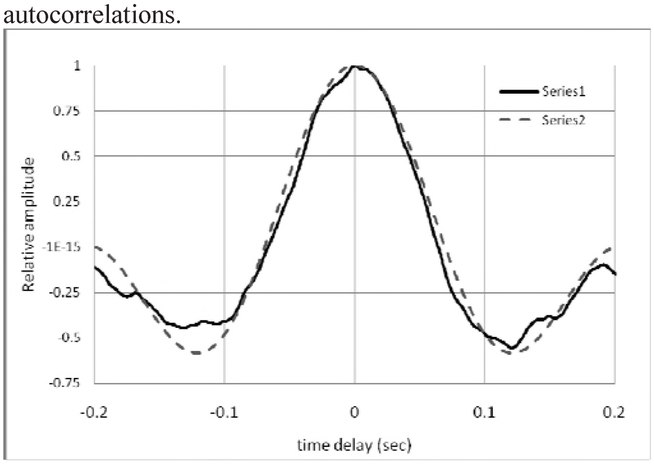

Figure 3. Cyclic pulse

The function $(1-(t/\Delta\tau)2)\cos p\ \tau/\Delta\tau)$ fits the cyclic pulse for $-\Delta\tau<\tau<\Delta\tau$. This then permits one to estimate the Fourier series coefficients (A_m) of the cyclic pulse. The series for A_m exhibits `structure` for small m, evolving into a regular pattern with slowly decaying amplitude (Figure 4). For each index m there is corresponding a frequency (f_m). For the data presented here $f_m \sim 0.8$ m Hz.

5. DISCUSSION

Since the tonal amplitudes decay at a rate of about 6dB/octave, the cyclic signal may well be audible, especially if the background noise at the point of reception is low. Although the human hearing is not very acute at low frequencies, the higher harmonics of the cyclic signal are well within the audible range. This is analogous to the well known case of large pipe organs where the fundamentals of the harmonics are below the nominal threshold of hearing.

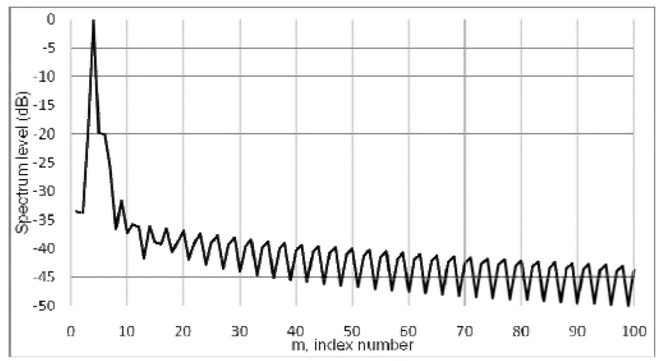

Figure 4. Spectrum level of cyclic pulse harmonics.

6. REFERENCES

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