Low-frequency Noise Propagation from a Small Wind Turbine Tower

Ehsan Mollasalehi, David Wood, Qiao Sun *

Department of Mechanical and Manufacturing Engineering, University of Calgary, AB, Canada

Noise propagation and vibration emission from wind turbines have been one of the major issues in the development of sustainable wind energy. Less noisy turbines have become available in recent decades because of improved design of airfoils and other components such as bearings and generators. However, there are still criticisms from either environmentalists or residents living close to wind turbines. Many aspects of noise have been studied. Still, there are some missed areas which need more investigations. One of those is in noise measurement regarding how to isolate turbine generated noise from ambient noise, and how different components interact in total noise generation.

In fact, a major barrier to the acceptance of small wind turbines is that they are perceived to be noisy particularly when mounted on monopole towers rather than traditional guy-wired ones. Monopole towers are thought to amplify the generated noise like a speaker, especially in low-frequency and infrasound bands. Turbines with downwind rotors propagate 10 – 30 dB higher infrasound levels, therefore these may exceed relevant assessment standard [1]. According to our previous study [2] on tower vibration using 24 accelerometers attached to the tower of an operating 2.4 kW turbine, most of vibration energy is concentrated in the lower frequency bands. It was observed that the first three natural frequencies (below 30 Hz) are exited more often while blades rotational speed varies up to 250 RPM. Thus, we believed that most of noise emission from the turbine structure is propagated in this region.

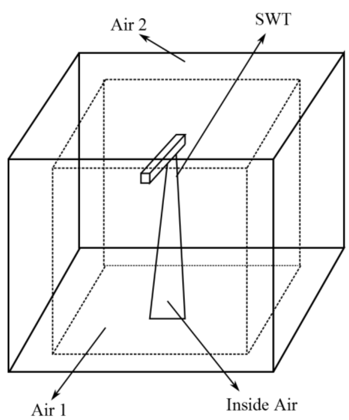

Figure 1: Tower surrounded by two air domains plus inside air domain

Investigation of noise characteristics of small wind turbines has been sparse. The well-known study by Lawson (1992) on the correlation of noise production and output power is mostly valid for the turbines with output power higher than 15 kW. Turbine noise has at least six aerodynamic sources which cannot be separated except using sophisticated multi-microphone arrays such as [3]. This project investigates how much the tower contributes to noise emission, and consists of three main steps; first, vibration survey by which natural frequencies and corresponding deflection shapes were calculated. Second, the results from the survey were used to verify the FE model. And lastly, the verified model was placed in the air domains such that the structural vibration generates sound waves. The wave equations of coupled structure-bounded fluid systems are not usually amenable to analytic solutions, and numerical methods are commonly applied, given that the special geometry of a thin semi-cone tower of varying diameter makes the analytical solution unrealistic. Therefore, the fluid-structure interaction (FSI) between turbine structure and surrounding media is conducted where both the acoustic wave equation (eq. 1) and the structural dynamics equation need to be coupled to each other.

$$\frac{1}{c^2}\frac{\partial^2 P}{\partial t^2} - \nabla^2 P = 0 \tag{1}$$

where c , P, and t represent speed of sound in fluid medium, acoustic pressure, and time, respectively. This equation along with the coupled normal acceleration of the tower at the fluid-structure interface was discretized in order to be solved by FE Method.

The simulation was performed on the 10.2m one-piece monopole tower. Blades were not modelled, and instead a rectangular box which holds the same weight as the nacelle and blades was placed on the top of

* emollasa | dhwood | qsun @ucalgary.ca

the tower. The around air domain contains two bodies; computational and absorbing domains with a Perfectly Matched Layers (PML) on the most outer boundaries. The schematic configuration is shown in fig. 1. The air inside of the tower was simulated as well, and separated by tower skin. This domain is assumed to be two-way coupled implying that the vibration generates sound plus the emitted sound has feedbacks on the vibration. Different forces are applied on the tower and the top block mass including cyclic thrust force, and drag force. These loads represent various wind load and rotating blades conditions. Based on preliminary simulations, it was observed that the highest SPL value occurs inside of the tower with maximum value of around 70 dB. This region, since has the minimum contact to outside air, amplifies itself and probably causes ringing tone that could be heard. Figure 2, for instance, includes two results in terms of noise pressure level (dB) on different faces.

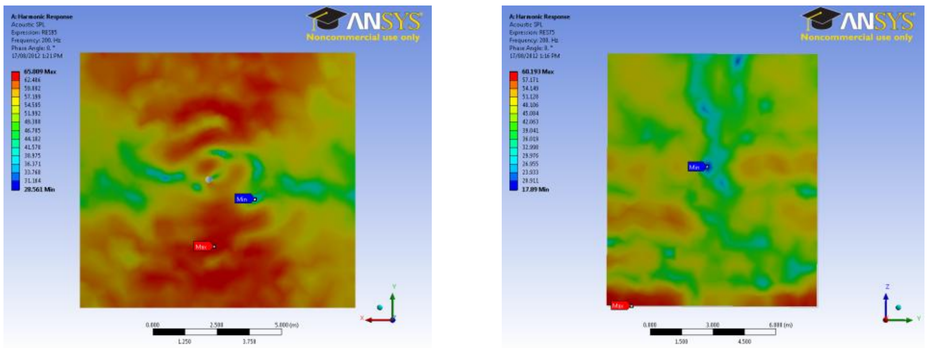

Figure 2: Sound Pressure Level (dB) left) on the ground, right) ZY plane

The propagation pattern is significantly different between wind and its normal directions. This difference reaches to 40 dB. No noticeable disparity was observed between upwind and downwind regions.

In the infrasound region, it was observed that the maximum emitted noise level at 10.2m from the base of the tower is about 20 dB less than human hearing threshold which is around 70-80 dB [4] at 15-20 Hz. On the contrary, the maximum vibration based on [2] happens at 10Hz that is second the bending mode. This implies that in terms of noise propagation in infrasound region, third resonance frequency plays an important role despite the pressure level is not high enough to be perceived. Such low noise levels are insignificant for environmental noise evaluation of wind turbines. In low frequency range, the average calculated SPL varies between 40-70 dB with the maximum value around 83 Hz. Although this frequency is not a tower resonance, a small peak was observed in the vibration survey implying the high contribution of this frequency band to generate sound pressure.

Further results and discussions including noise spectrums, far-field noise mapping, and overall noise level will be brought in the main context for different cyclic load conditions.

Keywords: Small wind turbine tower, Low frequency noise propagation, Fluid-Structure Interaction, Acoustic-Structure Interaction

References

[1]Jorgen Jakobsen, "Infrasound Emission from Wind Turbines", Journal of Low Frequency Noise, Vibration and Active Control, Vol.24 No. 3 pp.145-155.

[2]Ehsan Mollasalehi, David Wood, Qiao Sun, "Small Wind Turbine Structural Vibration", IMECE 2012, Accepted.

[3]Ramachandran R.C., "Localization of Wind Turbine Noise Sources using a Compact Microphone Array with Advanced Beamforming Algorithms", Berlin Beamforming Conference 2012

[4] Howe Gastmeier Chapnik Limited, "Low frequency noise and infrasound associated with wind turbine generator systems; a literature review", Ontario Ministry of the Environment, RFP No. OSS-078696.