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Acoustics and Sustainability:

How should acoustics adapt to meet future demands?

A study of wind induced noise in microphones

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ABSTRACT

Wind-induced noise often contaminates noise measurements in windy environments despite the use of wind-shields. Techniques have been developed by various researchers to reduce the influences of background wind induced microphone noises during measurement. However these techniques have not yet yielded accurate results. An attempt was undertaken in this study to improve on existing design methods and understand the mechanisms associated with wind noise measurements. This study aims to lay the foundation for further experiments to be conducted to investigate the performance and characteristics of wind noise in a measuring microphone. Qualitative study of the design and construction of a suitable experimental rig was carried out to investigate the effects and characteristics of wind noise on a measuring microphone in a controlled environment.

INTRODUCTION

Reliable and accurate measurement of wind turbine generator noise in wind farms has always been a challenging problem for acoustic engineers due to the constant presence and fluctuations in wind velocity, along with the presence of background noise in open spaces. As wind farms gain popularity due to high energy cost globally, the measurement of noises from operational wind farms are crucial to comply with the relevant environmental noise standards.

Measurements of noise source from wind farms are typically taken when the wind turbine is in operation during periods of strong wind. The development of a suitable technique to measure the environmental noise emission from wind turbine generators in a fast and uncomplicated manner is hence an urgent and difficult concern.

Attempts have been made to suppress wind induced background noise such as through the proper calibration of sound instruments [International Energy Agency, 1994] and the use of supplementary large wind-screens around the measurement microphone [Wind Test, 2002]. Yet, residual noise due to the interaction of the wind with the microphone was still present.

The recommended procedure for measuring the sound power levels of wind turbines are outlined by the International Electrotechnical Commission (IEC 61400-11 Standard), which defines the quality, type and calibration of instrumentation to be used for sound and wind speed measurements [International Electrotechnical Commission, 2002]. However, these methods cannot account for variations in meteorological conditions and complex geographical relations, making accurate measurements challenging.

Investigations into the performance and characteristics of wind noise have been conducted in the past. *Schomer* and *Raspet* [1990] deduced that wind can introduce errors of as much as 20 dB(A) over actual noise levels. As such, an obvious way to reduce wind noise variations would be to reduce the interaction of the microphone with the flow. *Shust* and *Rogers* [1995] considered the use of spherical foam windscreens in their experiments and found that their effectiveness decreased rapidly at low frequencies; which was exactly the region that had the most wind noise and is of prime interest to the measurement of wind induced noises in wind farms.

Bleazey [1961] experimented with spherical windscreens of various materials and concluded that the effectiveness of windscreens made out of silk worked best as it was equally effective in reducing wind noise, yet provided minimal attenuation to sound waves. In addition, Bleazey also discovered that increasing the radius of the sphere improved the overall wind noise reduction of the windscreen.

Consequently, *Blomquist* [1973] tested spherical foam windscreens and observed the impact of screen size and porosity on wind noise reduction performance. Testing was done indoors with a rotating arm device to generate wind. *Blomquist* concluded that if the main acoustic frequencies of interest were below 1 kHz, a 180 mm diameter windscreen of 1600 pore/meter porosity would be optimum. He also found that a higher porosity material offered no improvement in wind noise reduction.

Similarly, *Morgan* [1993] studied the significance of flow through the windscreen as a contributor to wind noise in screened microphones and concluded that air flow through the windscreen was not a significant source of wind noise in a wind-screened microphone. In addition, Morgan compared the reductions in flow velocity inside the windscreens and found that windscreens reduced the flow velocities by orders of magnitude more than they reduced the wind noise pressure, thus supporting his conclusion that flow through the windscreen was not a significant contributor to wind noise in a screened microphone.

The importance of wake shedding in the production of wind noise in a screened microphone was also investigated by

Morgan [1993] by comparing the wind noise of microphones using spherical and streamlined foam windscreens. The results indicated that streamlining did not improve the effectiveness of foam windscreens and that wake shedding was an insignificant source of wind noise in a screened microphone.

To achieve greater reliability in measurements of wind noise, this study sought to further investigate the complex mechanisms involved during the propagation and interaction of wind on a measuring microphone. Experiments to investigate the behavior of wind induced noise were carried out by analyzing the respective noise spectrum in a controlled environment.

EXPERIMENTAL SET-UP

To fulfill the experimental objectives, the proposed experiment involved suspending a measuring microphone with an attached cable from a four meter high platform, and spinning it in a circular motion. A schematic diagram of the proposed experimental setup is shown in *Figure 1*.

A Brüel & Kjaer 4189, ½” free-field microphone was suspended vertically at the tip of an 800 mm rotating arm with its axis perpendicular to the face of the oncoming wind, and driven by a variable speed electric motor. A hot-wire probe was subsequently connected to a Dantec Flowmaster Type 54N60 Anemometer, and attached onto the microphone to accurately measure the oncoming wind on the face of the measuring microphone. The speed at which the microphone travels was then varied accordingly to simulate wind blowing past the microphone at controlled speeds. The output signals from the Microphone Pre-amplifier and the Anemometer was fed into a B&K Type 2133 Frequency Analyser to be analysed. *Figure 2* shows the block diagram of the system layout.

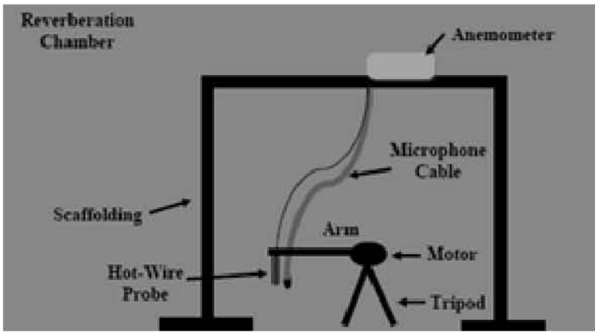


Figure 1. Schematic Diagram of Experimental Set-up

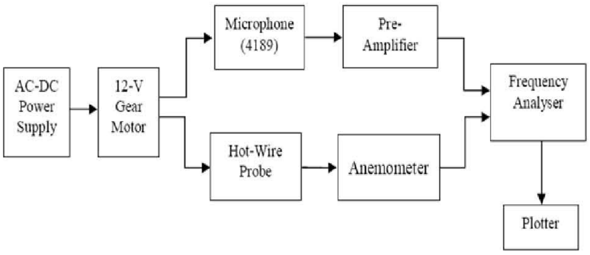


Figure 2. Block Diagram of Experimental Set-up

TEST METHODS

Experiments were designed to explore the feasibility of measuring wind noise in a microphone without external influences in a Reverberation chamber. Three sets of experiments were performed to explore the proposed objectives.

The experiments were conducted over a range of similar wind speeds. Selection of a feasible operating range of wind speed was made based on the range of practical applications and the system limitations of the experimental rig. To prevent physical damage to the experimental equipment, measurements were taken at measured wind speed intervals of 0.5m/s over a range of 0.5 to 5 m/s. Initial tests performed just after assembly of the test rig indicated that wind induced noise was prevalent at lower frequencies of 25 Hz to 1 kHz, which corresponds well with the findings of *Shust* and *Rogers* [1996]]. Wind noise measurements were subsequently focused on the noise spectrum in the lower frequency ranges of 25 Hz to 1 kHz.

The first set of tests was designed to measure the noise level of the electric motor with the microphone suspended 50 mm above the tip of the rotating arm. This was to determine the amount of background noise generated from the electric motor, which could be intrusive enough to affect subsequent sets of tests results. Measurements in these particular tests were taken over a wider frequency range of 50 Hz to 10 kHz to gauge the effect of background noise from the motor itself.

The second set of tests measured the spectrum of pr*e*ssure fluctuations from the Anemometer signal over the corresponding range of wind speeds. The results were subsequently helpful in evaluating and predicting the characteristics of wind noise in outdoor measurements. The third set involved measuring the wind noise with an unscreened microphone over the aforementioned range of wind speeds. The final set of experiments explored the influence and effectiveness of using a 90 mm foam wind-screen over a measuring microphone, to measure the wind noise over the range of wind speeds.

RESULTS & DISCUSSIONS

Wind Induced Noise

The plots of Linear SPL from the Motor and Unscreened microphone at various wind speeds are shown in *Figure 3* Their differences in SPL are also indicated in the lowest line. A difference in SPL of about 7 to 9 dB was observed for wind speeds below 2.5 m/s.

Consequently, the difference in Sound Pressure Level (SPL) between the motor noise and wind induced noise in the unscreened microphone showed a gradual but increasing trend in SPL difference, from wind speeds of 2.0 m/s onwards. This observation is in agreement with the findings during a sound assessment for the Madison (NY) Windpower Project, that both the existing background noise level and the wind generator source noise level increases with increasing wind speed [Huskey, 2001]. The results also indicate that wind induced noise will have a profound impact on SPL measurements in outdoor measurements at wind speeds greater than 2.0 m/s.

The SPL of the unscreened microphone was highest at the largest wind speed of 5 m/s. This was double the SPL of that measured from the initial speed of 0.5 m/s. With no indication of a drop in SPL with increasing wind speeds, this would imply that the effects of wind induced noise in a measuring microphone will constantly increase with higher wind speeds.

Figure 4 shows the motor noise spectrum measured at different wind speeds over a frequency range of 50 Hz to 6.3 kHz. The spectrum suggests that the SPL of the motor is significant at frequencies below 2.5 kHz. An observation of this spectrum also indicates that the SPL seems to follow a common trend with the peaks generally occurring at frequencies of 100 Hz, 250 Hz, 500 Hz and 1 kHz.

The noise spectrum of the unscreened microphone for various wind speeds are shown in *Figure 5*. The results indicate that main contribution of the wind noise was generated at 1/3 octave frequency bands below 100 Hz. Consequently, at wind speeds below 2 m/s, the SPL was observed to peak at a frequency of about 50 Hz; although the peak frequency at higher wind speeds appear to peak at lower frequencies of about 25 Hz.

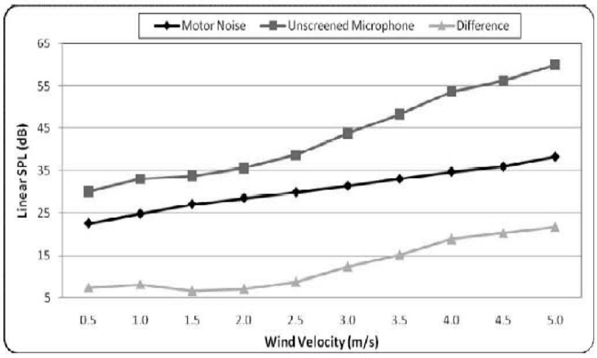


Figure 3. Linear SPL outputs from Motor Noise and Unscreened Microphone over a range of wind speed

Note: The bottom line (▲) represents the difference in SPL readings between the two

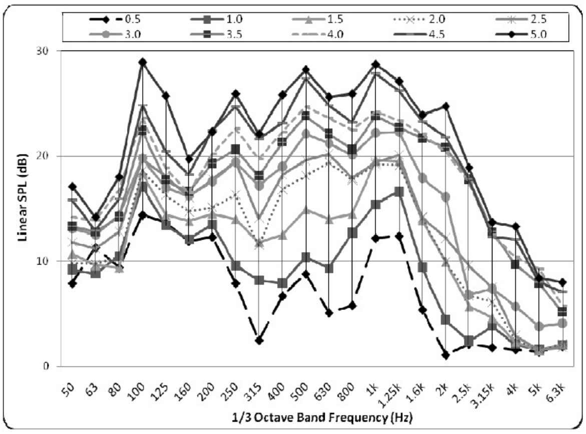


Figure 4. Noise Spectrum of Motor for various Wind Speeds

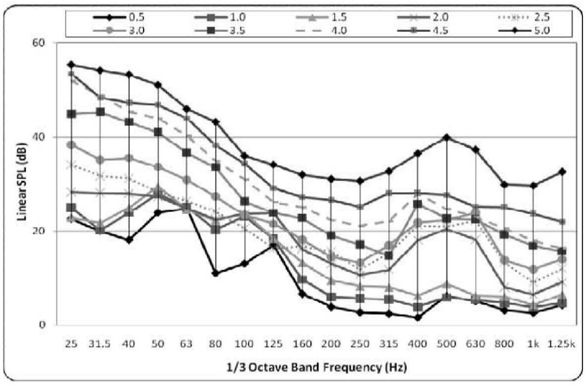


Figure 5. Noise Spectrum of Unscreened Microphone for various Wind Speeds

Effect of Windscreen

The effect of using a 90 mm foam windscreen over the measuring microphone is shown in *Figure 6*. The SPL decreased as predicted, with the reduction in SPL ranging from about 1 dB to 3 dB at wind speeds below 2.5 m/s, and 4 dB to 6 dB at larger wind speeds of up to 5 m/s.

The amount of reduction in SPL increased at wind speeds above 2.0 m/s, which corresponded with the analysis by *Strasberg* [1988] that wind noise in spherical and cylindrical windscreens increases with increasing wind speed.

The reduction in SPL registered a gradual decrease between wind speeds of 0.5 m/s to 1.5 m/s as illustrated in *Figure 6*. However, this trend was not strictly followed for 1/3 Octave frequency bands from 160 Hz to 250 Hz (*Figures 7 & 8*). This may be attributed to possible experimental errors encountered such as the rubbing of microphone and hot-wire anemometer cables against one another. Nevertheless, the noise Spectrum for both Screened and Unscreened microphone experiments for wind speed of 5.0 m/s (*Figure 8*) illustrate that the majority of reduction in SPL occurred at low frequency bands of between 8 Hz to 160 Hz and 250 Hz to 1 kHz.

The rate of reduction in SPL at higher wind speeds of above 2 m/s was rapid, while the resulting noise spectrum indicated that the reduction occurred at low frequency bands of between 8 Hz to 160 Hz and 250 Hz to 1 kHz. Conclusively, research [Bleazey, 1961 & Blomquist, 1973] has shown that the effectiveness of windscreens was dependent on the size and material.

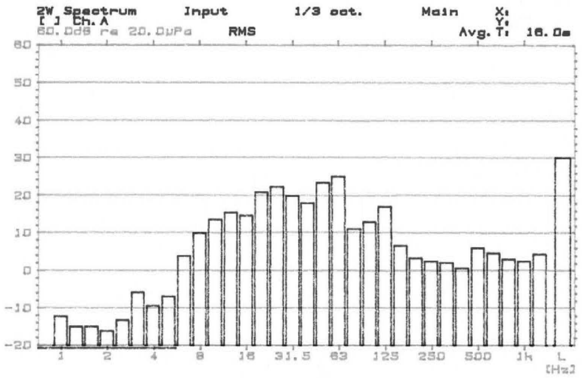
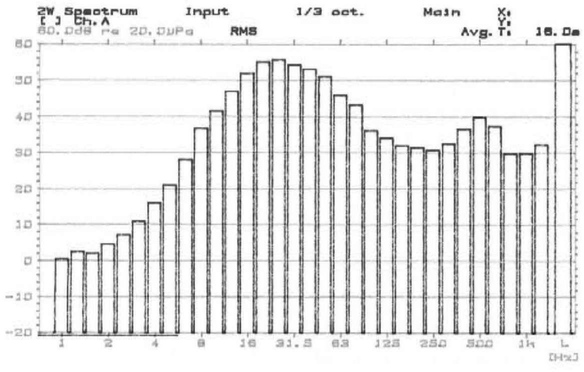
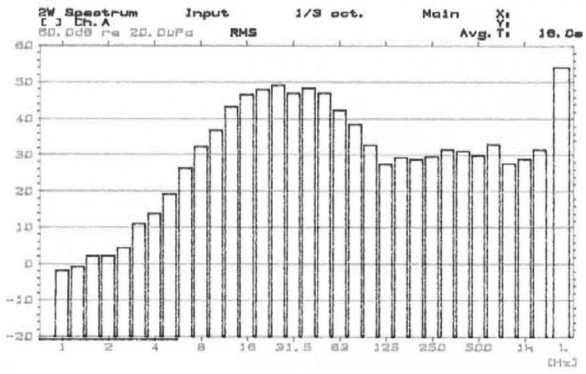


Figure 6. Linear SPL outputs from Unscreened Microphone and Screened Microphone over a range of wind speed

Note: The bottom line (▲) represents the difference in SPL readings between the Two



(a)

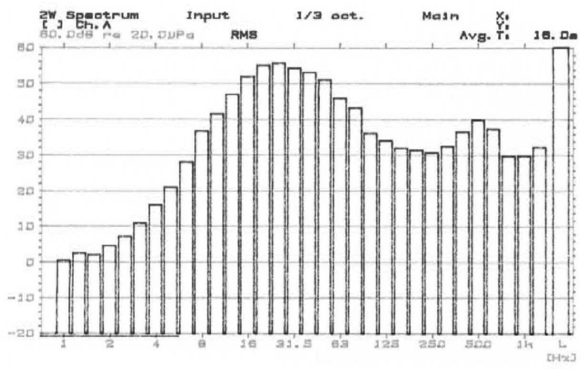


(b)

(a) Noise Spectrum of Unscreened Microphone @ 0.5 m/s wind speed

(b) Noise Spectrum of Microphone with Windscreen @ 0.5 m/s wind speed

Figure 7. Comparison of outputs from Unscreened Microphone and Screened Microphone at 0.5 m/s wind speed



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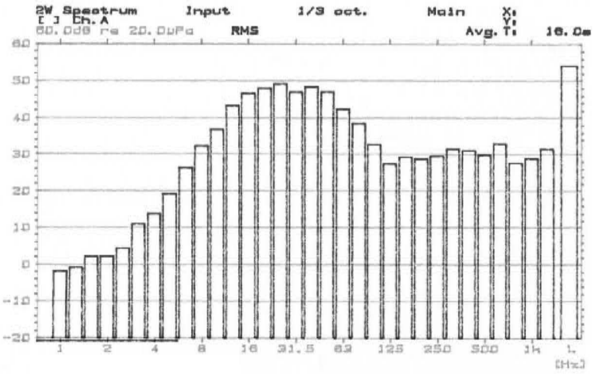

(b)

(a) Noise Spectrum of Unscreened Microphone @ 5.0 m/s wind speed

(b) Noise Spectrum of Microphone with Windscreen @ 5.0 m/s wind speed

Figure 8. Comparison of outputs from Unscreened Microphone and Screened Microphone at 5.0 m/s wind speed

CONCLUDING REMARKS

An experimental method to accurately measure wind noise in a controlled environment was undertaken in this study to investigate the mechanisms into the principal sources of wind induced noise. The experiments were performed with useful results obtained in laying the groundwork for further research to be conducted.

With the design and construction of a suitable experimental rig, further studies to build on the results of the experimental method are ongoing to expand the scope of this work in acquiring more data. The purpose of which, would enable the development of a better understanding on the behavior and mechanisms of wind induced noise; with the eventual aim of being able to confidently predict the effects of wind noise during outdoor measurements.

This investigation has demonstrated an experimental method in acquiring data which will contribute towards a useful outcome in being able to confidently predict the results of wind induced noise in wind farms.

ACKNOWLEDGEMENT

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