Aerodynamic Noise Analysis of Large Scale Wind Turbine

Haniffah Nur Akmal, Terumi Inagaki, and Tsutomu Tachikawa

Abstract— During the operation of a modern large-scale wind turbine, aerodynamic noise is generally considered to be the dominant noise source. Measurements and recordings were carried out on an upwind wind turbine with tower height of 44.2 [m]. Sound pressure levels can be measured, while human's perception based on the noise can be studied by using electroencephalograph (EEG) technique. In this study, the characteristics of aerodynamic noise were identified and the impact of the aerodynamic noise on human's brain waves were verified. As the results, two types of aerodynamics noise were observed, which are trailing edge noise and low frequency noise. Furthermore, when subjects listened to the recorded sound of aerodynamic noise, three periodic sounds with 30 [Hz], 86 [Hz], and 300 [Hz] at 55 [dB], the theta wave almost did not have any transformation. The alpha 1 wave almost decreased when subjects were heard to all the sounds.

Keywords— aerodynamics noise, brain wave, electroencephalograph, wind turbine.

I. Introduction

WIND energy as a power source is one of the alternatives to fossil fuels, as it is renewable plentiful and produces no greenhouse gases emissions, such as carbon dioxide and methane. However, there is some concern over the noise.

During the operation of a large-scale wind turbine, there are two potential sources of noise, mechanical noise and aerodynamic noise[1]. For the modern large-scale wind turbine, the aerodynamic noise is generally considered to be the dominant noise source.

Sound pressure levels can be measured, but, similar to other environmental concerns, the human's perception of the acoustic impact of wind turbines is, in part, a subjective determination. The human's perception based on the noise can be studied by using electroencephalograph (EEG) technique.

Therefore, the purpose of this study is to identify the characteristics of aerodynamic noise originated from a large-scale wind turbine and to verify the impact of the aerodynamic noise on human's brain waves, which are theta, alpha and beta waves.

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II. Experimental Method

A. Measurements, Recordings and Analyses Method of Aerodynamics Noise

Measurements and recordings were carried out on an upwind three-bladed ENERCON E40 wind turbine, which has a rotor diameter of 43.7[m]. The wind turbine is located on the Satomi Farm in Hitachioota, Ibaraki, Japan.

Four sound pressure level meters (CEM DT-8852) and four sound recorders (SONY PCM-D50) were used in the nose measurements. By setting the wind turbine at the center point the sound were recorded and pressure of the sounds were measured at 4 points; upwind as front side, downwind as back side, right and left sides of wind turbine. The phenomena were studied and the recorded data were analyzed using Fast Fourier Transform (FFT)[2], Sonogram and Wavelet analyses[3].

B. Measurement and Analyses of Brain Wave

Human perceptions based on the aerodynamic noise were studied by using EEG technique. For this study, four types of sound were used, which are recorded sound of the aerodynamic noise, three periodic sounds with 30 [Hz], 86 [Hz], and 300 [Hz] at 55 [dB]. Each periodic sound was composed with 1 [Hz] of beat cycle.

The measurement was held in shield room under darkness condition. During the brain wave measurement, the subject sat comfortably in front of two speakers (VICTOR UX-A5MD) and a woofer (VICTOR SX-DW77) with eye closing. Distance of the sound player devices with subject was 1.3 [m]. Firstly, subject listened to silence for 1 [min], then the four sounds for 2 [min] respectively. The four sounds were played randomly.

Brain waves were measured at 16 points on subject scalp. Changes (induction rate) of brain wave were obtained and te differences were analyzed by using FFT analysis. Three types of brain wave were studied, which are theta, alpha and beta waves. Alpha and beta waves were dived to slow and fast cycles respectively. In other words, the frequency of alpha 2 wave is larger than alpha 1 wave. As an example, the definition of the induction rate is defined as follows:

$$\textit{Induction rate of alpha wave} = \frac{\text{ratio of alpha wave during stimulation}}{\text{ratio of alpha wave in silent condition}}$$

III. EXPERIMENTAL RESULT AND DISCUSSION

A. Aerodynamics Noise

In Fig. 1 to 4, measurement results for 10 minutes (14:10-14:20) are shown. During the measurement, the average northwest wind speed was 9.1 [m/s] and the average of output energy is 355 [kW]. The sound pressure levels were different at each side (Fig. 1), which at the backside seemed to be the highest among others due to trailing edge noise. Besides, the sound pressure levels at the back and the front sides were higher than those of the left and the right sides.

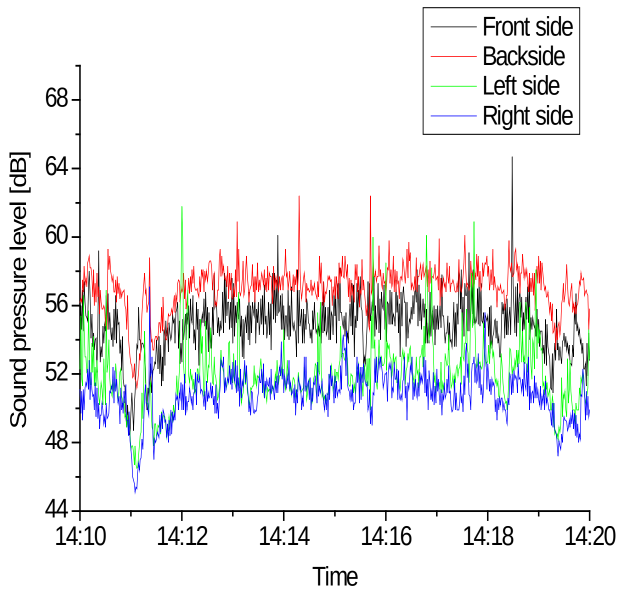
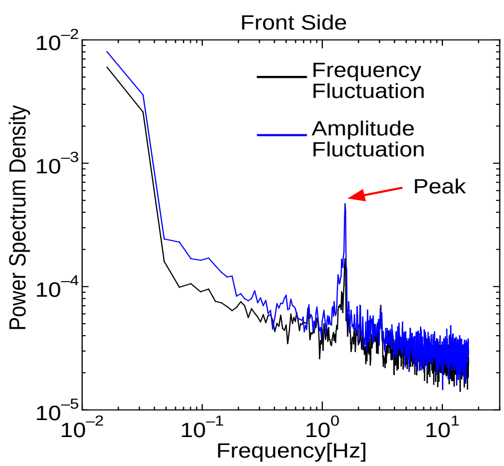
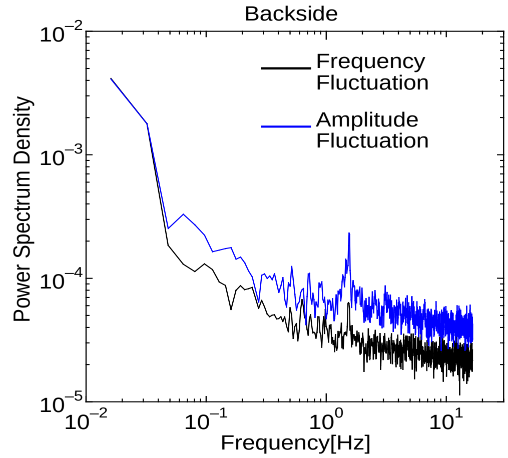


Fig. 1 Sound Pressure Level at 4 Points

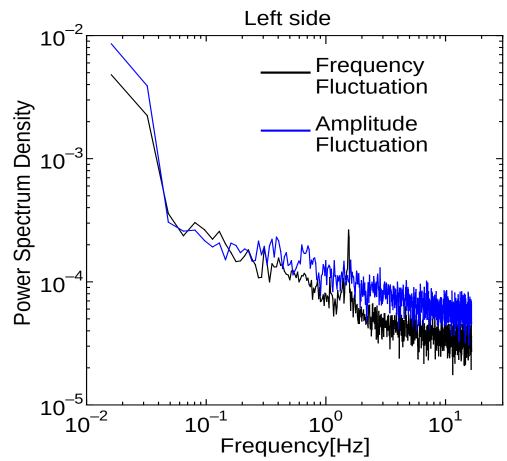
From the result of FFT analysis (Fig. 2), there was a peak of 1.5 [Hz] at each side, which means a time interval during one blade of the wind turbine passed the tower. From the calculation, the number of rotation of the wind turbine was 30 [rpm].



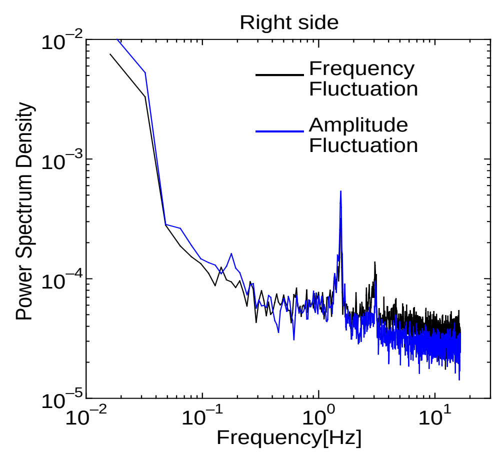
(a) Front Side



(b) Backside



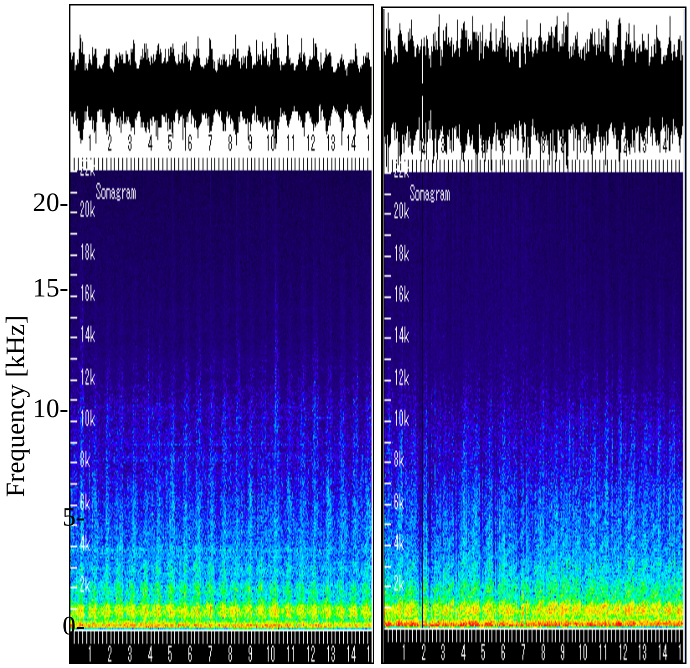
(c) Left Side



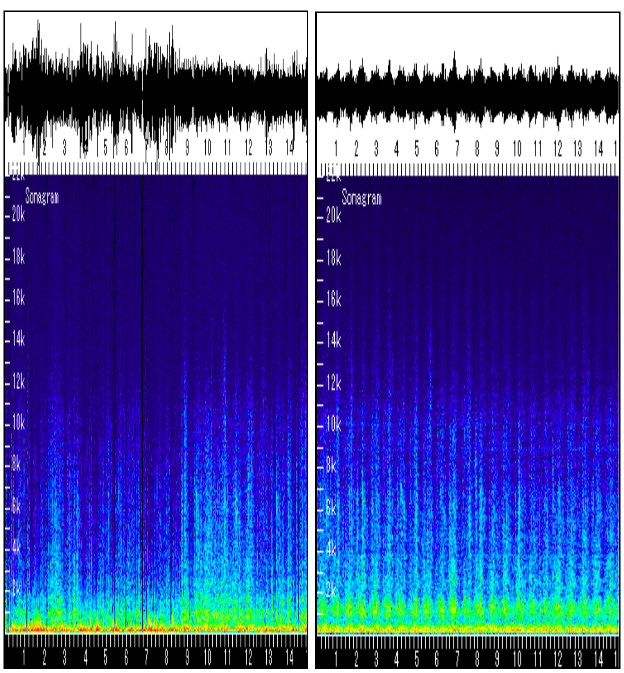
(d) Right Side

Fig. 2 Results of FFT Analysis at Each Side

The top of Fig. 3, pattern of sound wave at each side is shown, and in the bottom of the figure shows the sonogram analysis. The frequency ranges at the back and the front sides were wider than those of the left and the right sides. At each side, spectral density were high at the frequency range from 86 to 200 [Hz] due to low frequency noise. Beside, at the back side, the frequency range from 770 to 1200 [Hz] showed high spectral density due to the trailing edge noise inducted by eddy emission.



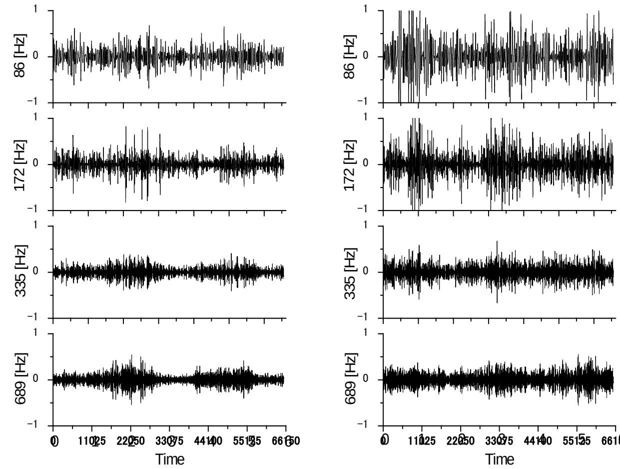
(a) Front Side (b) Backside



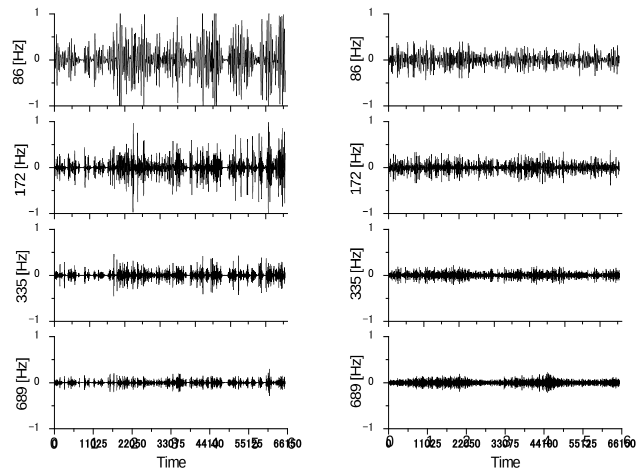
(c) Left Side (d) Right Side

Fig. 3 Results of Sonogram Analysis

From the result of wavelet analysis (Fig. 4), the fluctuation of sound frequency becomes high due to eddy emission. At the frequency of 86 [Hz], the fluctuation was the highest among others, which was same with the previous results of sonogram analysis. Therefore, the aerodynamic noise generated from the wind turbine contains low frequency noise.



(a) Front Side (b) Backside



(c) Left Side (d) Right Side

Fig. 4 Results of Sonogram Analysis

B. Brain Wave

Fig. 5 shows EEG mapping pictures of six subject with the average of induction rate of theta, alpha and beta waves when subjects listen to recorded sound, three periodic sound with 30 [Hz], 86 [Hz] and 300 [Hz] at 55 [dB] of sound pressure level is shown.

Theta wave almost did not have any transformation. Alpha 1 wave almost decreased when subjects were heard to all the sounds. The induction rate of alpha 1 wave, when a subject listened to te periodic sound with 30 [Hz], was the lowest among others and followed by the periodic sound with 86 [Hz], which mean subjects could not relax comfortably wen listening to the low frequency sound. Transformation of alpha 2 and beta 1 waves were not too clear as alpha 1 wave. Moreover, beta 2 wave increased especially at the periodic sound with 30 [Hz]. In other words, subjects feel stress and had unclear consciousness when listening to low frequency noise.

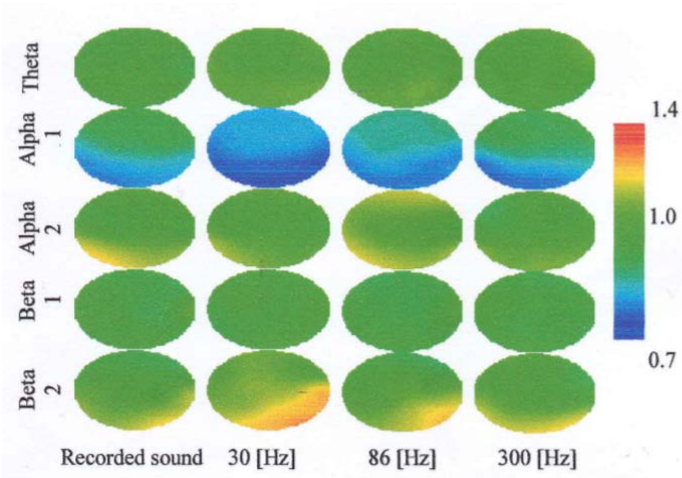


Fig. 5 Ratio of Brain Waves

IV. CONCLUSION

The sound pressure levels were different at each side. In this study, two types of aerodynamic noise were observed, which were trailing edge noise and low frequency noise. The sound pressure levels at the back and the front side were higher than those of the left and the right sides. Besides, the frequency range at the back and the front sides were wider than those of the left and the right sides. Furthermore, the induction rate of the alpha 1 wave at the periodic sound with 30 [Hz] was the lowest among others and followed by the periodic sound with 86 [Hz], which means subjects could not relax comfortably when listening to the low frequency sound. The beta 2 wave increased especially at the periodic sound with 30 [Hz]. In other words, subjects feel stress and had unclear consciousness when listening to low frequency noise.

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