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Measurement of Infrasound Generated by Wind Turbine Generator

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Abstract: This paper describes the development of a new sensor which uses a condenser microphone and a new system containing it as an element. The back of the microphone is covered with a seal chamber, which expands the frequency characteristic of the microphone to the infrasonic region. In addition, a windscreen is fitted to the sensor to reduce or eliminate wind noise. We developed a measurement system with this new sensor, installed it at a wind farm, and measured infrasound. The measurement results confirmed that the measurement system worked normally and could measure infrasound generated by wind turbines. Moreover, it was confirmed that the equivalent continuous sound level is highly correlated with the average rotor speed of a wind turbine.

Keywords: wind turbine, wind noise, low-frequency noise, infrasound, G-weighted SPL

1. INTRODUCTION

In recent years, the use of wind turbine generators has spread rapidly particularly in Europe and U.S.A, and the number installed in Japan is increasing. However, the acoustic noise generated by wind turbines causes a major environmental impact. This issue was first discussed in Europe in the 1980s, and became clear with large-scale wind power development in California in the U.S.A. As a result, an international standard (IEC 61400-11) for the method of measuring noise was published, and countermeasures have been examined.

In Japan, complaints about acoustic noise from wind turbines have been made by residents living near wind farms. In response, the Ministry of the Environment has summarized and published the principle of generation of low-frequency noise by wind turbines.

The main acoustic noise of wind turbines is not only audible sound of 20 Hz – 20 kHz, but also infrasound below 20 Hz generated by impulsive pressure fluctuations when the blade of the wind turbine passes through an area of lower wind velocity near a pole brace.

Infrasound is generated by various machines and structures, not only wind turbines, and exist everywhere, but the problem is small compared to the problems of audible noise and vibration. This is because if the sound pressure level of a noise region is less than the infrasonic frequency region, human beings cannot hear infrasound. However, larger industrial machines and structures have caused various infrasound noise problems in recent years.

In other countries, infrasound in work environments and factories has become a problem, and many researches have been carried out on the effects on physiology and psychology of prolonged exposure to infrasound of very high sound pressures of more than 120 dB.

In Japan, complaints have been made about infrasound in the environment, and research has been done on the influence on physiology and psychology of low-frequency sound including low-frequency audible sound of about 100 Hz [1-2].

Currently, sound level meters are used to measure audible noise generated by wind turbines, and infrasound level meters are used to measure infrasound. However, the lower limit of measurement frequency of an infrasound level meter is 1.0 Hz, and infrasound below 1.0 Hz generated by wind turbines is not measured. This paper describes the development of a new sensor with a condenser microphone and a new system containing it as an element. This new sensor is superior in sensitivity in the infrasonic frequency region than a condenser microphone and a ceramic microphone. Calculating data measured with this new sensor in discrete Fourier transform enables detailed frequency analysis including frequencies below 1 Hz. This enables the specification of source to be simplified, and the noise level of a specific frequency to be measured.

2. PRINCIPLE OF GENERATION

The frequency of infrasound by a wind turbine is given by

$$f = \frac{RZ}{60} \qquad (1)$$

where $f\,(\mathrm{Hz})$ denotes the fundamental frequency, $R\,(\mathrm{rpm})$ the rotor speed, and Z the number of blades. The fundamental frequency and high-order harmonics are generated.

In general, there are one to three blades rotating at approximately 30–60 rpm, and the fundamental frequency is less than several Hz.

In addition, the blades may be placed before the tower (windward, up-wind type) or after the tower (leeward, down-wind type). With the down-wind type wind turbine, the low-frequency sound depends on the construction characteristics. In America, R&D by MOD-1 reported that the influence of large machines extended to several kilometers. Therefore, the main type of wind turbine is now the up-wind type which produces less noise [2].

3. EVALUATION METHOD OF LOW-FREQUENCY NOISE

The evaluation of low-frequency acoustic noise uses sound pressure level (SPL) as the unit denoting the magnitude of pressure fluctuation of acoustic waves, in addition to Pa which is a unit of pressure. The minimum sound pressure generally audible to humans is approximately 20μ Pa, which is used as a reference acoustic pressure. The sound pressure level can be obtained as follows:

$$L_P = 10\log_{10}\left(\frac{P^2}{P_0^2}\right) \tag{2}$$

where, P_0 denotes the effective value of measured acoustic pressure and P the reference acoustic pressure.

In addition, equivalent continuous sound level has been adopted as an environmental noise evaluation quantity in Japan since June 1998, and will become an important index for noise evaluation in the future. This measure can express fluctuating noise in a statistical and stable manner. The degree of noise and the length of time a human being is exposed to it, is evaluated as an average value with time of the total noise energy over time, and indicated as a level.

$$L_{eq} = 10\log_{10}\left[\frac{1}{T}\int_t^{T+t}\frac{P^2(t)}{P_0^2}dt\right] \tag{3}$$

where $P(t)$ denotes the measurement acoustic pressure and T the measurement time.

Furthermore, The G frequency weighting is a compensation characteristic used to evaluate the physiology and psychology effects of infrasound. It is possible to evaluate how infrasound affects daily life such as mood or sleep by calibrating the effective value of measured acoustic pressure at a G frequency weighting sound pressure level.

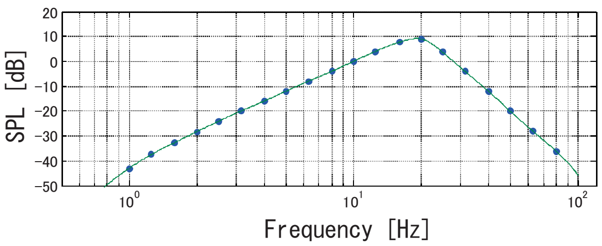

Fig. 1 The G frequency weighting (ISO-7196)

The G frequency weighting sound pressure level is stipulated in ISO-7196. An evaluation is done by comparing this sound pressure level to a reference value.

The G frequency weighting is based on the threshold at which infrasound can be perceived. When the G frequency weighting sound pressure level exceeds 100 dB, a human being can perceive infrasound, and when it exceeds 120 dB the sound feels stronger. Below 90 dB, infrasound cannot be perceived. However, this is only one method of evaluating infrasound; we must not evaluate it by this method alone.

4. MEASUREMENT SYSTEM

4.1 Sensor

A condenser microphone (EM-114, Primo) with the chamber connected to the back face was used as a sensor. In general, there is an orifice in the back face to give the microphone directivity, and the pressure receiver receives pressure from both the front and back. As a result, the same pressure is added to both sides, and so the microphone cannot sense minute pressure fluctuations. Therefore we covered the back of the microphone with a seal chamber and so the pressure receiver receives pressure only from one side and can sense minute pressure fluctuations. This expands the frequency characteristic of the microphone to the infrasonic region.

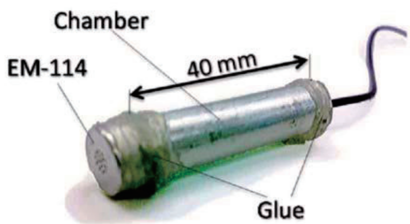

Fig. 2 Condenser microphone sensor

In addition, the measurement of infrasound by a wind turbine is greatly affected by wind noise because the measurement is done outdoors. We attached a windscreen to the sensor to reduce or eliminate wind noise. Figure 3 shows the sensor which we developed.

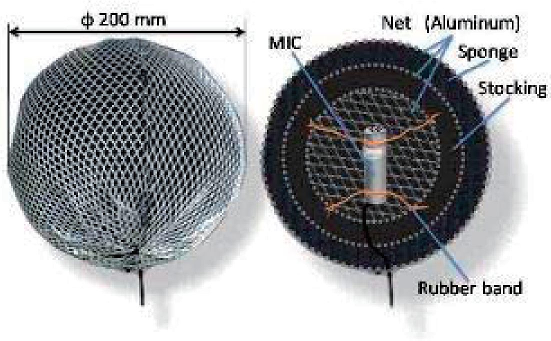

Fig. 3 Microphone with windscreen

4.2 Long-term measurement system

We used a data logger (NR-2000, Keyence) to record infrasound measurement data continuously for a long time. The signal from the microphone with windscreen passes through a circuit and is saved to a data logger directly. The measurement frequency bandwidth of this circuit is 0.16–16 Hz. In addition, data can be collected automatically at fixed intervals by inputting a constant voltage into the trigger input of the data logger at intervals fixed by a timer.

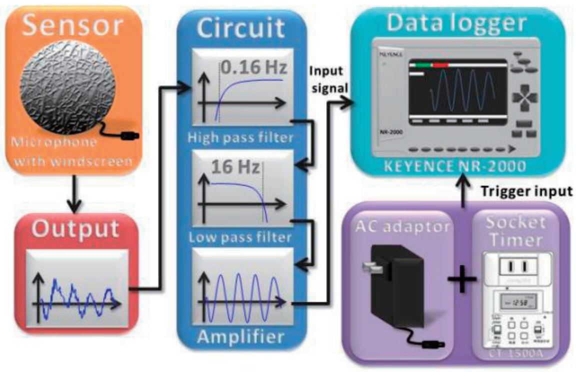

Fig. 4 System for long-term measurement of infrasound

5. MEASUREMENT

5.1 Measured object and location

We measured infrasound at a wind farm, which has ten wind turbines built on a ridge. We measured the infrasound generated by a wind turbine, by installing the long-term measurement system in the hut below the turbine.

When infrasound is measured indoors, sensitivity will be reduced if the room is sealed. Thus, for long-term measurement, we left only a ventilator open, and closed the door and windows of the hut. When the door and windows were open, the sound pressure did not attenuate.

The size of the hut was 1.8×2.4×4.5 m (W×H×D), and was about 20 m from the wind turbine.
Figure 5 shows the details of the measurement location, and Fig. 6 shows details of the measurement target.

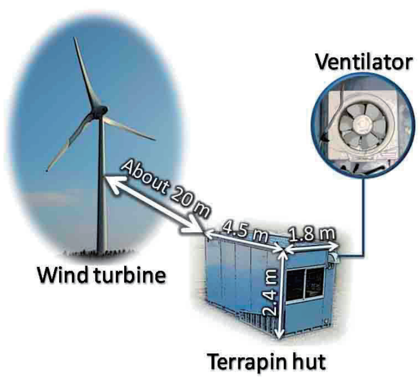

Fig. 5 Outline of measurement location

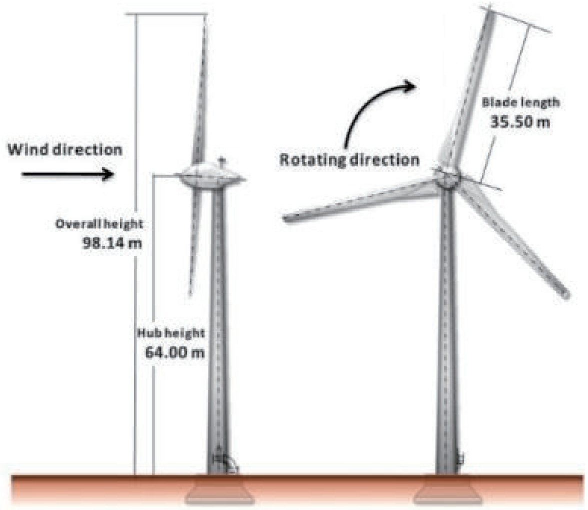

Fig. 6 General view of wind turbine

5.2 Measurement method and device

The long-term measurement system (Fig. 4) was used for measurement. The socket timer was set to be switched on once for 60 seconds every hour. Trigger input was done by AC adapter. The data logger was set to record the signal for 80 seconds, the sampling interval of the data logger was 10 ms, and the measurement was done for ten days, so the total number of recorded files was 240.

The sound pressure level and G frequency weighting of the measured signal were converted and plotted using MATLAB. In addition, the average wind speed and average rotor speed (average for 10 minutes) at the wind farm were measured. The equivalent continuous sound level for 80 seconds calculated by Eq. (3) was compared with the average rotor speed.

5.3 Measurement results

Figure 7 shows the measurement result of October 25, 2007 19:16 as a sample, and Fig. 8 shows the result calculated by Eq. (2) and the calibration result of a G frequency weighting sound pressure level.

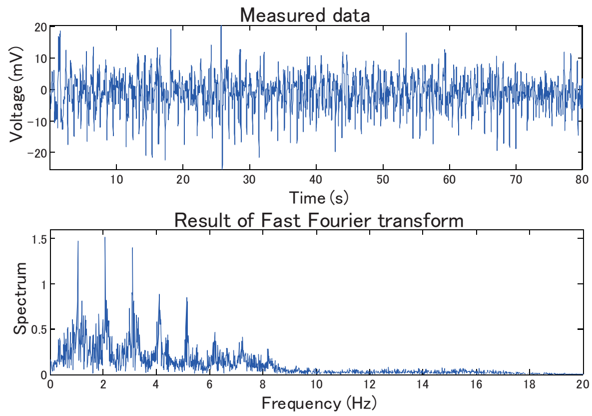

Fig. 7 Measurement signal of infrasound and result of FFT

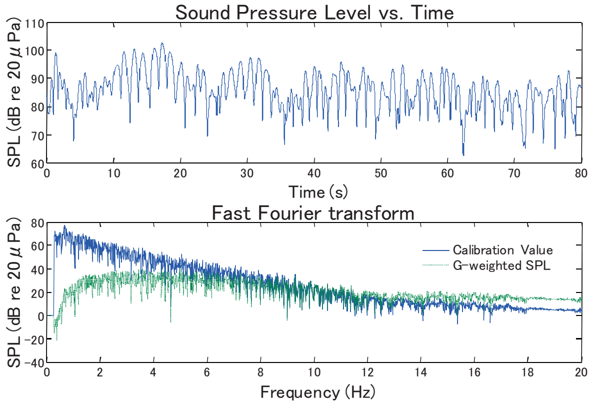

Fig. 8 SPL and G-weighted SPL

Figure 9 shows the relationship of average wind speed and average rotor speed recorded at the wind farm.

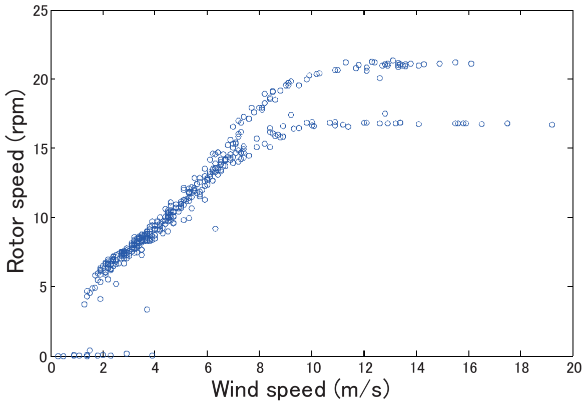

Fig. 9 SPL and G-weighted SPL

In addition, an equivalent continuous sound level for 80 seconds was calculated from 240 measurement results by using Eq. (3). Figure 10 shows the relationship of this and the average rotor speed.

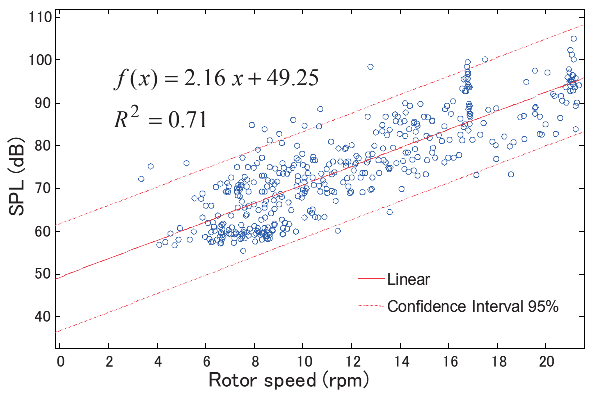

Fig. 10 SPL ($L_{eq.80}$) vs. 600-s averaged rotor speed

6. DISCUSSION

The average rotor speed of the wind turbine in the measurement period (19:10 to 19:20) of Fig. 7 is 20.99 rpm. Therefore, from Eq. (1), the infrasound fundamental frequency is $f = 1.05\text{Hz}$. The peak of this frequency domain matches the result calculated by FFT, thus confirming that the measurement system works normally.

The average rotor speed converges at 17 rpm and 21 rpm as shown in Fig. 9. This is in order to limit the output at night when infrasound is propagated easily. However, the equivalent continuous sound level for 80 seconds is about 70–100 dB when the average rotor speed is 17 rpm, and so the sound pressure level of infrasound cannot be limited adequately. There seem to be large errors, because the average rotor speed is the data for 10 minutes, whereas the equivalent sound level is 80 seconds, therefore in future the signal should be recorded for 10 minutes.

The regression line of the scatter diagram of Fig. 10 is expressed as $f(x) = 2.16x + 49.25$, and the coefficient of determination of this regression line is $R^2 = 0.71$. Therefore, the equivalent continuous sound level is closely correlated with the average rotor speed.

7. CONCLUSIONS

We confirmed that our developed system worked normally, and could measure infrasound generated by a wind turbine. It was already known that wind turbines generate infrasound, but our new sensor and measurement system enable more detailed frequency analysis including frequencies below 1 Hz, and identification and verification of the source. The result calculated by the regression line can be used as a standard for controlling infrasound.

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