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Recent field measurements of wind turbine noise in Japan

Hiroaki Ochiai, Kobayasi Institute of Physical Research.

3-20-41 Higashi-motomachi, Kokubunji, Tokyo 185-0022, Japan.

E-mail: ochiaih@kobayasi-riken.or.jp

Yasuo Inoue, INC Engineering Co., Ltd.,

1-15-18 Hyakunin-cho Shinjuku-ku, Tokyo 169-0073 Japan.

E-mail: inoue@inc.ihi.co.jp

Hiroyuki Imaizumi, National Institute of Advanced Industrial Science and Technology (AIST) .

16-1 Onogawa, Tsukuba, Ibaraki 305-8569 Japan.

E-mail: hiroyuki.imaizumi@aist.go.jp

Shinji Yamada, The Open University of Japan.

4-4-37 Takeda, Kofu, Yamanashi 400-8511, Japan.

E-mail: yamada@ms.yamanashi.ac.jp

Abstract

Recently, complaints against low frequency sound generated by wind-turbines occur at several areas in Japan. The Ministry of Environment, the Government of Japan has started investigation on the wind-turbine noise.

We carried out field measurements of the noise and the low frequency sound at three areas, where the complaints about the wind-turbine noise have occurred. Low frequency sound level meters were arranged at the positions close to the wind-turbines, and outside and inside houses of the complainers.

As a result of the measurement, we have found that;

(1) The sound pressure levels of infrasound (< 20Hz) are 20dB or more lower than the hearing threshold of human [1], [2] at the distance of about 100-150m from the wind-turbines,

(2) From the measurements inside the houses, it is presumed that the complaints are probably caused by the tonal components at frequency range from about 160 to 200Hz, and

(3) To understand the characteristics of the wind-turbine noise at each measuring point, it is effective that a continuous measurements by using Leq, 10s and on-and-off operation of the wind-turbine during the noise measurements. Especially, the latter is useful to know whether or not the complainers actually listen to the wind-turbine noise and at what operation condition of the wind-turbine they feel uncomfortable and complain against the wind-turbine.

1 Introduction

To prevent global warming, construction of wind power plants has been introduced in Japan, and 1683 wind-turbines are operating at March 2010. Recently, complaints against low frequency sound generated by wind-turbines occur at several areas. The Ministry of Environment, the Government of Japan has started investigation on the real status of the wind-turbine noise. We carried out field measurements of noise and low frequency sound at the areas where the complaints about the wind-turbine noises have occurred.

In this paper, we describe on the result of the measurements at these areas. In this paper the word “noise” sometimes includes noise and low frequency noise.

2. Outline of measured area and measurement method

The outlines of the measured wind-turbines are shown in Table-1. The measured wind-turbines are all up-wind types, about 100m heights and the rated power is 1.0MW or 1.5MW

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Table-1 Outline of the measured wind-turbines

Area	Total height (m)	Rated power (MW)	Rated wind speed (m/s)	Cut-in wind speed (m/s)	Cut-out wind speed (m/s)
A	98.7	1.0	12.5	3.0	25.0
B	100.0	1.5	12.0	3.0	25.0
C	100.0	1.5	12.0	3.0	25.0

The noise and the low frequency sound were measured in four houses at three areas (area A, area B and area C). The layout of the measuring points is shown in Table-2. The measuring points were arranged near the wind-turbine, at the distance of 100-150m, and inside and outside of the complainer’s house at the residential side, at the distance of 210-680m.

The measurements were carried out near the wind-turbine and inside and outside of the complainer’s house at the same time. During the noise measurement, the complainer's houses were located on the leeward side of the wind-turbine at any area. In the measurement, the output signals of the sound level meter and the low frequency sound level meter were recorded with a data recorder.

Table-2 Layout of the measuring points

Area	Near the WT	Residential site	Complainer's house		
	Distance from the WT		Distance from the WT	Outside	Inside
A	150m	A-1	240m	○	○
		A-2	210m	○	○
B	125m	B	350m	○	○
C	100m	C	680m	○	○

The self-evaluation of discomfort on the wind-turbine noise by the complainers was carried out inside of the house together with the noise measurement. In the self-evaluation of discomfort, the complainers marked how they feel the noise momentarily without any information on the operational condition of the wind-turbine.

In the time of the noise measurement, the wind-turbine was stopped for about ten minutes. The wind speed at the nacelle height, and the rotor speed of the wind-turbine were informed from the wind-turbine managers.

1/3 octave band equivalent sound pressure level of ten seconds (Leq, 10s) was calculated from the recorded tapes, continuously. The calculated data were divided into two groups of operated and non-operated condition and were arranged according to the wind speed at the nacelle height.

3. Result of measurements

3.1 Frequency characteristics of wind-turbine noise

(1) Area A; Frequency characteristics measured in area A are shown in Fig.1, Fig.2 and Fig.3. The sound pressure level differences of the noise and the low frequency sound were observed according to on-and-off operation of the wind-turbine, near it and at the complainer's house A-1 and A-2 (the distance from the wind-turbine: about 240m and 210m).

At the measurement point near the wind-turbine, the low frequency sound at 31.5Hz and tonal sound of 160-200Hz were observed. The same tonal frequency components were observed inside the complainer's house A-1 and A-2, also. The sound pressure levels of noise in the complainer's house A-1 (the entrance door was opened), exceeded the hearing threshold at 40Hz or more, and the noise in the complainer's house A-2 exceeded the hearing threshold at 80Hz or more. On the other hand, even near the wind-turbine, the sound pressure levels of infrasound (20Hz or less) were about 20dB or more smaller than the hearing threshold.

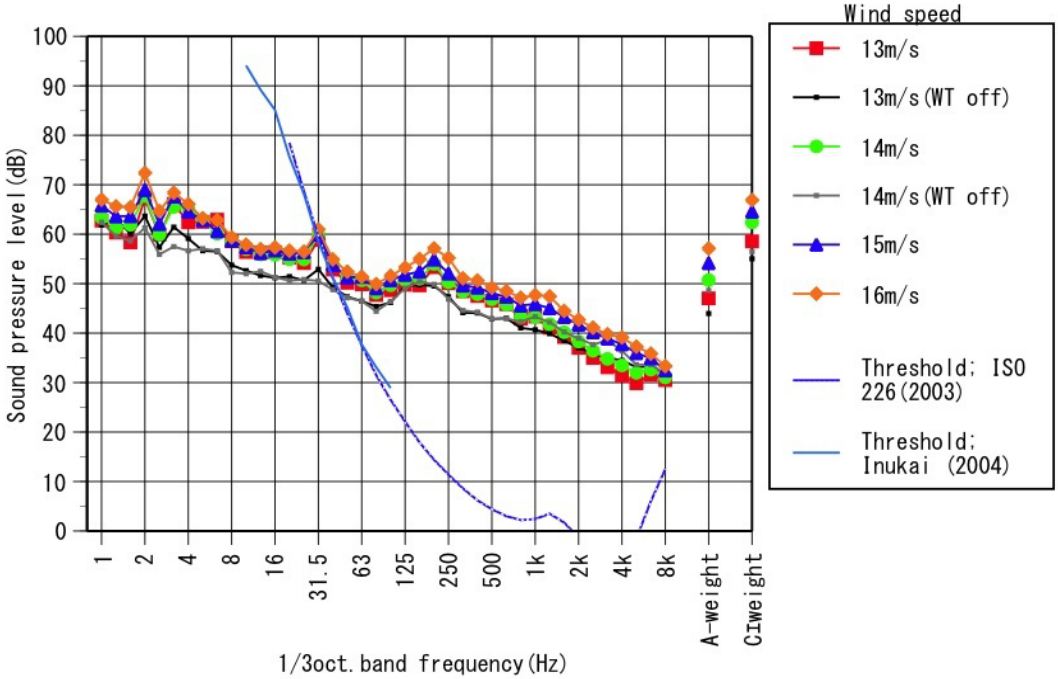

Fig-1 Frequency characteristics of wind turbine noise
;Near the wind turbine (Area A)

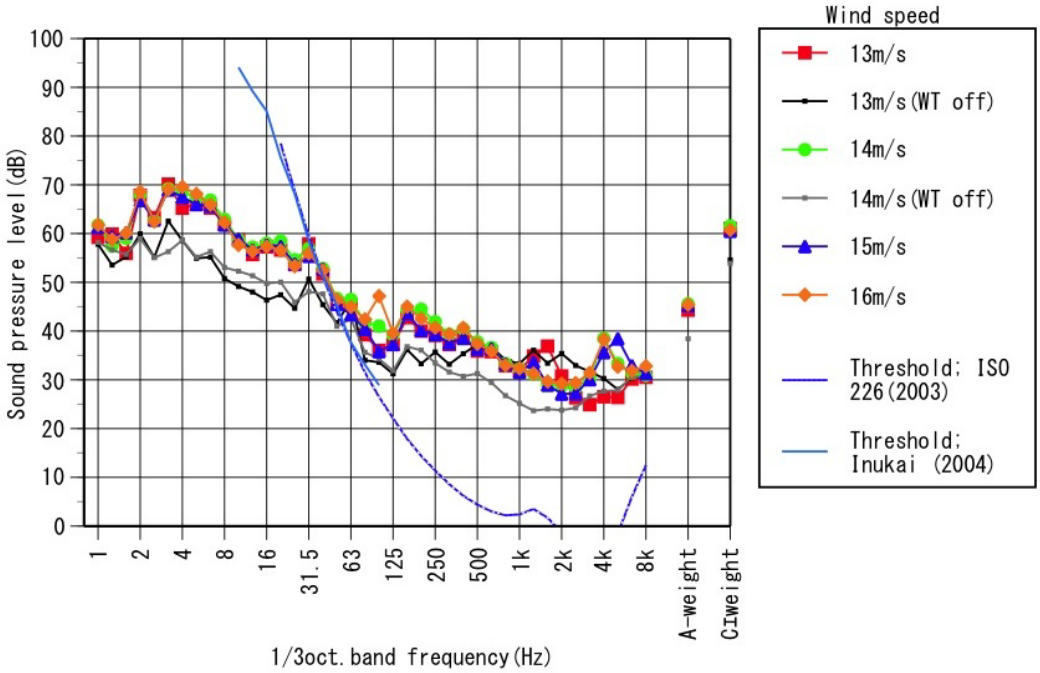

Fig-2 Frequency characteristics of wind turbine noise
;Inside of the complaner"s house A-1

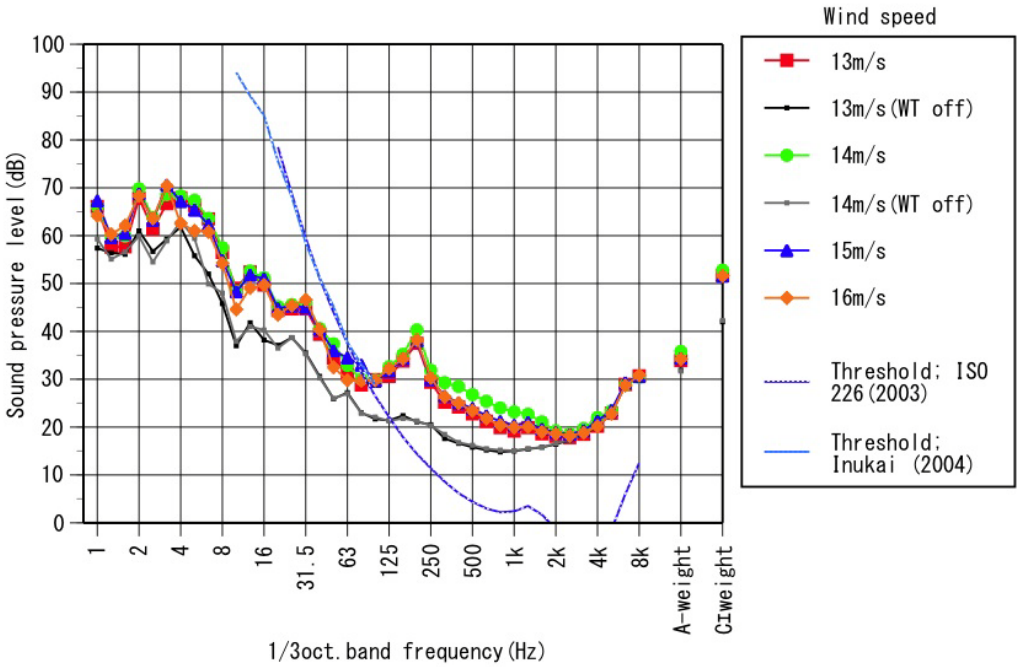

Fig-3 Frequency characteristics of wind turbine noise
;Inside of the complaner"s house A-2

(2) Area B; Frequency characteristics measured in area B are shown in Fig.4 and Fig.5. The sound pressure level differences of the noise and the low frequency sound were observed according to on-and-off operation of wind-turbine, near it and at the complainer's house B (the distance from the wind-turbine: about 350m).

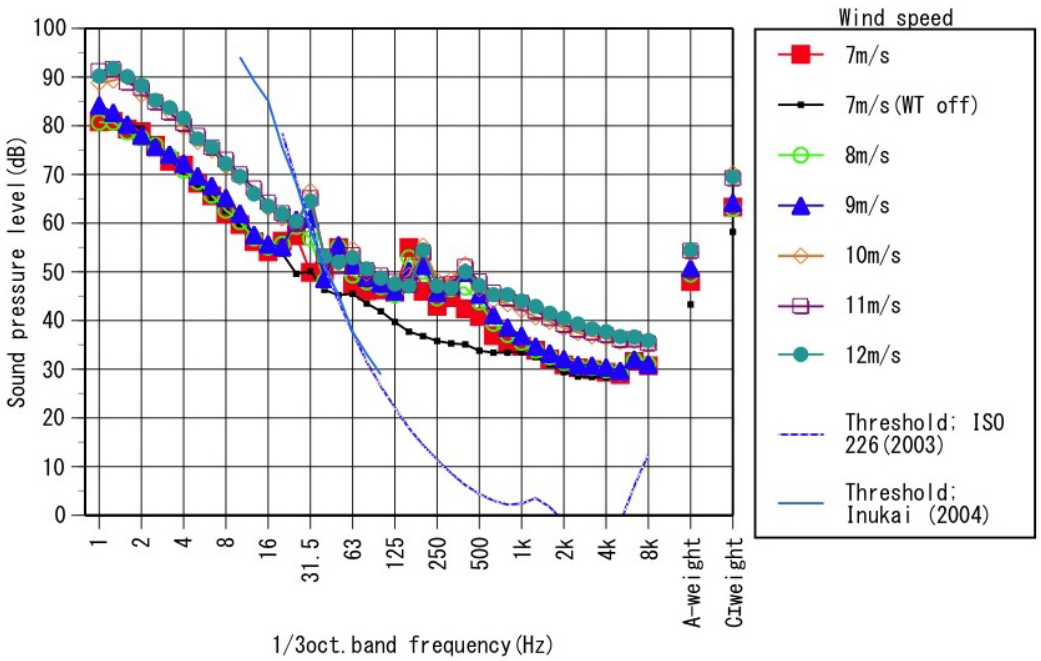

Fig-4 Frequency characteristics of wind turbine noise
;Near the wind turbine (Area B)

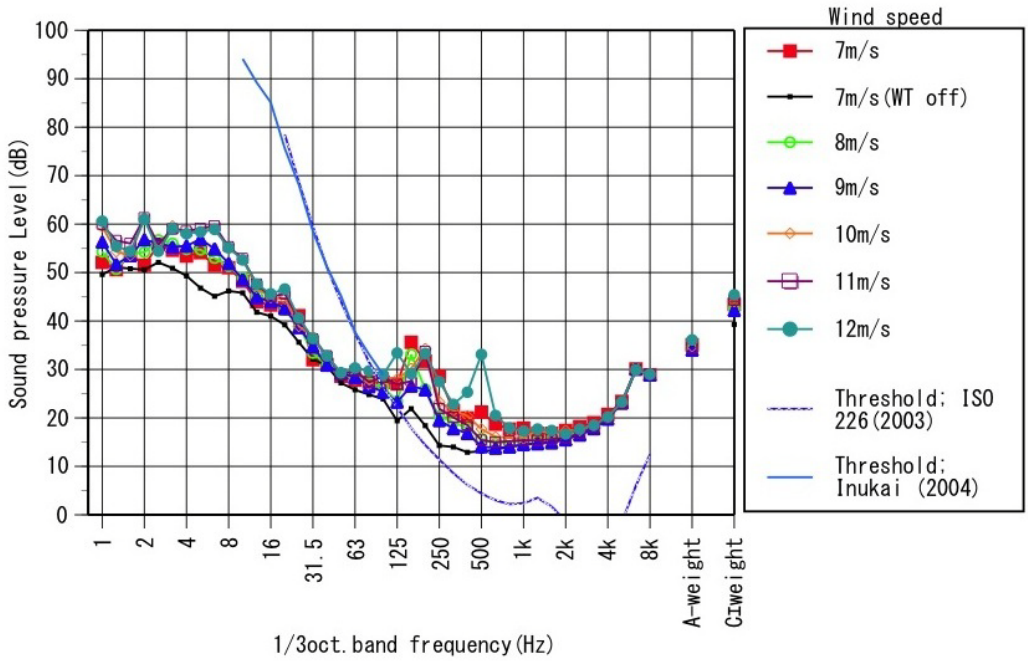

Fig-5 Frequency characteristics of wind turbine noise
;Inside of the complaner"s house B

At the measurement point near the wind-turbine, the tonal frequency components of 160-200Hz were observed. The same tonal frequency components were observed inside the complainer's house B.

The sound pressure levels of noise and low frequency sound in the complainer's house B exceeded the hearing threshold at 100Hz or more. On the other hand, even near the wind-turbine, the sound pressure levels of infrasound (20Hz or less) were about 20dB or more smaller than the hearing threshold, in area B, also.

(3) Area C; Frequency characteristics measured in area C are shown in Fig.6 and Fig.7. The sound pressure level difference of the noise were not detected according to on-and-off operation of the wind-turbine inside the complainer's house C (the distance from the wind-turbine: about 680m), though the sound pressure level difference of the noise and the low frequency sound was observed near the wind-turbine by on-and-off.

The tonal frequency components of neither 25-31.5Hz nor 160-200Hz, which had been observed near the wind-turbine, were not observed inside the complainer's house. Inside the house, another tonal frequency component of 12.5Hz was measured. It is assumed that this tonal frequency component of 12.5Hz is a low frequency sound generated by vibration of fittings caused by wind.

The sound pressure levels of noise in the complainer's house C exceeded the hearing threshold at 125Hz or more. On the other hand, even near the wind-turbine, the sound pressure levels of infrasound (20Hz or less) were about 20dB or more smaller than the hearing threshold, in area C, also.

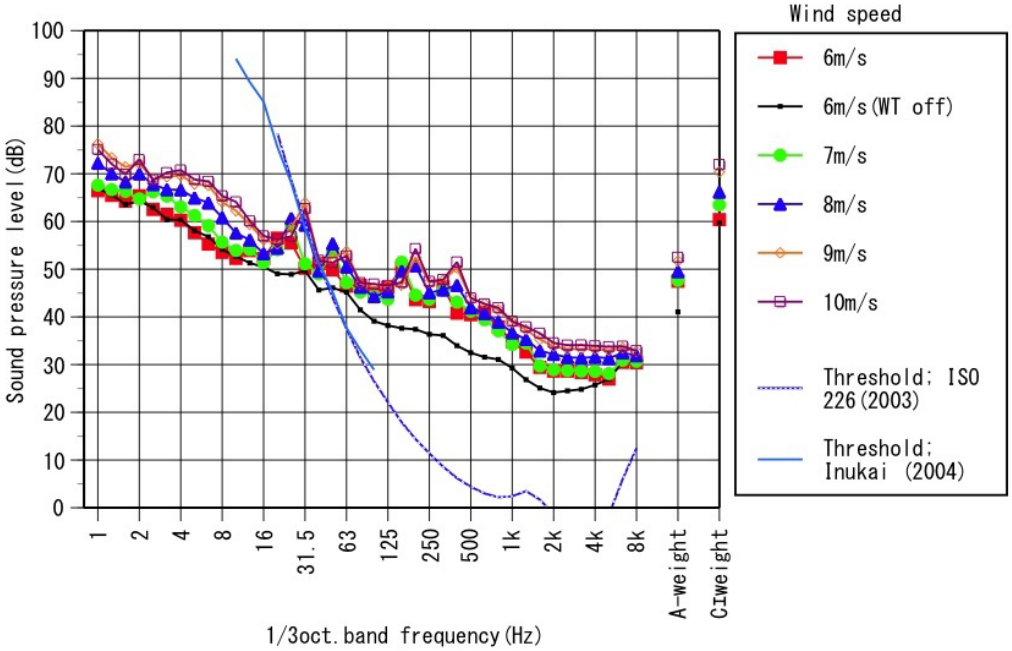

Fig-6 Frequency characteristics of wind turbine noise
;Near the wind turbine (Area C)

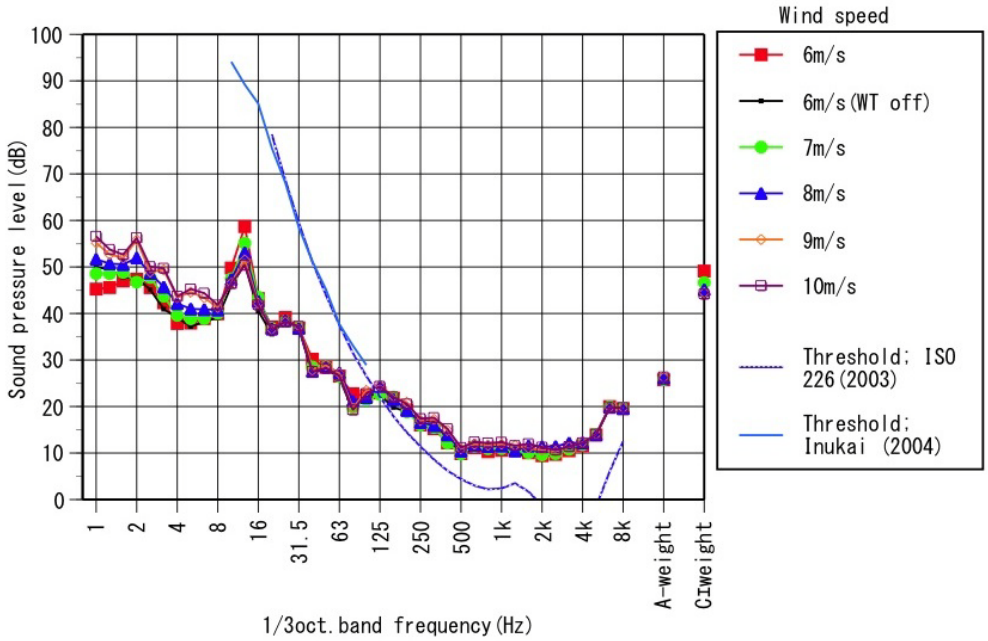

Fig-7 Frequency characteristics of wind turbine noise
;Inside of the complaner"s house C

3.2 Fluctuation of sound pressure level of wind-turbine noise

The level differences were observed according to on-and-off operation of the wind-turbine inside the complainer's house in area A and area B. But, the level difference

according to on-and-off operation was not detected clearly, inside the complainer's house in area C. As the data of the rotor speed every ten seconds was received from the wind-turbine manager at area B and C, the time histories of the rotor speed and the sound pressure level were analyzed.

(1) Area B; Examples of the sound pressure level fluctuation of the noise and the low frequency sound near the wind-turbine in area B and inside the complainer's house are shown in Figure-8 and Figure-9. The time fluctuation of the rotor speed every ten seconds, which was informed from the wind-turbine manager, was also shown in the figures.

The sound pressure level near the wind-turbine decreases when the wind-turbine stops (when the rotor speed is 0), as shown in this figure. When paying attention to the change in the sound pressure level of 160Hz and 200Hz, which is the tonal frequency components of the wind-turbine noise, the frequency shifted from 200Hz band to 160Hz band according to the decrease of rotor speed at the time of before and after stopping. Moreover, the fluctuated width of the sound pressure level of 160Hz was about 6dB before the wind-turbine stopping, but in the time of re-operating after stopping it was about 15dB. So, the fluctuation width became larger than before it stopped.

The rotational speed of the wind-turbine has decreased when it operates again, though it was almost constant (rating speed) before it stopped. Thus, the fluctuation of the sound pressure level seems to be in approximately good agreement with the fluctuation of the rotor speed.

(2) Area C; Correspondence figure to this area C is not shown in this paper.

Near the wind-turbine, the sound pressure level decreases as the wind-turbine stops (when the rotor speed is 0). The width of the sound pressure level fluctuation at 160Hz, which was the tonal frequency component when the wind-turbine operated, was 7-8dB.

However, the level difference according to on-and-off operation of the wind-turbine was not observed, inside and outside the complainer's house, which is 680m apart from the wind-turbine. It is supposed that the sound pressure level of the wind-turbine sound is the same level or less as the background noise level at this point.

3.3 Self-evaluation of discomfort

(1) Area A; The complainer in A-1 house did not accept to do the test of self-evaluation of discomfort. The complainer in A-2 house recognized the level change by on-and-off operation of the wind-turbine.

(2) Area B; According to the result of the self-evaluation of discomfort in area B, the complainer answered to be the most unpleasant when the wind-turbine operates again after stopping. The complainer answered to the questionnaire before the measurement, " In weak wind, I feel the sound more unpleasant rather than in strong wind. ". The result of self-evaluation is corresponding to the answer of questionnaire executed beforehand.

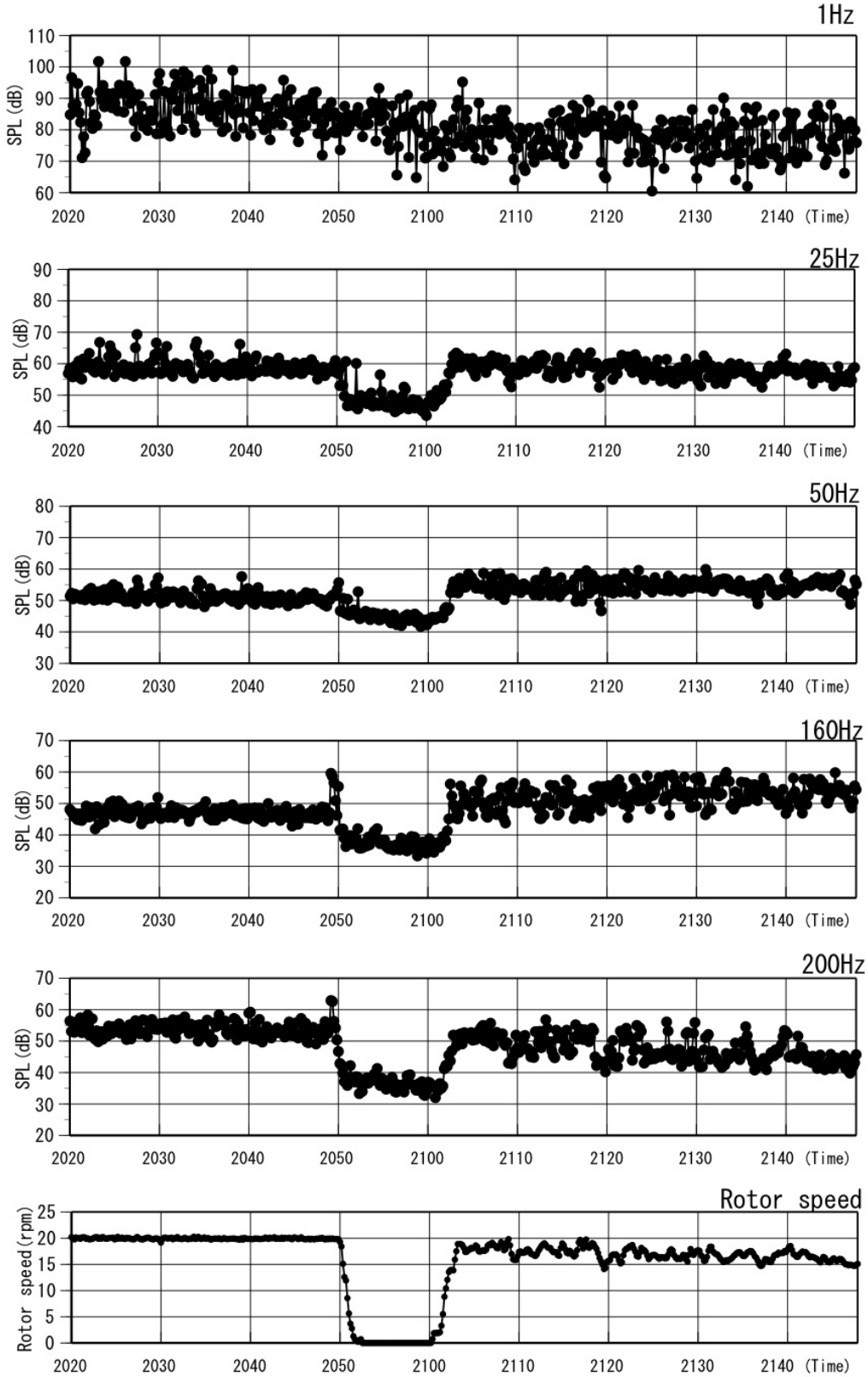

Fig-8 Example of the sound pressure level fluctuation of wind turbine noise near the wind turbine and time fluctustion of the rotor speed in area B

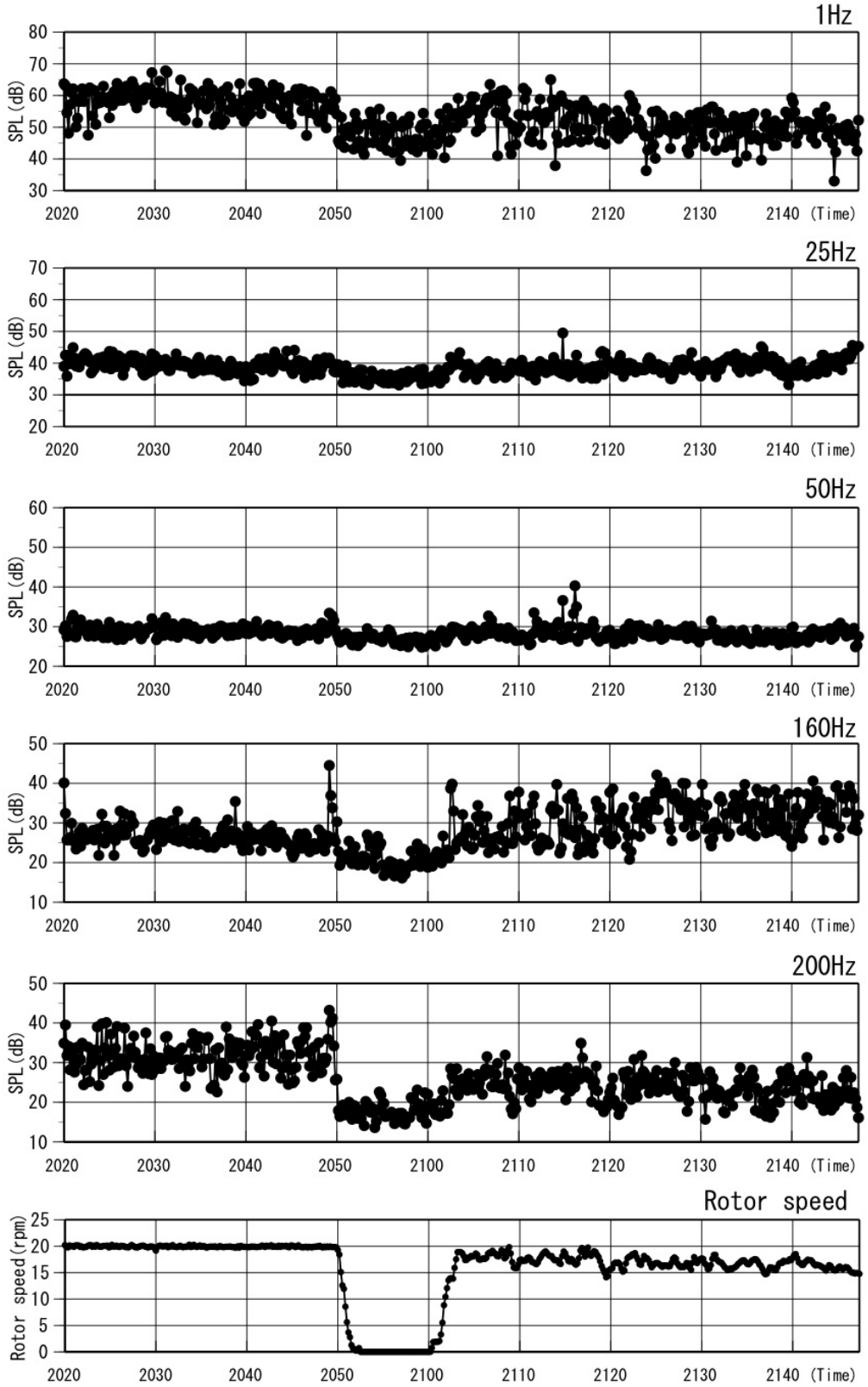

Fig-9 Example of the sound pressure level fluctuation of wind turbine noise inside of the complaner"s house B and time fluctustion of the rotor speed in area B

(3) Area C; Two of three complainers recognized on-and-off of the wind-turbine operation according to the test of self-evaluation of discomfort in area C, and one of two had time lag for about ten minutes after the wind-turbine stopped. However, the other complainer was not able to distinguish the change of its operation. Because the level difference between the wind-turbine noise and the background noise inside the house was little, so, it is assumed that the complainers are difficult to recognize the change of the operational condition.

4. Discussion

The sound pressure level difference in the complainer's house according to on-and-off operation of the wind-turbine, the sound pressure level inside the complainer's house of area-A and B changed according to on-and-off operation of the wind-turbine.

On the other hand, the sound pressure level did not change inside the complainer's house of area-C by on-and-off of the wind-turbine.

The correspondence between the tonal frequency components near the wind-turbine and those inside the complainer's house were inspected and the results are shown in Table-3.

Table-3 The relation between the tonal frequency components near the wind-turbine and those inside the complainer's house

Residential site	The tonal frequency (Hz)						
	2	3.15	12.5	25-31.5	50-63	160-200	400
A-1	Y	Y		Y		Y	
A-2	Y	Y				Y	
B						Y	
C			N				

Marked as "Y" indicates that the same tonal frequency component near the WT

Marked as "N" indicates that different tonal frequency component near the WT

indicates that the SPL is smaller than the hearing threshold level

In Table-3 the tonal frequency components marked as "Y" shows that the frequency near the wind-turbine is the same inside the house and "N" shows the frequency near the wind-turbine is not the same inside the house. The frequency region, where the measurement results are smaller than the hearing thresholds, is shown by "Grayish hatch" in the table.

It is said that the low frequency sound, which is less than hearing threshold, does not cause psychological affects according to many research papers (ex. Leventhall; LFN2008, [3]).

From these results, in this measurement at three areas, it was clarified that the cause of the complaint may be the tonal noise at 160-200Hz.

5. Conclusions

The noise and the low frequency sound were measured in three areas where the complaints concerning the wind-turbine noise have occurred.

As a result of the measurement, we have found that;

(1) The sound pressure levels of infrasound (< 20Hz) observed are 20dB or more lower than the hearing threshold of human at the distance of about 100-150m from the wind-turbines,

(2) From the measurements inside the houses, it is presumed that the complaints are probably caused by the tonal components at frequency range from about 160 to 200Hz,

(3) To understand the characteristics of the wind-turbine noise at each measuring point, it is effective to do continuous measurement by using Leq, 10s and on-and-off operation of the wind-turbine during the noise measurements. Especially, the latter is useful to know whether the complainers actually listen to the wind-turbine noise and in what operating condition of wind-turbine they feel uncomfortable and complain against the wind-turbine.

Acknowledgment

INCE/J was commissioned to make an investigation report by the Ministry of the Environment of Japan in 2009. This paper is an arrangement in some parts of the investigation report about low frequency sound.

References

[1] ISO: 226 (2003): Acoustics - Normal equal-loudness contours.

[2] Inukai, Y., Yamada, S., Ochiai, H., & Tokita, Y., "Acceptable Limits and Their Percentiles for Low Frequency Noise in Ordinary Adults and Complainants", 11th International Meeting on Low Frequency Noise and Vibration and its Control, 117-127, Maastricht, the Netherlands, (2004).

[3] Leventhall. G, “Low Frequency Noise. What we know, what we do not know, and what we would like to know”, 13th International Meeting on Low Frequency Noise and Vibration and its Control, 1-26, Tokyo, Japan, (2008).