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Observation of vibration velocity at many parts of wind turbine and relational analysis with propagated sound to surroundings

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Summary

Authors had carried out many kinds of trial to understand characteristics of wind turbine noise. In this study, authors also newly tried measurements of the excited vibration on many parts of wind turbine such as outside surface of nacelle for storing power generation system and tall tower by using a laser Doppler vibration meter. Observation and analysis of the natural frequencies of blade vibration at rotation stopping state were done. Investigations on the noise in surroundings of wind turbine were also done. We tried the FFT analyses on them with high resolution to obtain detailed frequency characteristics. Then, relational analyses between vibration velocity and noise propagated to surroundings were added to ordinal spectral analyses only for the propagated wind turbine noise to make origins of tonal components clear. It first could be understood that both sharp spectra at near 1 Hz as slightly lower on a blade and higher on a tower were appeared in the analysed results. In analyzed results of the vibration velocity and propagated sound in the normal operation continued state, a lot of sharp spectral peaks with exceeding of 10dB from each base level of vibration and noise were recognized in the broad frequency range from very low to several hundreds of Hz's. It also could be understood that there were high coherencies between vibration velocity and wind turbine noise at frequencies with high spectral peaks. And certain values of coherency as exceeding 0.3 or up to 0.6 were remained even for the case of noise received at distance of about 200m from a wind turbine.

For sound source modelling, these results clearly show the existences of both sound sources in the wind turbine noise. One is aerodynamic sound with broadness and low frequency prominent components caused by rotating blades in the strong wind flow and another one is remarkable discrete frequency components originated in the vibration on power generation mechanical system. They together propagate to far surroundings. For some applications to reduce wind turbine noise and to make audible simulation for evaluating effects of the noise, such a modelling with two kinds of sound origin or hypothesis based on the experimental studies as we made will be effective.

1. Introduction

Authors had been interested in the low frequency noise problem for several years, and had actually researched for some themes. For recent example of domestic low frequency noise problem, we investigated radiation and propagation of noise from a heat pump type water boiler working in mid-night into an adjacent house. Then, we could recognize that a lot of spectral components superior as added on the broad band noise in the low frequency area by using FFT analysis with fine frequency resolution.[1)]

Moreover, we proposed the improving idea on perforated plate by imaginary increasing of thickness of plate with extending tube type parts behind opening holes to realize high sound absorption at low frequency, for example lower than 100Hz under keeping back air space as shallower than 100mm. By this method, we can take additional countermeasures of the sound absorbing for low frequency noise even in small dowelling rooms.[2)]

Because wind turbine had been rapidly spread in world wide under the common perception that it is one of most important clean and renewable power generation technique even though it has intense noise at low frequencies and it causes noise problem in wide surroundings.

Of course, we had been interested in the problem of wind turbine noise and had visited many wind power generation facilities including old type constructed in the 1990s and new type in the 2010s in various places in our country.[3)] Those wind turbines had hub height from 30m to several tens meters, rated power from several hundreds kW's to 2 MW. So, simple field surveys/measurements by the recording of the wind turbine noise at each facility and in surroundings had been done for many visited sites. We could also have recognized a lot of sharp spectra at low and mid frequency in the analyzed results on the recordings of wind turbine noise. After these basic research works, we were interesting in such sharp spectra in wind turbine noise and in origins of strong spectra.

In order to make the origins clear, we decided to make other measurements with new theme of investing existence of vibration excited on the wind turbine.

In this study, we tried to measure vibration on many parts as very long blades, cylindrical hard steel wind tower and light-weighted frame of nacelle which store dynamo and various equipments for electric power control and for cooling at high top of the tower. We made the spectrum analyses of not only the radiated wind turbine noise but also vibration velocity, and made relational analysis between both.

Analyzed results are reported in this paper to make them useful for understanding characteristic of the wind turbine noise, for clarifying noise generation mechanism, for modelling to make audible simulation and for establishing the way to control and to reduce both of noise radiation and excitation of vibration.[4)]

2. Field investigation on wind turbine noise and vibration on wind turbine facility

2.1 Outline of observation and analysis

Some of authors had visited a lot of wind power generation facilities for basic pre-investigation studies to understand outline of the wind turbine noise. In our first step studies, we had simply put single or two more sound level meters near the base of each target wind turbine tower. The output sound signals from them were stored on PCM type recorders by wave-type form. All data were re-stored in hard drive type mass storages to be analyzed, and then we tried analyses to understand characteristics of the noise by using digital signal processing software on personal computers (PC).

After these simple investigation and in the second stage of this study, following investigation s with observations and analyses on vibration were added to those of wind turbine noise in the two or more sites in 2011 and 2012.

The outline of these common field measurement and analysis is shown in Fig.1. Standard type sound level meter (RION NL-20 etc.) or wide frequency range sound pressure meter with keeping flat response of microphone sensitivity at low frequency of 2Hz (RION XN-2P) was put on the near point of tower base. Another one of the same type was used for additional observation at the different point near the tower or another point not far way. The laser Doppler

vibration meter was used to make easy remote observation of vibration excited on many parts on the high and distant wind turbine from the ground by keeping the synchronization with the sound level meters on the ground. The laser vibration meter was put on a point near to the base of a wind tower as shown in Fig. 1. Output signals from the measuring instruments for sound and vibration were recorded on a PCM data recorder (RION DA-20, Roland R-05 for Simple measurements) at a time.
The laser light was basically focused on a point on the outside surface of frame of the nacelle where dynamo, driving mechanism as a set of gears for increasing rotation of blade to the dynamo and other supporting equipments for working power generation system as cooling were stored, and the vibration velocity of a wind turbine in normal operation by rotating of blades was observed.
Several points on the surface of cylindrical tower as in the propagation root of vibration from the nacelle toward the base on the ground were chosen.
As for the vibration observation, the model of laser vibration meter with red laser light type (Polytec RDV-100) for short distance was selected for a lot of observations on the low and small wind turbine in the early research stage and another model with infrared laser light type (Polytec RSV-150) for far distance of several hundreds of meters was selected in the last stage observation for the high and large wind turbine tower.
When wind flow is strong enough to rotate wind turbine continually and to keep state of normal operation of generation electricity, we made measurements of both sound and vibration in the basic wind condition.
The “On-Off” test of the rotation of the wind turbine was added as an optional condition. In the test, the wind turbine was forced from normal state of rotation (On) to stop (Off), was re-started after several minuets and was recovered to normal continuous rotation state (On). The vibration velocity and the wind turbine noise were observed continuously while time was passing in the test. In addition to these optional observations, when the wind was weak and the wind turbine stopped naturally, the residual noise was observed. In the same condition, laser light was focused on a point on the blade and vibration was observed, and it was analyzed to understand characteristics of vibration excited on the blade and its natural frequency.

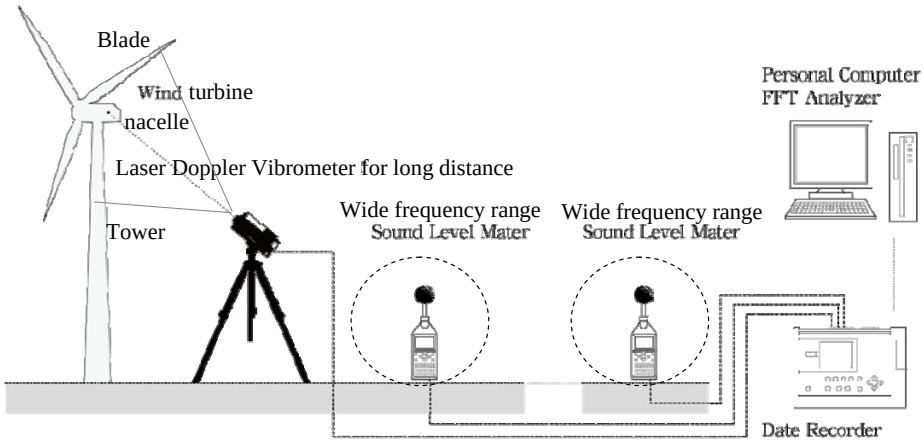

Fig. 1 Common system of observation system for vibration on wind turbine facility and sound propagated to near points and to surroundings.

2.2 Spectral analyses of wind turbine noise

Some representative data were selected from stored data of wind turbine noise, and were analyzed. Examples of the analyzed results by using FFT software on PC are shown in Fig. 2 (A). In this figure, frequency is displayed in the horizontal axis by the logarithmic scale, and each spectral density par unit frequency width is displayed in the longitudinal axis.
Rated power and constructed year of each wind turbine is added in the same figure. For the reference, frequency characteristics by ordinal one thirds octave bandwidth analysis are also shown in Fig. 2 (B).
As a whole, levels of wind turbines with older construction age are relatively high even though their rated powers are lower. Tendencies on the spectral density with weakening by increasing

of frequency are clearly shown in the analyzed results by FFT software on a PC. There is a similar tendency even in the results by the ordinal 1/3rd octave band analyzing method. Even though there is individual difference for each, quantitative tendency were shown by examples of levels in frequency bands as 30-40dB in 1 kHz, 45dB-55dB in 250Hz and 50dB-60dB in 63Hz band. It can be simply said that the components in low frequency area are superior as already reported by many researchers.[5-9] Frequency characteristics of the same were reconfirmed in this study too. More over, it can be understood that the levels are high in the bands of 31.5, 50, 63, 125 160, 250 and 500 Hz of analyzed results.
As for analyzed results with fine resolution by FFT method shown in Fig. 2 (A), a lot of independent spectral components are sharply appeared in frequency area from about 20 Hz to 700Hz and at frequencies higher than 1000Hz. These strong spectral components can be significantly distinguished from the broad base level of each wind turbine noise that has high levels in the low frequency area. We thought that very sharp spectral peaks originated in the rotational or vibrate machines and in the resonances of material or parts composing facility. These descriptions are conclusion at the first stage of this study.

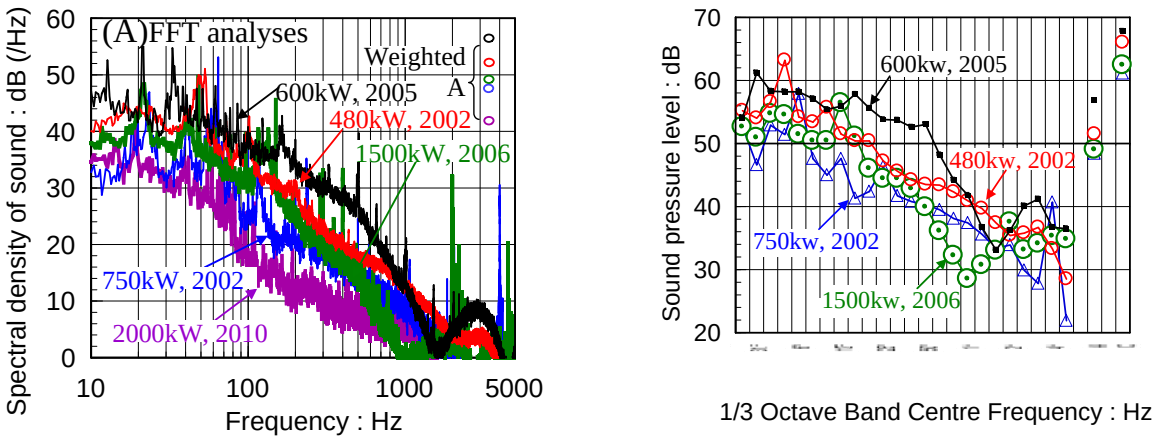

Fig. 2 Analyzed examples of wind turbine noise observed at a point close to base of each target wind turbine.

2.2 Trial observation of vibration on wind power generation facilities with the noise

For second stage of the study, vibration observation for wind power generation facility was tried in 2011 based on the already analyzed results and its consideration introduced just before. Target facility was constructed in 2003. It has nacelle and hub of blades at the top of tower with height of 60m and it has relatively high rated power of 1,500kW.
Season of this trial was summer with calm climate, so wind was weak and the wind turbine did not rotate in a couple of day as shown in Photo 1. Simultaneous observation between vibration and the wind turbine noise could not be done. We thought that observation of the characteristic vibration of the blade would be able to be executed in just non-rotating state. Then, the observation with changed aim was actually done.
The example of analyzed result by FFT calculation on the observed vibration is shown in Fig. 3. An independent spectrum with sharpness is appeared at about 1Hz. As for more high frequency, spectral peaks at 3Hz, 6Hz and 9Hz were recognized even though they are relatively weakened. Frequencies of these sharp spectra are lower than frequency area of the main frequency components in the analyzed result of wind turbine noise as shown in Fig. 2. It can be thought that sharp spectra in very low frequency vibration observed on the blade are not originated from aerodynamic sound caused by wind flow strong enough to operate power generation but from the characteristic vibration on blade just directly excited by moderate wind flow. And, it may be remarkable fact that frequency of 1Hz with existing excellent spectrum is very near to the typical modulation frequency of the swish sound which characterize the wind turbine noise as introduced and reviewed by many researchers including D. Bowdler.[10-12]
In these experiments, relation between the vibration and the noise could not be made clear, but example of the characteristic vibration of the blade could be caught for the first time. It was thought that the important data had been obtained.

After this experience, authors had thought to have to execute the relational observation between vibration and noise again. Afterwards, new observation plans were made and their some parts were actually executed.

Next, an easy and simple observation with success is introduced. Chosen wind turbine for the observation target had been constructed in free accessible open site, as shown in Photo 2, in twelve years ago of 1994 and its rated power was very low to be 275kW. Its construction aim was not only for verification test on power generation but also for the advertising demonstration by a power generation company. The tower has hub height of 30m at the top of tower. Therefore, small type model of laser vibration meter limited for short distance was used to observe the vibrations on both surfaces of the tower and the nacelle frame.

Because next trial observation had been done in winter season when the wind strongly blew, the target wind turbine rotated enough for power generating and the simultaneous observation between wind turbine noise and vibration could be done at last. An example of analyzed result of the vibration velocity on the surface of the frame of nacelle on the top of tower and the noise received on the ground near to tower base is shown in Fig.4.

A lot of sharp and independent spectra are appeared in this analyzed result.

Spectra at near 30HZ, 70Hz, 110Hz, 260Hz and strongly 650Hz are commonly appeared in both analyzed results of vibration velocity and noise.

Photo 1 Target wind turbine with three blades in non-rotation state in the calm summer.

Photo 2 Old model type wind turbine constructed in a park.

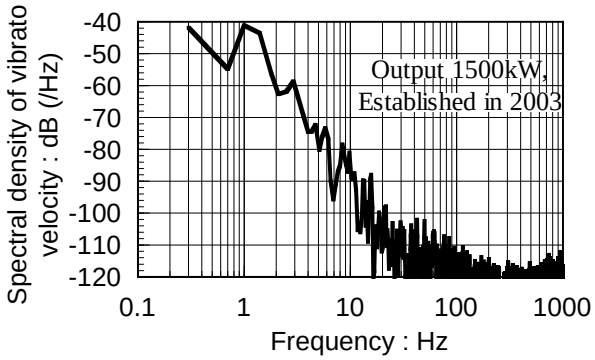

Fig. 3 Example of spectral analyzing of vibration on the blade of a wind turbine.

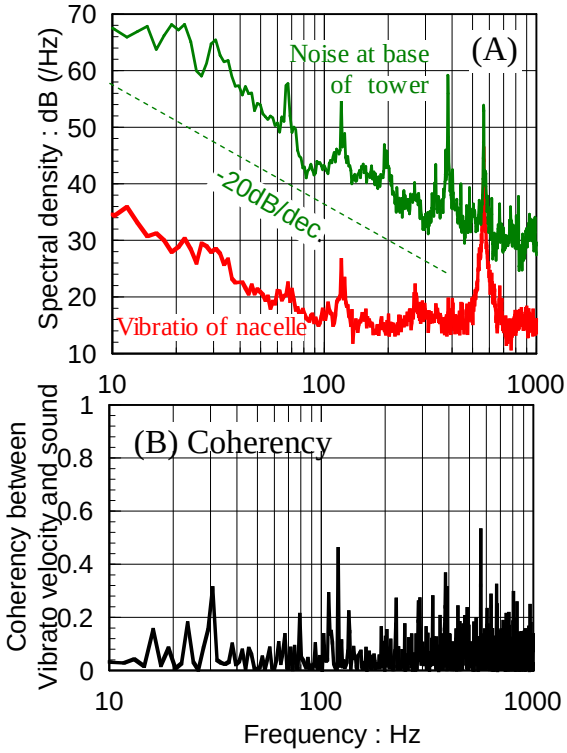

Fig. 4 Analyzed relations between vibration velocity and wind turbine noise at a point close to base of a tower.

The coherence function between the vibration velocity and the noise was also analyzed to confirm the strength of relation between both. A lot of values exceeding 0.2 can be seen in the analyzed result, and the values higher than 0.4 are also shown. High coherency values correspond to the sharp spectra at just above-mentioned frequencies especially at 30Hz, 110Hz and 650Hz.
It can be judged that the sharp and strong spectra included in the wind turbine noise originate from the vibration excited on many parts of wind power generation facility. Fukushima and Uchida reported that the noise observed even in far surroundings of wind turbine commonly had superior components in both octave bands of 31.5, 63Hz and occasionally in 125Hz band.[7-8)] Our analyzing result of coherence function agrees well to the descriptions in their reports about frequency bands of excellent spectra in their reports about wind turbine noise.

3. Vibration on wind turbine

3.1 outline of method of observation and analysis

We made a plan for more detailed observation based on the consideration as described just above. New target wind power generation facility had height of about 80m to the hub from the ground surface, and the diameter of rotor with tree blades was about 80m. And it had new gearless type dynamo with rated power of 2MW in the nacelle at the top of cylindrical steel tower. A large type model of laser vibration meter for long distant remote observation were put on the ground closed to the base of the tower or other position with distances of several tens meter, for example 80m, from the base. Two or three wide frequency range sound pressure meters were used. One of them was put on the point near to the tower for the reference and others put on the points with distance of about 86m, 166m or 216m. The outline of setting of the measuring instruments was the same as shown in Fig. 1.
Many detailed observations were done in the autumn of 2012, when wind condition had enough strength for normal power generation. In during of the observations, we tried "On-Off" test of the operation of power generation by forcing non-rotation/stop of wind turbine for short time interval. And, we tried some kinds of observation in the condition with weak wind velocity lower than cut-in velocity of 3.5m/s.
After this field work, data in the typical or suitable condition were selected from whole collected data for understanding and consideration about wind turbine noise.
Typical digital signal processing analysis methods in the FFT software on PC were applied on the raw wave-type file data. The spectral analyses and the relational analyses between sound and vibration were done for some purposes.
In these FFT analyses, frequency resolution was selected to be very fine as about 0.3Hz by data-window widths of 2^{17} for sampling frequency of 48kHz, and each spectrum was indicated as each density for unit frequency width of $48{,}000/2^{17}$ Hz.
For the comparison between vibration velocity and noise, the values of vibration velocity were converted to the relative ratio values against the imaginary reference velocity of 4.8×10^{-8} m/s which is equivalent to the value of particle velocity in the air corresponded to the reference sound pressure of 20×10^{-6} Pa. Then, analyzed result of the vibration velocity was displayed as relative level in dB by the same way as for the sound pressure level.
When wind flow was weak and the target wind turbine was naturally stopped, vibration velocity at a point on the blade, at some points on the frame of nacelle and at a point near top of the tower were observed by the laser Doppler vibration meter put on a position with distance of tens of meters from the tower.

3.2 Results of analyses and their considerations

Analyzed results are show in Fig. 5. A little difference of wind condition might be added to the analyzed result of vibration velocity on each target point.
In the result on the blade, phenomenon of strongly vibrating only at 0.7Hz is clearly shown. And then, the characteristics of vibration of the blades almost directly reflect on the analyzed result on a point at the side of nacelle frame. On the other hand, a strong vibration is appeared at 1.1Hz for the point of top of the tower, and two or more spectral peaks can be seen as the

hypothesis of higher-order resonance frequencies of the tower with reflection of hard steel structure.
The wave form in the time domain on the blade vibration is shown in Fig. 6 and its analysed result of auto-correlation function is shown in Fig. 7 for the reference. Clear periodic wave form in the Fig. 6 and almost sine-wave in the Fig. 7 are shown, and it can be recognized that just characteristic vibration is excited on the blade under very weak wind condition without the influence of aerodynamic turbulence around the blade.
In the comparative test of operation, the wind turbine was changed from the state “In operation” (On) with regular rotation to the state “Out of operation”(Off) by forced stopping rotation, and then it was changed to state “In operation”(On) by recovering rotation, the comparative analyses were also done by following sequential time changes of state of the operation. Continuously analyzed results of vibration velocity at a point on the bottom of nacelle are shown in Fig. 8 by 3D display method. As following to the sequential time pass, changes of A-Weighted sound pressure level of observed at a point close to the base of tower, and zoomed up parts for both states are shown in Fig. 9 with the level observed at 86m distance for the comparison. Both results in Fig.8 and in Fig. 9 have significant level changes following to operational state change. In the A-weight sound pressure level, periodic level change with time period of about 1s or longer is appeared in the relatively high averaged level in the state “In operation” (On). It seems to be an evidence of amplitude modulation in the swish sound characterizing wind turbine noise as well introduced or explained by many researchers.[10-12)]
Fig. 10 shows analyzed results of vibration velocity at a point of nacelle and those of the sound pressure observed at a point on the ground close to tower base. In these figures of the analyzed results of both vibration and noise are shown and compared by each operational state. In Fig. 10 (A), sharp spectrum is appeared at 0.7Hz in the analyzed result of vibration velocity in the state “In operation” as in Fig.10 (A). This frequency corresponds with spectrum of characteristic vibration observed on the blade of in non-rotation. Other significant spectra are appeared in more high frequency range from 2Hz to 400Hz. It can be confirmed that level of vibration velocity clearly decrease into “Out of operation” by the forcing to stopping state of rotation of blades and also dynamo.
Sharp spectral peaks still remain as at 2.5Hz, 25Hz, 30Hz, 60Hz and 110Hz in the frequency range above-mentioned because parts of all equipments in the nacelle could not be stopped in the temporal state of “Out of operation” by forcing and they continued to excite somewhat vibration in the nacelle.
In the analyzed result of the noise shown in Fig. 10 (B), spectral densities in the case “Out of operation” weaken by several dB’s in all frequency area compared with those “In operation” and sharp peaks are disappeared and frequency characteristics became smoother. It is remarkable that decreasing of level for overall frequency is fewer than that in the vibration velocity.
For the reference, analyzed result is added in Fig. 10 (B) for while blades were not rotated by weak wind condition. The base level is lower about 10dB than that in the “In operation”. Such a little level difference between “In operation” and “Out of operation” is considered as follows. Even if wind turbine is “Out of operation” by forcing rotation stop, blades are exposed in the strong wind flow, and then air flow turbulence generated just around blades and it is called the aerodynamic sound with the same meaning. And then, it propagates widely. The propagated sound keeps the higher level than that in the case of non-rotation in natural breeze condition.
Authors more deeply considered the influence of vibration on the wind turbine noise based on the coherence function analysis between vibration velocity and noise. Result of the analysis for each state is shown in Fig. 10 (C). Coherency is obviously higher in the frequency range from several Hz to several hundreds of Hz in the state “In operation” than in the state “Out of operation”. These results mean that many spectral components at frequencies with high coherency values are strongly included in the noise radiated to surroundings of wind turbine as that they originated in the vibration.
So, we also considered about the noises received at more far two points. One of them was a little away from the tower with distance of 86m and slant distance of 117m from the top of the tower, another was more far way with distance of 216m, with slant distance of 230m.

Analyzed examples are shown in Fig. 11. A lot of numbers of spectral peaks can be recognized in the analyzed results for every observation points including far point in the frequency range from 10 to several hundreds of Hz's. The level difference between both spectral characteristics for the point close to the tower and those for point of 86m can not be easily confirmed as shown Fig. 11 (A). On the other hand, it can be understood that the level at point of 216m decrease about 5dB compared with one in the nearest point right under the tower. Analyzed result of coherence function between the vibration velocity at a bottom of the nacelle and the noise received at the point of 216m is shown in Fig. 11 (B). And, a lot of numbers of spectral peak can be recognized in the analyzed results for every observation points including far point in the frequency range from 10 to several hundreds of Hz's. At the time before the analysis of coherence function were done, it had been thought that phase change would be caused while sound propagates for certain distance by the air flow turbulence in strong wind, and then influence would be appeared as decreasing of coherency between source and response. In the case of the noise received at a point of 216m, it can be understood that the coherency values are still keeping high as about 0.2 at several number of frequencies and over 0.6 at 110Hz and 220Hz. And, it also can be thought that the pure tone components exist with exceeding in the noise at certain distant point like this case. The pure tone components included in wind turbine noise are related to the vibration excited on the wind turbine facility. The coherence function between noise received at near point to the tower and that at the point of 216m was analyzed as the additional trial. The analyzed result is shown in Fig. 11 (C) and high values appeared in the frequency range from ten and several Hz's to one and half hundreds of Hz's as like as between the vibration and the noise. Remarkable high coherency chain is appeared in the frequency from 1.5Hz to 7Hz. For such analyzed characteristic in very low frequency area, we can make image that turbulence is generated by the existents of blade in the strong wind flow, it means aerodynamic sound, then it propagates to each observation point. Commonly received somewhat reflects in observed results by high coherency.

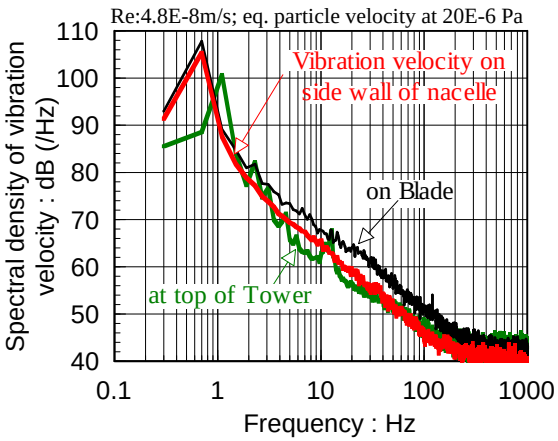

Fig. 5 Observed examples of vibration velocity on representative part of wind turbine in a very weak wind condition.

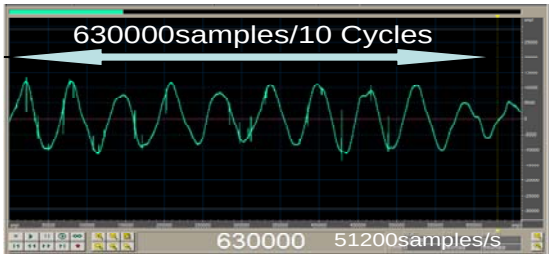

Fig. 6 Wave form of the vibration velocity on the blade of a wind turbine in the state of stopping of rotation. The value of 630000samples/10cycles by sampling frequency of 48kHz is the same to 1.3s=630000/48000/10 and it is equivalent to 0.7cycle/s very near the modulation frequency of swish observed in this measurement.

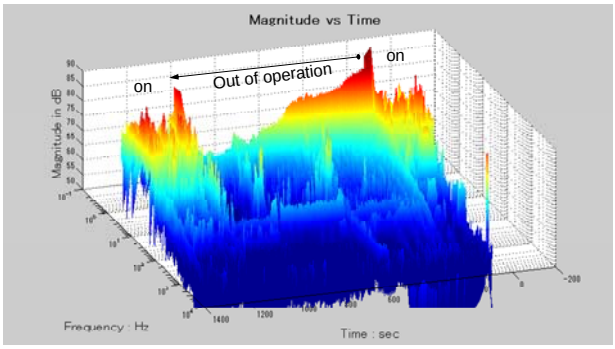

Fig. 8 3D display of time change of vibration on nacelle bottom in "On-Off" test.

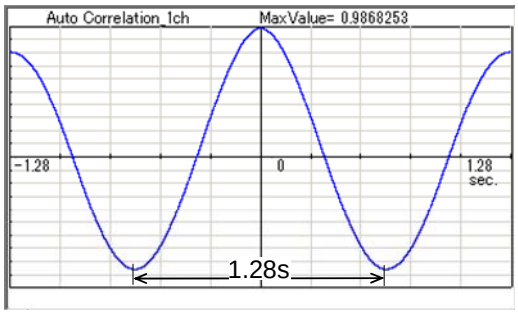

Fig. 7 Auto correlation function of the vibration velocity on the blade of a wind turbine in rotation stopping. One cycle has about 1.28s as near the one cycle period in the Fig.6.

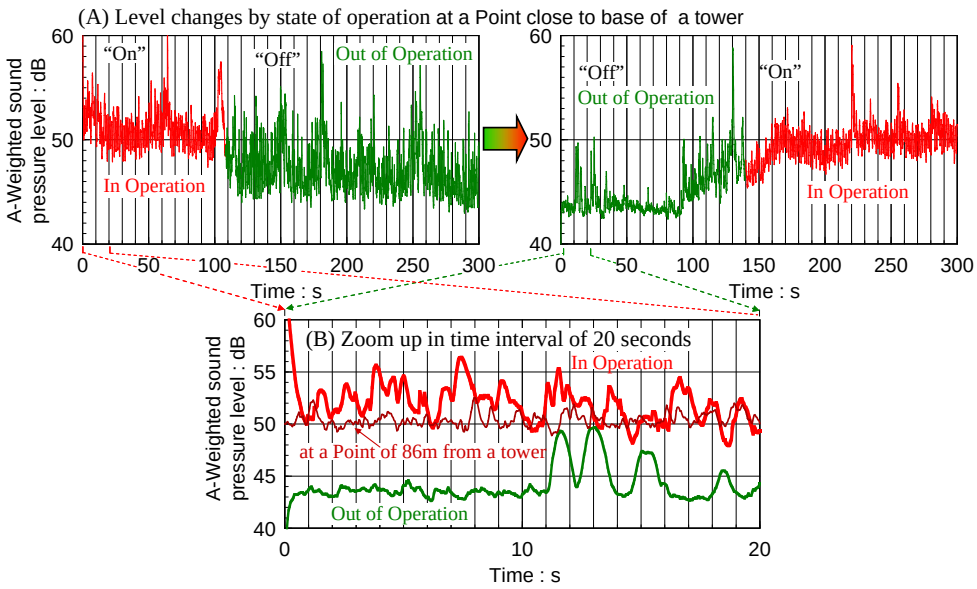

Fig. 9 Time changes of A-weight sound pressure level in the On-Off test of operation as "In operation" and "Out of operation" by forcing temporal stopping of rotation of wind turbine.

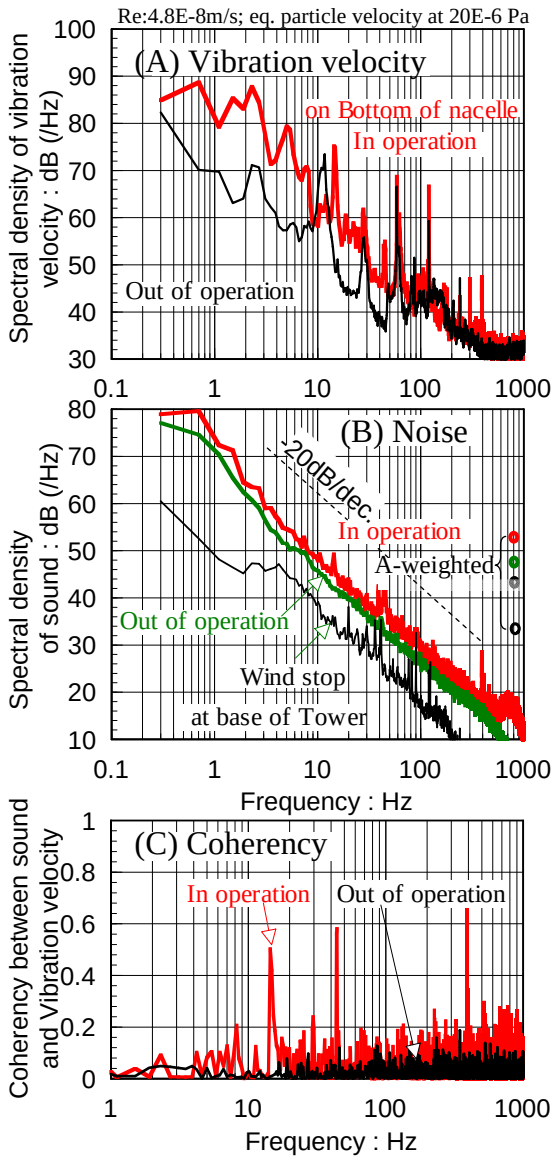

Fig. 10 Comparisons of analyzed vibration of the nacelle and noise at base of tower in both conditions "In" and "Out" of operation.

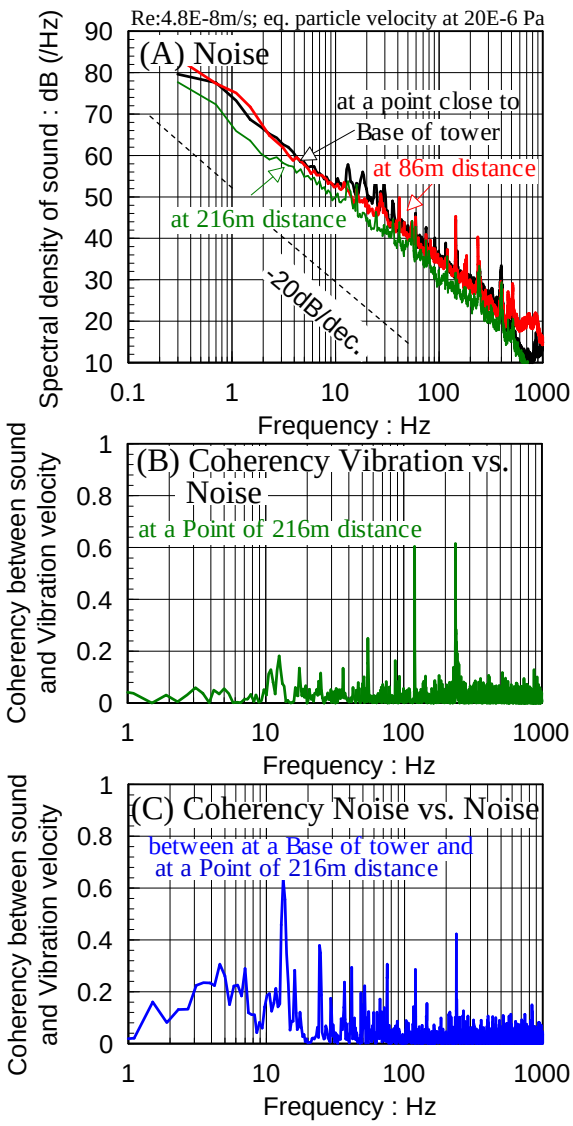

Fig. 11 Analyzed wind turbine noise at near and distant points from tower (A), coherency between vibration velocity on nacelle and noise at far point (B) and coherency between both noises at near and far points (C).

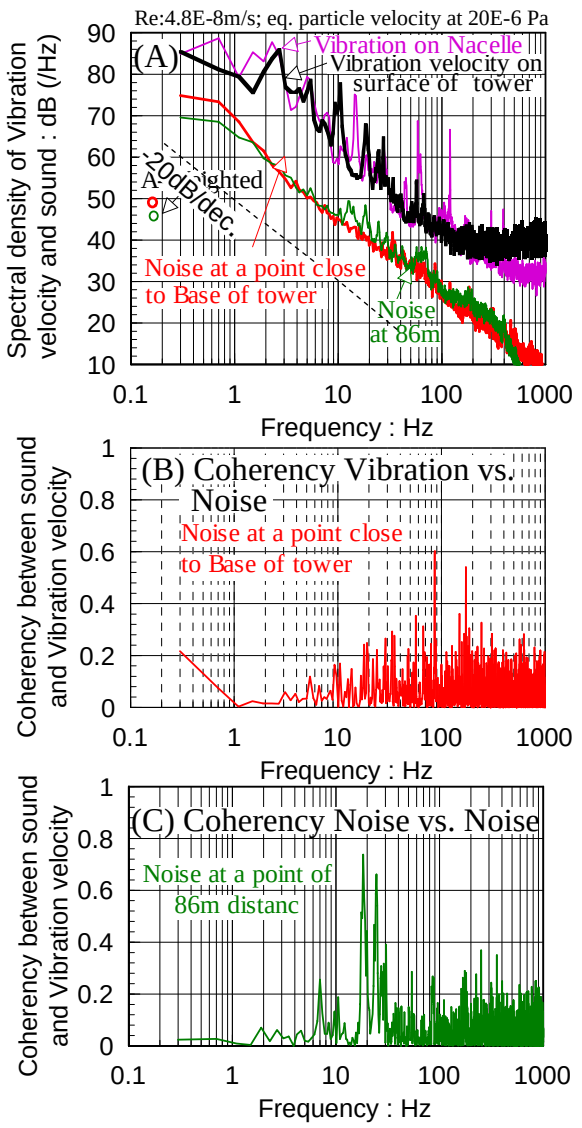

Fig. 12 Comparisons of analyzed vibration on surface at a point with half height of tower and noise observed at near and a little far points (A) and coherency between among them (B) and (C).

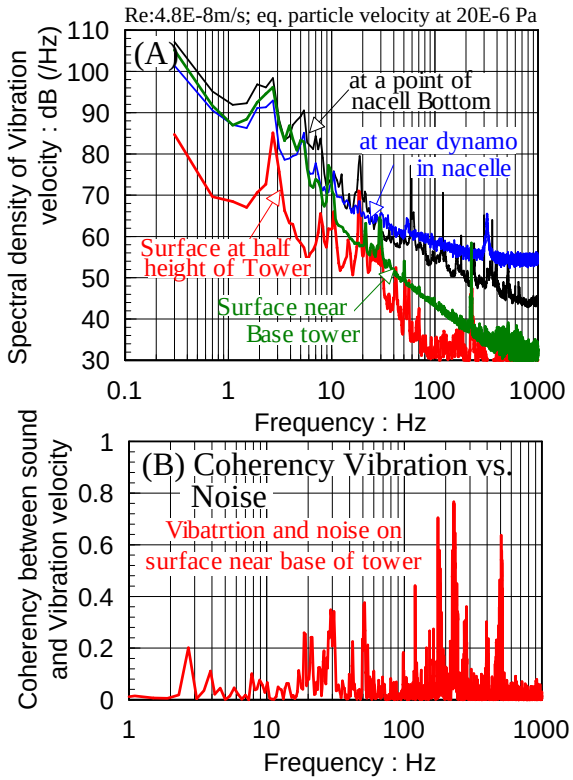

Fig. 13 Comparisons of analyzed vibration on the representative surface on the tower and on the bottom of the nacelle (A), and coherency between vibration on the surface near the base of tower and noise received at its near point (B).

4. Influence of high spectra exceeded from broad band component

Finally, authors consider the component originated in the vibration and appeared as excellent spectra in the noise at surrounding points of the wind turbine facility by the following ways. We can recognize the tendency in the wind turbine noise that low frequency components are superior in the analyzed results by FFT, and their dependences on frequency are roughly approximated by " -20dB/decade " as examples introduced in Fig. 10 (B), Fig. 11(A) and Fig.12(A), which are shown by the relation between "Logarithmic scale for frequency" and "Spectral density every unit frequency width". So, authors corrected these display way to be corresponded to similar 1/N-th octave band analysis. It was very simply based on the level correction as "+3dB" for every octave increasing of frequency. Moreover, we made A-Weighting correction for taking the auditory evaluation on the corrected results.

Corrected samples by basis of such two steps are shown in Fig. 14 for the analyzed results as previously shown in Fig. 11 (A). As for the influence of the noise radiated from wind turbine on the audibility by according to the corrected results shown in Fig. 14, it can be evaluated so that the noise with randomness has main share in the frequency range from one and half of Hz's to several hundreds of Hz's. As sharp and independent spectra in the low and mid frequency range of the share and included in more low frequency area, their levels are high as out-

standing from the broad base levels of the wind turbine noise, and it is understood that components originated in the excited vibration on the wind turbine are not to be buried.
Even though authors could not make both quantity and auditory evaluation [13] of parts of sharp and high spectral components, meaning the same pure tones, compared with basic components in the over all sound with broadness yet, it seems that wind turbine noise has to be evaluated from both points of view as basic levels of broad random noise and tonality additionally. The old type models of wind turbine have independent strong spectral components as shown in Fig. 15. Both points are important and necessary to find out the main parts which consist origins of wind turbine noise, for example blades or nacelle, and to take countermeasure for the old type wind turbine with still remaining certain life-time for operation.
Our investigation way for wind turbine noise will be useful to understand detail of noise and to make important points in noise problem clear. And it is also important to make accurate sound source model for the application study to evaluate the wind turbine noise not only by quantitatively as high or low in dB but also by another way as hearing of audible simulation. [4]

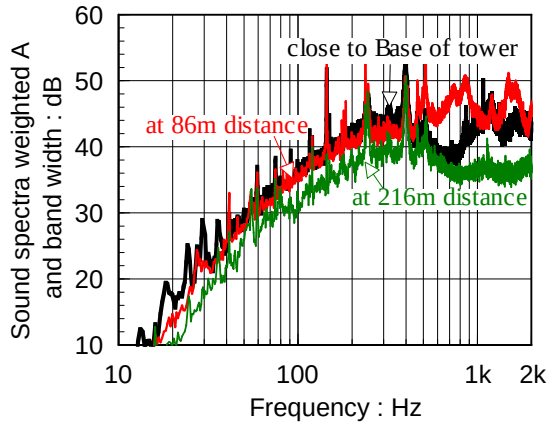

Fig. 14 Corrected sound spectra by A-weighting and by band width difference at each frequency range of low, middle and high as +3dB/Oct. on FFT analysis outputs previously shown in Fig. 11 (A).

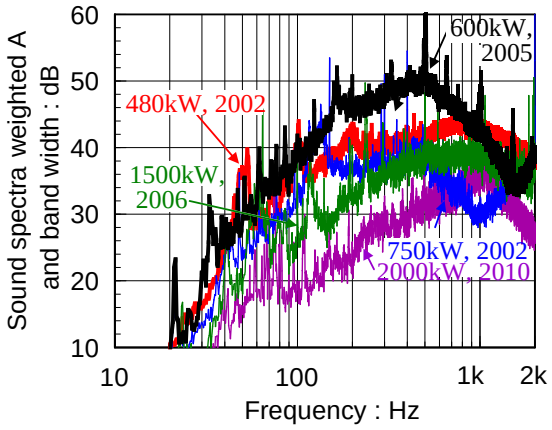

Fig. 15 Corrected sound spectra by the same way as shown in Fig.14 on the representative data of wind turbine noise located some places in Japan shown in Fig. 2.

5. Conclusions

Authors have been studying on wind turbine noise problem for examples to understand characteristics of noise, noise source and noise propagation to surroundings. Then, we can have following conclusions from many observations and analyses.
(1) Authors could simultaneously observe the propagated noise and vibration velocity at many parts on the wind turbine facility.
(2) We could observe and analyze the natural frequency of blade vibration. It was a little lower than 1Hz as near the amplitude modulation frequency of swish sound and it might be enhancing the modulation.
(3) It could be recognized again by our studies that wind turbine noise had broadness and main share in low frequency area.
(4) Sharp spectral peaks in the frequency range from a low frequency to mid frequency of several hundreds of Hz's are appeared in both analyzed results by FFT on vibration velocity excited at many parts on the wind turbine and on the propagated noise in surroundings.
(5) High coherency values about 0.2 and as over 0.4 or 0.6 were shown at many frequencies in the analyzed result between vibration velocity and noise.
(6) The relation between vibration velocity at wind turbine facility and noise received at a point with distance over 200m still remains.
(7) It seems that the influence independent strong spectra as pure tone components originated in vibration excited on wind turbine can not be disregarded on the audibility especially in the case of old model of wind turbine with many vibration sources and with still remaining machinery life-time for operation.

Remarks

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