Low-noise Design for Wind Turbine Blades

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Noise reduction of wind turbines has recently become more important due to increasing large-scale turbine developments, stringent noise regulations, and installation of wind farms near residential areas. Wind turbine noise is mainly caused by broadband noise from the blades and can be reduced using noise prediction technologies. Mitsubishi Heavy Industries, Ltd. (MHI) has developed a new method to predict blade noise based on a computational fluid dynamics (CFD) approach and an empirical formula. This method can be used during the preliminary blade design and has been validated using an actual model. In this report, we present a less noisy blade that was developed by applying this approach at the design stage.

1. Introduction

Power production by renewable wind energy has risen sharply in recent years against a backdrop of demand for global warming reduction and energy security. Additionally, development of larger-scale turbines with higher output per unit has increased to ensure profitability and efficiency.

Figure 1 shows the relationship between the sound-power level of turbines and the rotor diameter. For larger-scale wind turbines, a longer rotor diameter results in higher sound-power levels, and the effects of the circumferential velocity at the blade tips induced by the longer blades surpass the effects of rotation frequency.[1] Therefore, increasing the rotor diameters is the main cause of increased sound-power levels.

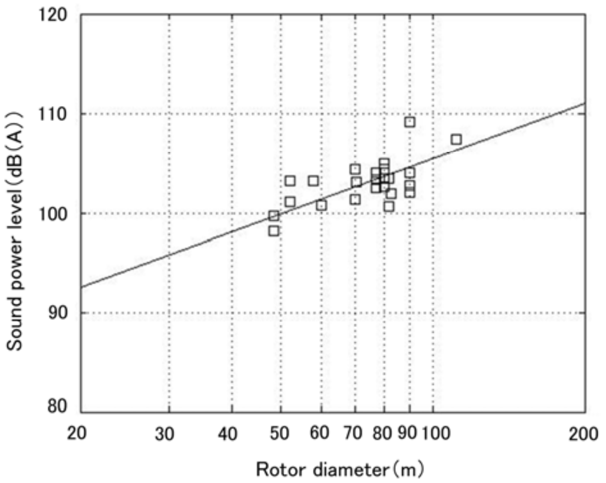

Figure 1 Variation in the sound power level of a wind turbine[1]

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As larger-scale wind turbines are built and more wind farms are constructed near residential areas with lower wind speeds, citizen complaints have increased, including in Japan, and environmental noise assessments at the planned sites have become more critical. Thus, predicting and reducing turbine noise has become more important during the planning phase of wind-power system developments.

Wind turbine noise is traditionally classified into two main sources: aerodynamic blade noise and mechanical noise from nacelles and towers. The former is dominant for the large-scale wind turbines (1-3 MW class) currently installed at many wind farms. Therefore, the aerodynamic noise generated at the blades must be minimized to reduce the total turbine noise. A blade-noise-prediction technology applicable at the design phase is essential.

To be practical, the prediction technology must be fast and accurate because the blade noise must be evaluated simultaneously with the blade performance and loads.

An unsteady computational fluid dynamics (CFD) approach is available for aerodynamic noise prediction, but it is not practical because large-scale wind turbines are too large as analysis targets and require too much computational effort. Another approach using an experiment-based two-dimensional (2D) blade empirical formula can predict noise in less time, but is not as accurate when applied to wind turbines. To improve the accuracy of the formula, it must be expanded to the whole blade to include blade-shape effects.

Mitsubishi Heavy Industries, Ltd. (MHI) has developed a new approach to predict broadband blade noise by combining a steady CFD method that can provide good accuracy and calculation speed for blade design needs with an experiment-based empirical formula. In this report, we describe the new prediction approach and introduce a higher-performance low-noise blade design that was developed using it.

2. Noise Prediction Approach

MHI’s noise-prediction approach, which combines steady CFD and an experiment-based empirical formula, uses the blade-noise prediction formula developed by Brooks et al. of NASA.[2] Here, we outline the Brooks formula-based prediction method. The Brooks formula can predict the noise spectrum of 2D blade cross sections and can be used for the total turbine noise by dividing the blade into many sections to predict the noise spectrum of each section.[3]

To apply the Brooks formula to MHI’s wind turbines, we developed an approach for broadband blade-noise prediction by including the following techniques to improve the accuracy and shorten the calculation periods.

- Consideration of the rotation effects of three blades revolving on the axis, i.e., changes in the diffusion distance and orientation due to the position change of the revolving blades.
- Consideration of the airfoil geometry, as the Brooks formula was derived for NACA0012 airfoils. The boundary thickness of each airfoil is estimated by CFD beforehand, assuming that the flow changes due to the airfoil are significant in the boundary layer thickness. This boundary-layer thickness is then supplied to the prediction formula.

Our noise-prediction approach follows the steps outlined below.

(1) Calculate the inflow wind speed and angle of attack of each divided blade section based on the blade shape, wind speed, blade rotation frequency, and blade pitch angle.

(2) Predict the boundary-layer thickness of each section based on the inflow wind speed and angle of attack by using steady CFD.

(3) Predict the noise level of each section based on the blade shape, inflow wind speed, angle of attack, and boundary-layer thickness by using the Brooks formula.

In this way, the time required for the noise prediction can be shortened substantially by using both the experiment-based Brooks formula and the steady CFD results, enabling the blade design and noise evaluation to be performed simultaneously.

During the design phase, various parameters such as the airfoil, code length, twist angle, and rotation frequency must be changed. However, MHI’s approach is suitable as a noise-evaluation method during this phase because it can predict noise values in short periods of time, even when these design parameters are changed.

Figure 2 compares the predicted and actual measured noise values for a real model. The plot illustrates the consistency between these values; the differences in the sound-power level of the turbine are within ±2 dB at each reference wind speed, showing the validity of MHI's approach.

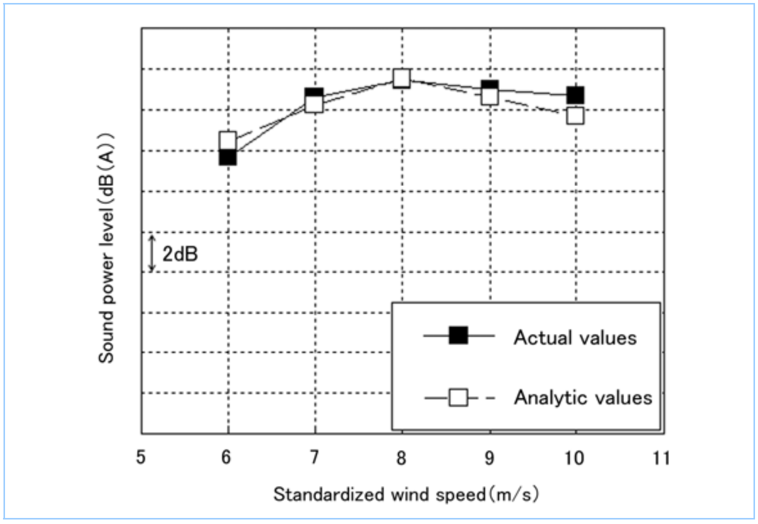

Figure 2 Actual and analytical values of the sound power level

3. Noise Reduction

To reduce the generated noise, it is important to understand and analyze the noise characteristics and identify the noise frequencies. MHI's approach has the benefit of predicting the frequency characteristics of the generated noise. **Figure 3** presents an example plot obtained using our approach, showing the aerodynamic noise spectrum of each noise source in a wind turbine. The major noise components are the turbulent boundary-layer noise and trailing-edge bluntness noise; these occur at frequencies of 200 Hz-1 kHz and 2-3 kHz, respectively. Based on the frequency characteristics, the target noise source that must be addressed can be identified.

In this noise-prediction approach, the blade is divided into several sections so that the noise level of each section can also be identified. This allows us to focus on a particular blade section to reduce the total noise efficiently. **Figure 4** shows an example of the noise predictions for each blade section. There is a higher noise contribution at the blade tip because the turbulent boundary layer noise is the major component of the spectrum (as shown in Figure 3) and the noise level increases with the circumferential velocity. These results show that the noise source to be addressed primarily is the turbulent boundary layer noise generated at the blade tip. This allows us to focus on noise reduction by identifying the noise types and locations during the design phase and develop less noisy blades efficiently without degrading their performance. Using this approach, MHI succeed in developing a less-noisy blade that was 2 dB or more quieter compared with conventional blades.

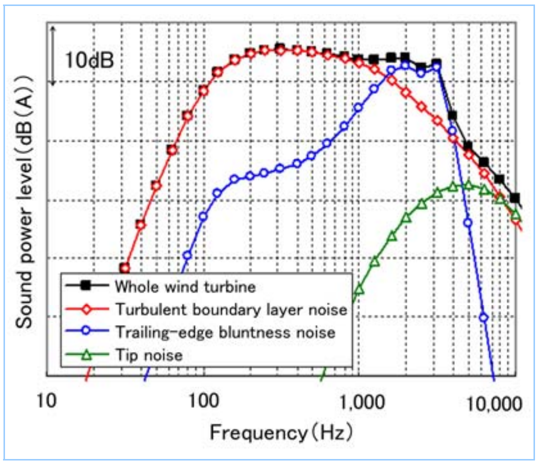

Figure 3 Predicted spectrum of each sound source

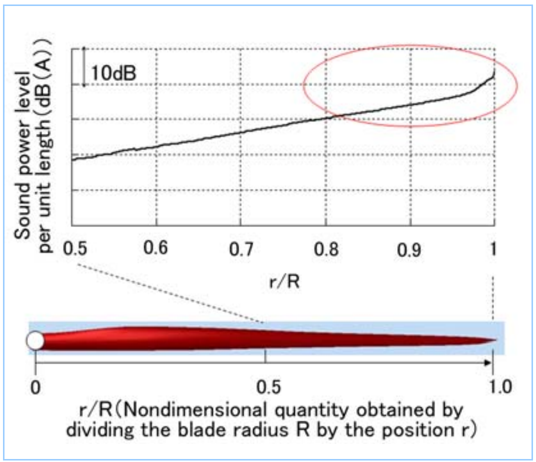

Figure 4 Noise distribution in the blade-length direction

4. Conclusion

Wind turbine noise reduction has become more important from the viewpoint of environmental assessments, and further noise reduction has been demanded. To develop quieter blades, it is important to identify noise sources and their locations to reduce the noise during the design phase. A prediction method to evaluate noise quickly and accurately during the design phase is essential. In this report, we presented a practical noise-prediction method for wind turbine blades that can exploit current computational capacities and keep the speed of blade development. This method has allowed MHI to develop a high-performance less noisy blade that supports eco-friendly wind turbines. These turbines will provide effective natural energy use and will pass environmental assessments.

References

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3. Grosveld F.W., Prediction of Broadband Noise from Large Horizontal Axis Wind Turbine Generators, AIAA-Paper 84-2357 (1984)