Experimental Study on the Noise Distribution Law in Sound Field of the Horizontal Axis Wind Turbine Near Wake

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Abstract. This paper measured the propagation law of the acoustic radiation of certain airfoil blade in the near wake and obtains the noise parameters with different tip-speed ratio and measuring position by using the PULSE system. The results show that in low frequency band the rotation fundamental frequency and harmonic of the blade is main ingredients in the acoustic radiation of the near wake. With the harmonic number increasing, the energy of the acoustic radiation decreases and the noise of the middle blade is stronger than the noise of blade tip. The vortex structure leads the speed uneven distribution along the wing span. The test section presents three different regions which have obvious characteristics and the three regions are affected by the center vortex, the tip vortex and the free diffusion with the increase of the testing radius. The experimental results reveal preliminarily the propagation law of the noise radiation in the near wake and provide reference for the subsequent study.

1. Introduction

Wind turbine radiated noise has become a major factor affecting the promoting of wind power utilization. In recent years, seeking different mechanism of the formation about the aerodynamic noise becomes a goal in this field. The cognition of wake noise propagation law is also the foundation of the performance prediction and the design about wind turbine aerodynamic characteristics[1].

In 2004, the US National Renewable Energy Laboratory Oerlemans and Migliore[2]， completed more acoustic wind tunnel testing of wind turbine airfoil by using acoustic arrays. Followed in 2005, Oerlemans[3] led the survey work completed during the laboratory acoustic arrays of wind turbine operation. The diameter of the test wind turbine is 58 meters and the sound equipment is an array of 152 microphones constitute. In 2009, Wu Yadong[4] from Shanghai Jiaotong University conducted the study with the trailing edge of inspiration and internal flow turbomachinery aerodynamic noise problems, obtained axial velocity, important length scale of the tail and the wake turbulence characteristic length trace parameters by use hot-wire anemometer to measure the stator wake of detailed flow field. In 2012, Technical University of Denmark BERTAGNOLIO Franck[5] used experimental methods to try to develop an assessment of wind turbine blade trailing edge noise testing techniques. Measured blade NACA0015 across in a wind tunnel, Hotline probe on the 3 d mobile scaffold in behind the blade, at the same time made the KE 4-211-2 microphones at the bottom of the blade surface to measure the pressure fluctuations. This study broadens the fan noise research methods. In 2013, Wu Yue[6] from the Chinese academy of sciences based on beamforming method for locating wind turbine aerodynamic noise has been studied and influencing parameters were optimized. In 2014, Gao Zhiying[7] of Inner Mongolia university of technology studied the winglet on the influence of wind turbines near wake sound radiation, The experimental used five levels of factor 5 and found S tip winglet structure was the best under different tip speed ratio with better power amplification effect.

Exploration of wind turbine wake noise radiation law can improve the utilization efficiency of wind turbine and provide some reference to the structural dynamic characteristics, this experiment is triggered at the same location to ensure data collection, the comparative analysis of parameters

more convincing.

2. Experimental equipment and experimental scheme

2.1. Experimental equipment

① The experiment was made in the wind tunnel of Key Laboratory of Wind Energy and Solar Energy of the Ministry of Education in College of Energy and Power Engineering Inner Mongolia University of Technology. The diameter of the experimental section is 2m and the maximum stable wind speed is 20 m/s;

② The horizontal axis wind turbine in the experiment has three wind turbine blades, its rotor diameter 1.4m, for a S airfoil blade, fixed pitch. Rated to flow 10m, rated tip speed ratio $\lambda = 5.5$;

③ The researcher adjust the rotor speed through a resistive load regulation, using a Fluke company NORMA5000 type power analyzer to monitor the output power and the motor frequency;

④ Sound field is tested by the PULSE system of Danish B&K company and data acquisition front-end is 3160-B-042 type, B&K microphone for company 4189-A-021 type of B&K company;

⑤ An infrared photoelectric sensor that can output low level trigger signal.

2.2. Experimental scheme

Fix the microphone stand point position，set the sampling frequency and the sampling time. From the side away from the wind wheel rotation begins 50cm intervals tested for 10 different axial positions of 10cm. Noise test system shown in Figure 1.
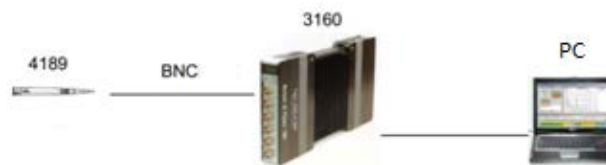

Fig.1 System diagram of noise measurement

Test area is defined as a three-dimensional coordinate with the wind wheel rotation axis perpendicular to the plane of rotation of the wind wheel through the plane of the wind turbine blade airfoil tip leading edge point of intersection of the axis of rotation of the wind wheel and the plane of the wind wheel rotation center, set up To coordinate origin O. Origin and parallel to the flow axis by the X-axis and the flow is taken to the X-axis positive direction. By origin parallel to the ground and the vertical flow as the Y axis, Y axis is the direction as shown in figure 2, schematic for plane along the coming flow for test. Passing through the origin perpendicular to the ground of the axis is the Z-axis, perpendicular to the ground to take up as a positive Z-axis. Wakes measuring point by the parameter r, d, θ is defined, where r is the measured points and the origin O of the radial distance, θ is the measured point, the connection with the OY axis angle formed by the center, d as the X axis direction and distance from the origin.

Wind speed is fixed at 10m/s and the tip speed ratio was λ=4，4.5，5，5.5，6，6.5，7. The test section is selected from the origin of O by the d=50cm start the arrangement of 10 section along the positive X axis, 10cm step. Because the 3 blade of the wind wheel in the circumferential direction symmetrical distribution and each blade had same shape and installation angle and axial flow in the flow channel has always been a uniform and stable, so it can be seen as the flow in the 3 flow channel was uniform. The measurement area is taken as 1/3 circumference. The measurement of Radial position from the blade root 20-90cm, 10cm step.

Attached light reflection sheet at the flange connected the blade and the hub, the photoelectric sensor arranged just above the cabin. It can provide a triggering signal for the test system, Ensured the experimental data are obtained under the trigger position θ =90 degrees.
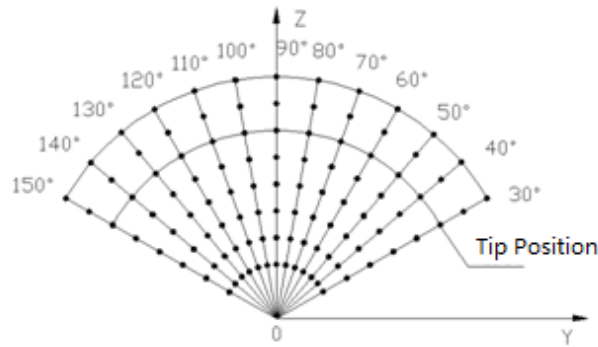
Fig.2 Diagrammatic arrangement of measuring point

3. Sound field analysis of experimental results

3.1. Frequency domain characteristics analysis

In order to eliminate the influence of background noise for later signal analysis , it is necessary to identify the aerodynamic noise characteristics with wind tunnel. Without installed wind machine, the acoustic signal which wind tunnel opening experimental section provides stable 10 m/s wind speed as the analysis of the background noise. As shown in figure 3, For d = 50 cm, θ=-50，r=70cm point of wind tunnel background spectrum. Wind tunnel entrance power fan rotation noise and harmonic are the main components of the background noise. In the frequency domain containing the center frequency is about 3000Hz frequency broadband noise and produced higher harmonic 6000 Hz、6000Hz。
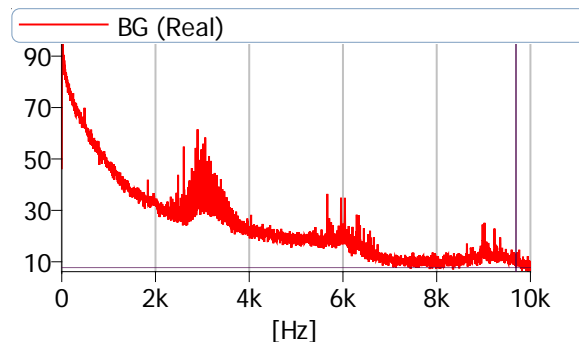

Fig.3 Spectrum of wind tunnel noise

As shown in figure 3，Experiment records the noise of different axial, circumferential and radial positions of each measuring point, for example，basic characteristic of the noise spectrum is analyzed，which freely choose 6 tip speed ratio, 60 cm axial position, 140 circumferential degrees, point 6.
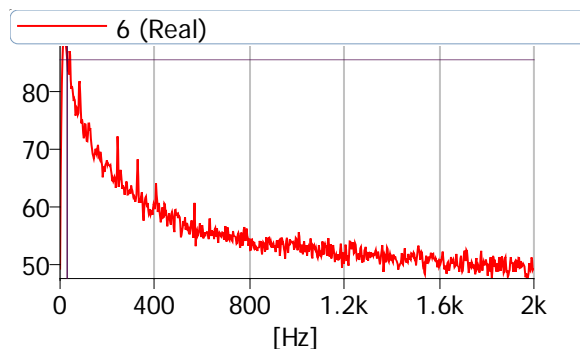

Fig 4 Noise frequency spectrum of measurement point 6 in 140 angle λ=6，d=60cm

By analyzing the above spectrogram, the noise energy of wind turbine mainly concentrates below 600Hz, the fundamental frequency of wind wheel rotation is 37.5Hz in this condition，and the spectrogram peak of wind wheel noise appears respectively at where the fundamental frequency is 37.5Hzas well as the harmonic relationship is 75Hz、112.5Hz、150Hz、187.6Hz. The results show

that the noise of these frequencies is caused by wind wheel rotation. The noise of this experimental wind turbine′s distribution is relatively wide in the frequency domain. From the perspective of energy distribution, the noise of the fan plays a dominant role in the low frequency and the main noise is vortex noise in the median and high frequency. In addition, the energy has the trend of decrease with the frequency increases. Vortex noise in the high frequency has not the characteristics point of obvious peak, is a kind of broadband noise, is caused by interaction between the blade and inflow turbulence leading to vortex and it is related to the rotating speed of blade, the airfoil section and the turbulence intensity.

3.2. The analysis of sound level

The author takes the tip speed ratio 5.5, axial 90cm test section as an example to explain. It is presented in Figure 5 that there are 8 test points named sequentially 1-8 in radial distribution.
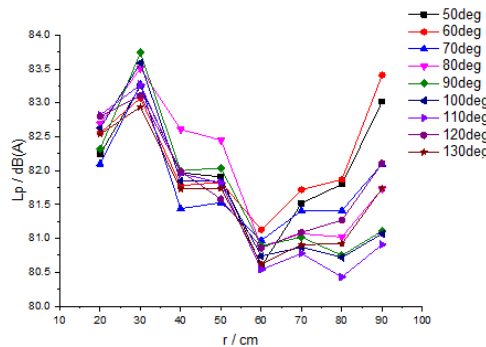

Fig.5 Sound pressure level of different point in λ=5.5，d=90cm

The measuring points 1, 2, 3 respectively located in the hub, the center of vortex and the area which attachment vortex influenced, and there is a noise peak at measuring point 3; in addition, the measuring points 4, 5, 6 respectively located in the area which tip vortex influenced, and the noise value in test point 6 is higher than test point 5; the sound pressure level at measuring point 7,8 which is outside radius increased continuously. The noise in the middle of blade is higher than the tip of blade. According to the previous research shows that it is because the aerodynamic load in the middle of blade is higher than that of tip, and the pressure fluctuation produced by the middle of blade is stronger than the tip of blade, so that the radiation noise appears uneven distribution along the radial. According to the generation and propagation law of tip vortex, the tip vortex fell off after their own rotated around the vortex core center simultaneously it is also around the wind turbine rotation axis move to the downstream at a certain helix angle and the wind turbine rotation reverse the spiral motion. The test section is 90cm away from the wind turbine rotation center , which inevitably affected by the upstream tip vortex spreading, causing the sound pressure level at measuring point 7, 8 outside blade radius increased. Because of the complexity of the upstream vortex structure propagation, the distribution of the sound pressure level at measuring points 7, 8 of the section in different testing rotation angle is dispersed, in contrast, the measuring point in sound pressure level distribution of the section which is located in the center of the vortex and the area influenced by tip vortex effects in different rotation angle is concentrated.

4. Conclusions

This paper, by using PULSE noise test system, analyzes horizontal axis wind turbine wake sound field characteristics and preliminarily draws the following conclusions:
● In near wake of the rotor, Low frequency is based on the rotation of the baseband and harmonics. The harmonic components generated by the rotor rotating is inspired with the increase of harmonic frequency and sound radiation energy gradually reduces. Through analysis of the sound pressure level finds that the middle of the blade noise is whole higher than the tip of the blade. Because the middle of the blade aerodynamic load and pressure pulsation are stronger than the tip of the blade. On the other hand, the spread of upstream to downstream vortex structure development will affect test section and leads to the uneven along the radial distribution of noise.

- Noise analysis found that there exist the characteristic obvious three different areas in the test section. Combined with the experiment results and previous research show that the three areas are mainly influence on the center of vortex and the tip vortex as well as the free diffusion, with the increase of the radius of the test.
- The experiment preliminarily explored noise radiation law on the horizontal axis wind turbine near wake aerodynamic and provides a reference for further research for wind turbine noise control.

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