Research Status of Wind Turbine Aerodynamic Noise

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ABSTRACT: The research status of wind turbine aerodynamic noise is summarized. Firstly, summarizes the generate cause of the wind turbine aerodynamic noise. Secondly, from the study of the theory, experimental studies and numerical calculation research of the wind turbine, and emphasizes explain the method appliance of experiment and numerical calculation research. Finally, the optimization design method of wind turbine aerodynamic noise is discussed, and summarizes the development trend in research of wind turbine aerodynamic noise. It laid the foundation for vertical axis wind turbine aerodynamic noise in research.
KEYWORD: Vertical Axis Wind Turbine; Aerodynamic Noise; Noise Optimization

1 INTRODUCTION

As the consumption of non-renewable energy and the environment worsening, the use of renewable energy obtained people's attention, wind energy is a clean and renewable energy, in order to deal with such outstanding problems as the energy crisis and environmental deterioration, China has developed a strategic action plan for energy, it points out that focus on optimization of energy structure, and the proportion of wind energy in the overall energy increased significantly by 2020.

Wind turbines conversion of wind energy into electricity, according to the Angle between the generator main shaft and the ground can be divided into horizontal axis wind turbines and vertical axis wind turbines. Vertical axis wind turbines has the following advantages: it needs less space when running, easy to installation and maintenance; No Windward rudder and can accept any direction wind; low Start-up wind speed. Therefore, it was popularization and application in the urban and rural in recent years, however, with the small vertical axis wind turbine promoting, its produced some disadvantages by the attention of people, its noise problems become one of the main causes to limit its popularization and application, people live for a long time in this environment has serious detriment to their physical and mental health. Small vertical axis wind turbine divided into mechanical noise and aerodynamic (pneumatic) noise when rotating, mechanical noise generated by vibration that natural wind effects on the wind turbine structure .also generator rotor cutting Magnetic line and generated noise, wind turbine is mainly refers to the air flow and blade interact to produced. Aerodynamic noise is more complex compared with the mechanical noise and involved in a wider frequency range. Small vertical axis wind turbines in normal conditions, the aerodynamic noise plays a decisive role, therefore, analyze the generating mechanism of aerodynamic noise is theoretical basis to reduce the overall noise of the wind turbines.

2 THE SOURCE OF WIND TURBINE AERODYNAMIC NOISE

Wind turbine aerodynamic noise is caused by fluctuating pressure changes that fluid and wind turbines interaction, mainly includes the rotation noise and vortex noise. Rotation noise, also called discrete noise, is a periodic harmonic noise, the spectrum is components of each order harmonic of the rotor rotation frequency, and decreased with increasing order of the sound pressure level, usually dominant in the low frequency part of the spectrum. Vortex noise, also called broadband noise, the frequency spectrum is continuous distribution, usually smaller than the rotation noise of sound pressure level, mainly distributed in the high frequency part of the spectrum. The characteristic of noise spreed in air is low frequency noise attenuation slower in the transmission, high frequency noise is attenuated fast in the transmission.

Rotation noise generate mainly has the following reasons: (1) wind turbine impeller rotates and flap surrounding fluid periodically, the fluid pulsation

pressure change; (2) in the wake of the fluid pressure and speed significantly lower than the surrounding fluid, the nonuniform noise fluid pulsation pressure change; (3) the periodic rotating vertical axis wind turbines and wind speed changes in wind turbine generate unceasing change of lift and drag of the blades, then fluctuating pressure change; (4) on the opposite side of the blade pressure is different, the same place every time after blades, a pressure change. Vortex noise generate mainly has the following reasons: (1) blade surface turbulent boundary layer, lead to pulsation pressure change; (2) when accumulated to a certain degree of the turbulent and vortex will fall off, lead to pulsation pressure change.

3 RESEARCH METHODS OF WIND TURBINE AERODYNAMIC NOISE

There are many Wind method to research turbine aerodynamic noise, the research also have different methods even from the same point of view. Based on the classification of the research methods, mainly divides into theory research, experiment research and numerical calculation. Thus, from these three aspects of wind turbine aerodynamic noise research methods and advances analyzed and summarized.

3.1 *Theory research of Wind turbine aerodynamic noise*

In 1952, the French mathematician Lighthill in order to solve the problems of large civil aviation engine jet noise, he deduced Lighthill equation, and marked the beginning of modern pneumatic, but this equation cannot be used in the conditions of solid boundary decided. Curle use Kirchhoff method to generalize the Lighthill equation to consider the effect of stationary object solid boundary, and get Curle theory, but did not involve the acoustic problem of solid boundary and fluid interaction. Lowson study the sound field characteristics in a free space of a moving point, then the result is directly used to established helicopter rotor noise model. In 1969, Ffowcs Williams and Hawkings use the theory of generalized function method promote Curle theory to the border of the movement's influence on the sound, get FW-H equation, the equation is as follows.

$$\frac{\partial^2 p'}{\partial t^2} - c^2 \frac{\partial^2 p'}{\partial x_i^2} = \frac{\partial^2}{\partial x_i \partial x_j} T_{ij} - \frac{\partial}{\partial x_i}[p_{ij}\delta(f)\frac{\partial f}{\partial x_i}] + \frac{\partial}{\partial t}[\rho_0 v_i \delta(f)\frac{\partial f}{\partial x_i}] \quad (1)$$

The right of Equation (1) represent sound source, such as quadrupole source, dipole source and monopole sound source, through further study the total sound power of monopole, dipole and quadrupole source in direct proportion to velocity of the fourth, six and eight power. Later, Farassat transfer the integral form of FW-H equation, and was successfully used in prediction of helicopter rotor and Plasma fan noise near field and far field. Amiet given up power density spectrum expression of far field of wing according to the number characteristics of turbulence, in 1993, Lowson had corrected the model of Amiet, given the wind turbine noise prediction model of rotating turbulence according to turbulence noise model of wing.

Theory of wind turbine aerodynamic noise prediction method mainly includes theoretical models to predict and semi-empirical formula to predict.

Aerodynamic noise Models theory to predict

Theoretical model do some assumptions to established model on the premise of guarantee the basic laws of physics constant , it solved based on analyze wind turbine flow field and acoustic field. Crighton hypothesis wind turbine trailing edge noise into a series of vortex through an infinite long plate edge, and established theoretical prediction model of wind turbine based on the hypothesis. Xin H.S. had analyzed the mechanism of small wind turbine aerodynamic noise, focusing on analysis and comparison rotation noise and vortex noise, finally he concluded that rotation noise sound power increase 15dB-20dB when circumferential speed double, The vortex noise is cause by vortex and blade pressure pulsation that vortex separated .

The semi-empirical formula 0f aerodynamic noise to predict

Semi-empirical formula is established on the basis of experiment, through a large number of experimental data analysis, summarize the general law, and fitting the data to find the corresponding formula model. Grosveld is proposed for prediction method of large horizontal axis wind turbine broadband noise, the principle is based on the semi-empirical model of wind turbine measurement of sound science, it good for forecast and measure the far-field noise. Li Y.L. who domestic proposed turbulence noise semi-empirical formulas on the basis of combining Amiet, and predicted to wind turbine aerodynamic noise models of the AOC-15/50, prediction results is matching measured results. Si H.Q. through research a semi-empirical mode low wind turbine aerodynamic noise, the model put turbulent flow noise and fan blade airfoil autoexcitation noise superposition, the total sound pressure level of wind turbine is obtained, finally verified effectiveness of the semi-empirical model by experiment.

The Research of Aerodynamic noise theory heavily promoted the development of field of pneumatic noise, and laid the foundation for the study of the wind turbine aerodynamic noise, made it possible for the design of the low noise of wind turbine.

3.2 *Study of the aerodynamic noise test method of wind turbine*

The Research of Wind turbine aerodynamic noise mainly concentrated in the experiment of wind tun-

nel test, it mainly measure the flow field and acoustic field. The test of the wind turbine noise measure the wind turbine noise spectrum use the microphone, get the components of noise through analysis frequency spectrum, Brooks studied using the method of multi-point measurement of microphone on airfoil aerodynamic noise, found that broadband noise is priority of airfoil aerodynamic noise, and arise the pure tone noise. In addition, that collect aerodynamic noise of wind turbine use the microphone array technology, Gwang-Se L. use 42 microphones form matrix, to measure the mainly part emergence of wind turbine aerodynamic noise under the rated conditions of main parts, Pearson conduct low speed wind tunnel test of small H vertical axis wind turbines when considering blocking ratio is below 14%, the results show that the broadband noise is the largest contribution to the noise spectrum. Gao Z.Y. through the experiment to research wake flow of s-shaped blade tip and aerodynamic noise characteristics of wind turbine, found that winglet is able to reduce the pressure pulsation of blade tip, reduce the noise radiation.

At present, due to the complexity test environment of wind turbine, so the experiment of wind turbine aerodynamic noise also has certain difficulty, it can't completely avoid mechanical noise impact on the aerodynamic noise in the measurement, the measurement of the aerodynamic noise is more difficult.

3.3 *The calculation research of wind turbine aerodynamic noise*

With the improvement of computer hardware quality and rapid development of computational fluid dynamics(CFD), the numerical method of aerodynamic noise is widely used. Through Rec(Reynolds number)judge the fluid sate, the Rec number is2000~ 3000, it is turbulence when more than Rec and laminar flow when less than Rec, the formula (2) is the formula of Reynolds number.

$$\mathrm{Re} = \frac{\rho v l}{\mu} \tag{2}$$

Type: ρ as the fluid density, as the fluid velocity, l as the characteristic length, μ as the coefficient of viscosity.

Flow field is calculated by use CFD to solve the continuity equation of fluid and not closed N-S equations for velocity field and pressure field, and then calculate sound field, the maximum frequency of acoustic field calculation relate to the calculation step length setting, formula (3) as the maximum frequency calculation method, f is the maximum noise frequency, $\triangle t$ as the calculating step length. Finite difference method, finite volume method, finite element method and boundary element method is a common method of computational fluid. Finite volume method is control volume that divided computation area into a series node which representative, through integration of the control volume of conservation governing equations to reduce discrete equations, the discrete equation that educed by finite volume method can ensure conservation of characteristics, and the physical meaning of coefficients is clear, it is most widely used way to solve the fluid problem.

$$f = 1/(2\Delta t) \tag{3}$$

The flow is turbulent state When Wind turbine Normal work, the main methods solving continuous equation and navier-stokes equations are Reynolds time-averaged (RNS), large eddy simulation (LES) method and the direct simulation (DNS) method. Sanghyeon Kim method use Reynolds time-averaged, navier-stokes equation and FW-H equation to analyzed flow field of S type small wind turbine, it conclude that aerodynamic noise is consists of blade through frequency noise and the noise of vortex shedding, and use that conclusion conduct low noise design to blade, make aerodynamic noise reduce 2.7 dB. Gao Y.W. deduced the blade surface strong vortex method, the vortex lattice method was improved, using the same grid with aerodynamic calculation, quickly solve the acoustic characteristics of the far sound field, and the validity of this method is verified by experiment. Xu J.W. is analyzed and compared three kinds of numerical methods for calculating aerodynamic noise, they are common method to calculating aerodynamic acoustics, Lighthill sound analogy method and mixed method, and through these three methods of application example to illustrate the advantages and disadvantages of each method as well as the conditions for application, it is concluded that, Lighthill acoustic analogy method to predict is more accurate than the CFD software on far sound field of aerodynamic noise, but big error for the near field noise; mixed calculation method to predict the aerodynamic noise in engineering is closer to real, but cannot apply this method to high-frequency aerodynamic noise.

The numerical method can accurately capture the flow field and acoustic field, and can be show intuitive, but its high requirement for the quality of the grid, computation quantity is big, the key is choose the appropriate grid scale and model on numerical analysis. Along with the improvement of calculation method and computer hardware, the numerical method can become the main method of analysis wind turbine aerodynamic noise.

4 OPTIMIZATION RESEARCH OF WIND TURBINE AERODYNAMIC NOISE TEXT AND INDENTING

The goal of research Wind turbine aerodynamic noise is design low noise wind turbines, the aerody-

namic noise influenced by rotor parameters and working conditions, optimized design reasonable for wind turbines, can reduce the aerodynamic noise of wind turbines.

Kim reduce the aerodynamic noise through changing the blade Angle to rotation axis of S type wind turbine, but this method has limitations, need to repeat modeling, and has certain blindness, Li C.F. research the effect of wing trailing edge flap parameters to performance through introducing orthogonal design of experiment, the orthogonal experiment decreases the number of analysis experimental group, but its optimal solution is provided by the experimental data of some combination, can't provide clear direction for further optimization. In order to simplify Tedious modeling in optimization, Yi Z.J. using differential and the arc length that through center to solve the corresponding horizontal axis, and then use SolidWorks macro recording to design parametric program of Blade section, and realize blade airfoil can be automatically drawn, using the semi-empirical model to predict the aerodynamic noise, Powell method is used to optimize the NACA0012 airfoil.

5 SUMMARY

In summary, wind turbine pneumatic studied more both at home and abroad, has made remarkable achievements in experimental and numerical calculation, but relatively few in the wind turbine aerodynamic noise, and most of them concentrated in the study of large horizontal axis wind turbine. With the promotion of small vertical axis wind turbine, the Pneumatic noise problems will be attracted widespread attention, so proposed reasonable theoretical prediction model, experimental method and numerical calculation method on small vertical axis wind turbine have great significance to the design of the low noise small vertical axis wind turbine.

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