Study on Model of Fans with Uneven Blade Spacing

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Abstract. We established the CFD simulation model of unequal and equidistant blades in the paper, the pneumatic performance of fan was tested and the aerodynamic performance and aerodynamic noise of the model are analyzed. The differences between the simulation data and the experimental data are small, indicating that this simulation model is consistent with the actual situation.

1. Introduction
When the position of the z-2 blades was arbitrarily determined and the remaining two blades will be obtained by solving the equilibrium constraint equations. Multiple objective functions based on radiation power were designed, and each objective function was optimized, finally the optimal circular distribution of the blade was obtained by calculating the minimum threshold of noise for the most suitable objective function. Based on the calculation of impeller discrete noise, Sun xiaofeng[1] discussed the influence of axial flow fan unequal distance blade on fundamental frequency noise. According to The BLL theory of S.E. Wright[2] he derived the acoustic radiation formula for unequal distance fans. Xu jiafu[3] applied the design of the blade's unequal distance to the motor fan and explored the influence of the blade's different spacing and arrangement on the harmonic strength. He also analyzed the noise reduction mechanism of the unequal distance fan, and designed the fan blade spacer angle that makes the sense noise PNL minimum.

2. Model building
The research object of this paper is an unequal pitch 7-blade fan, and an isometric blade fan. The circular angle parameters of equidistant and unequal blades are shown in table 1. The unequal distance fan diameter is 490mm, the hub diameter is 180mm, the maximum operating speed is 3500rpm, and the working flow area is between 0m³/s and 4m³/s. The model software UG is used to model the wind pipe test bed of the unequal fan and equal fan in 3D. In order to ensure the simulation accuracy, the cross-sectional size of the model inlet and the position of the static pressure interception surface should be strictly established according to the test device. The length of the inlet part does not need to be completely consistent with the test equipment, it is only necessary to avoid the fan's influence area, so it takes 4.9 M. The exit of the experiment is free, so the exit part should be large enough to ensure that the fan affected area is avoided. The length of the exit area is 6m and the diameter is 6m and the structure diagram is shown in figure 1. According to the flow field characteristics of the pipeline inlet to the free exit and the flow distribution law of the area near the fan, the fluent model includes: the import pipeline, the transition zone and the free exit zone. The blade surface of the fan is divided into small size grids, while the fan hub is transitioned with large size grids as shown in figure 2. In order to
capture the complex vortex flow around the fan, a suitable size rotation area is established in area 4, because the tip vortex, separation flow, etc. mostly appear at the tip of the leaf. In order to better capture the complex flow field information at the tip of the leaf, the mesh of tip and rotating area should be refined. In order to ensure the accuracy and reduce the calculation period, according to the rule of streamline distribution, the hexahedral mesh division is used to divide the inlet area and the exit area, and the tetrahedral grid division is used to divide the transition area. Using Hypermesh software for grid division, the entire pipeline flow field grid model is shown in figure 3, with a total of 1.36 million grids. The sharing of tetrahedral and hexahedron grids can be used to define inconsistent grid boundaries in Fluent software so that different types of grids can be combined and simulated air flow can pass through, thus satisfying the software's computational requirements. The fan flow field established in this paper belongs to the category of low speed pressure. Therefore, the CFD calculation of fan performance uses the SIMPLE algorithm[4], the RNG turbulence model[5], and the CFD calculation of fan noise uses the PISO algorithm[6].

The mesh division of equidistant fan, the establishment of CFD simulation model, the parameter setting and method of calculation are all consistent with the unequal distance fan. Except for the angle between the blades, other parameters including diameter and leaf type are the same as those of the unequal distance fan. The specific vane circumferential angular parameters are shown in table 1.
Table 1. Peripheral angles of equidistant and unequal leaves

|          | Peripheral angle(°) of equidistant fan | Peripheral angle(°) of unequal distance fan |
|----------|---------------------------------------|---------------------------------------------|
| blade 1  | 51.4                                  | 53.5                                        |
| blade 2  | 102.9                                 | 103.5                                       |
| blade 3  | 154.3                                 | 149.5                                       |
| blade 4  | 205.7                                 | 210.5                                       |
| blade 5  | 257.1                                 | 256.5                                       |
| blade 6  | 308.6                                 | 306.5                                       |
| blade 7  | 360                                   | 360                                         |

3. Performance test of fan and its equipment

In this paper, the pneumatic performance of the equidistant and unequal fan is tested by the wind pipe test stand as shown in figure 4. The device is mainly composed of test pipe, flow load plate, drive motor and sensor, etc. Among them: conical inlet 1 and flow loading board 2 change the import flow Q(m3 / s) by changing the flow area of the loading board; Rectifying grille 3, 5 has the effect of stabilizing air flow; Pressure gauges 9 and 10 are used to measure the static pressure at the entrance of the test pipeline and at the monitoring surface P_{sp} (Pa); The drive motor 8 gives a different fan speed n(r/min); Speed, torque sensor 7 measures the speed and torque value T(N·m) under the current operating conditions of the driving motor.

![Figure 4. Structure diagram of wind pipe device](image)

During the test, by changing the flow area of the flow loading plate to control the inlet flow and the system impedance, the three performance indicators of fan static pressure, shaft power and static pressure efficiency can be obtained. The static pressure of the fan is read out by the pressure gauge at the monitoring surface. The shaft power and static pressure efficiency of the fan are obtained according to the following formulas\[7,8,9\] (1) and (2):

\[
P = \frac{Tn}{9550} \quad (T \text{ is torque; } n \text{ is speed.}) \tag{1}
\]

\[
\eta_{st} = \frac{qP_{sp}}{1000P} \times 100\% \quad (P_{sp} \text{ is Static pressure, } q \text{ is flow.}) \tag{2}
\]

4. Analysis of results

The pressure monitoring surface is set up in the finite element model. After the calculation reaches steady state convergence, not only the monitoring surface static pressure value obtained after 2000 iterations of the simulation model is read, but also the average value of the import and export flow of the wind pipe model, and the stable value of the rotation shaft torque. By formulas (1) and (2), we can calculate the CFD aerodynamic performance parameters of the unequal distance fan. The simulation and test parameter comparison diagram of the aerodynamic performance of the unequal distance fan
(figure 5) is obtained by comparing the experimental data of the static pressure, axial power and static pressure efficiency of the unequal distance fan and the simulation data.

![Figure 5. Simulation and experimental performance curve of unequal distance fan](image)

According to figure 5, with the increasing of the inlet volume flow, the static pressure of the unequal distance fan is reduced, while the axial power change is relatively stable and slow, and the variation of the static pressure efficiency is increased first and then reduced. The maximum static pressure efficiency of the unequal distance fan is 28.67 %, which is located near the volume flow point 2.13 m³/s, so the working flow point of the unequal distance fan is 2.13 m³/s. At the fan working flow point, the errors of static pressure, shaft power and static pressure efficiency were -3.04 %, 4.37 % and -4.46 %, respectively. In short, the errors between the simulation data and the experimental data are small, indicating that this simulation model is consistent with the actual situation.

5. Conclusion
The numerical calculation of the unequal-distance fan is carried out, the simulation model of the unequal-distance fan is established, the model is divided into grids, and the simulation calculation begins after the model is set up, the simulation results are compared with the test results. The comparison between the calculated and experimental data shows that the CFD simulation method has a high accuracy and the error is less than 4% , which proves the feasibility of using CFD method to predict the aerodynamic noise of fans. The finite element model and simulation method of Fan aerodynamic noise provide the foundation for the prediction and research of fan aerodynamic noise.

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References
[1] Sun X.F. (1986) Study on Aerodynamic Acoustic Characteristics of Fan with Unequal Pitch. Journal of Beijing University of Aeronautics and Astronautics., 4:144-152.
[2] Wright S.E. (1969) Sound Radiation from a Lifting Rotor Generated by Asymmetric Disk Loading. Journal of Sound and Vibration., 9: 227-226.
[3] Xu J.F. (1987) Discussion on Fan Motor with Unequal Distance Blade. Motor Technology., 1:9-12.
[4] Li H.Z., Sun J. (1989) Research on Calculation Method of Transmission Torque of Silicone Oil Fan Clutch. Journal of Internal Combustion Engine., 7: 45-52.
[5] Yang W. (2003) Analysis and Practice of Using Methyl Silicone Oil as the Thermostatic Bath Liquid for Measuring the Kinematic Viscosity of Oil. Diesel Locomotive., 3: 35-36.
[6] Huang X., Wei X.H., Li W.R. (2012) Calculation Method of Viscosity Blending of Dimethyl Silicone Oil. Guangzhou Chemical Industry., 19: 34-35.
[7] Ma J.F., Yuan M.J., Liu Q.H., etc. (2008) Numerical and Experimental Study on Aerodynamic Noise of Centrifugal Fan with Unequal Distance. Noise and Vibration Control., 28:100-103.
[8] Wu D.Z., Zhao F., Yang S., etc. (2015) Numerical Study on the Influence of Blade Distribution on Pneumatic Noise of Miniature Fans. Fan Technology., 57:20-25.
[9] Liu Z.C., Kong F.Y., Wang Y., etc. (2017) Effect of Non-equidistant Blade Distribution on the Pressure Pulsation of Vortex Self-suction Pump. Journal of Drainage and Irrigation Machinery Engineering., 35:113-118.