ISSN: 2414-1895 DOI: 10.6919/ICJE.202004_6(4).0005

Analysis of Aerodynamic Noise Characteristics of Forced Air-conditioning System of Motor

Zhiqiang Huang[a], Weichao Zhang[b]

Southwest Petroleum University, Mechanic and Electronic Engineering, Chengdu 610000, China.

[a]huangzq@swpu.edu.cn,[b]1239614834@qq.com.

Abstract

In order to study the aerodynamic noise characteristics of the forced air-conditioning system of the motor, the three-dimensional numerical simulation of the flow characteristics of the motor is carried out by using computational fluid dynamics technology, and the large eddy model and Lighthill acoustic model are used to carry out the numerical simulation analysis of the acoustic field characteristics of the motor. The results show that there are a lot of unsteady flow in the shroud, which is the main reason of aerodynamic noise. By analyzing the flow characteristics and aerodynamic noise characteristics, it is found that the main noise area lies between the leading edge of the centrifugal fan blade and the inner wall of the shroud. The energy is mainly concentrated in the frequency range of 450-3000 Hz, and the main order is 1-9. Based on the theory of energy contribution rate, it is estimated that the power contribution of eddy current noise is 98.7%, which is the main noise source.

Keywords

Aerodynamic noise; Order analysis; Order contribution rate.

1. Introduction

Aiming at the problem of motor aerodynamic noise, scholars at home and abroad have done a lot of research in the aspects of motor aerodynamic noise characteristics, noise source, propagation path and noise reduction through the combination of numerical simulation and test [1]. Zhang Yadong [2] et al. Took the vehicle alternator as the research object, studied its aerodynamic noise characteristics with the sliding grid technology and large eddy simulation method, and optimized the aerodynamic noise design and noise reduction analysis for the radial grid distribution angle of the front cover. Kang Qiang [3] and others calculated the internal flow field and far-field aerodynamic noise of the vortex fan of the fuel cell vehicle by using the computational fluid dynamics CFD and the finite element method. It provides a certain basis for vehicle layout and noise reduction. Lee [4] uses CFD to calculate the overall performance and local flow field of the axial-flow fan, taking the pressure rise and efficiency as the main response, and discusses the main influence of design parameters on the response. Kim [5] simulated the aerodynamic noise of the fan with the method of combining test and simulation, put forward the noise reduction method of notching along the direction of rotation on the suction side surface of the blade, and evaluated the influence of these design factors on the noise of the axial cooling fan through numerical analysis. Shao Wei [6] and others used CFD to analyze the aerodynamic noise of a construction machinery motor model, and found that the original structure of the wind guide cover is unreasonable, so as to optimize its structure, and the noise reduction effect is obvious. Zhang Jianhua [7] et al. Predicted the noise radiation of a centrifugal fan by using the FW-

ISSN: 2414-1895 DOI: 10.6919/ICJE.202004_6(4).0005

H equation. Through analysis, it was found that the impeller outlet in the volute tongue area was the most important noise source area.

The study of aerodynamic noise at home and abroad provides a reference for the flow field and noise analysis of forced air-conditioning system. In this paper, the outlet box outside the enclosure is simplified and the fluid domain finite element model is established without affecting the sound field. CFD is used to calculate the flow field distribution of the motor model, and FW-H equation is used to calculate the aerodynamic noise, which is compared with the measured value. The research results can provide a theoretical basis for understanding the aerodynamic noise produced by the forced air-conditioning system.

2. Analysis of motor aerodynamic noise characteristics

2.1 Establishment of numerical model of motor aerodynamic noise

The forced air cooling system of the motor mainly includes cooling fan, air guide cover and other components, and the basic parameters are shown in Table 1. According to the two-dimensional drawings provided by the manufacturer, the three-dimensional model of the motor is established by drawing software. Neglecting the thickness of the motor shell, a cylindrical fluid domain model is established, which is 4 times of the characteristic length of the motor.

Table.1 basic parameters of motor cooling fan and wind guide hood for vibroseis

Fan		Air guide hood	
Fan diameter /mm	Leaf number	Diameter /mm	Diameter of circular air inlet /mm
420	9	617	300

By using Boolean operation, the final fluid domain model is obtained by subtracting the volume of rotating domain from the volume of fluid domain. The relative motion of the rotating part and the stationary part is realized by using the sliding grid technology. The model of the rotating domain and the fluid domain of the fan is shown in Figure 1.

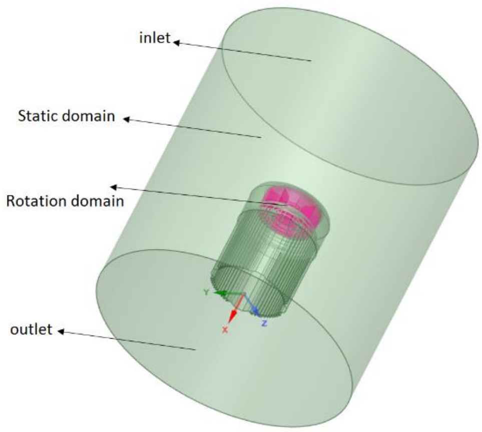


Fig.1 Computational domain model

Due to the small volume and complex structure of the calculation domain, in order to reduce the calculation time and obtain more accurate results, unstructured grids are used in the calculation domain. In order to select the appropriate grid size, the calculation accuracy, hardware equipment and calculation time are comprehensively considered through the comparison between the grid cell size setting value in the previous literature [8-9] and the actual setting calculation. Finally, the cell size is determined as 5 Mm, the mesh division results of the calculation domain model are shown in Figure 2.

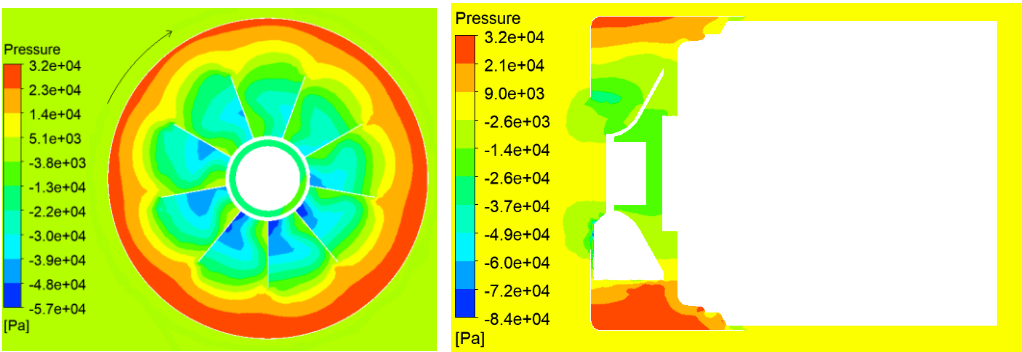
ISSN: 2414-1895 DOI: 10.6919/ICJE.202004_6(4).0005

Fig.2 Computational domain grid

2.2 Analysis of calculation results

2.2.1 Analysis of flow field characteristics

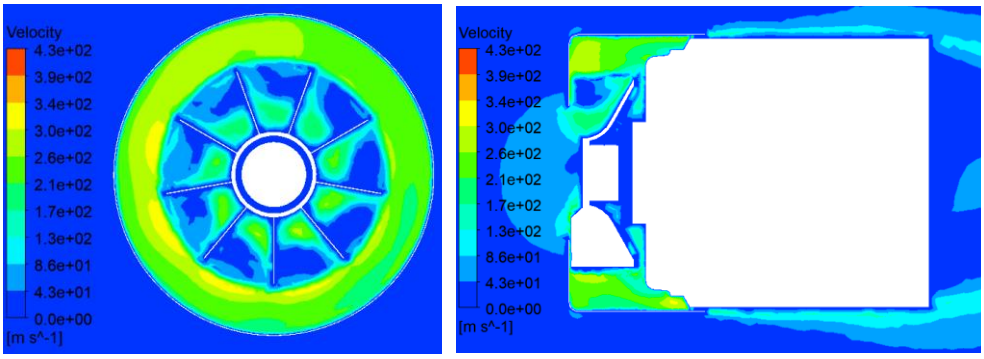
Fig. 3 is the result of pressure distribution. According to Fig. 3 (a) of cross section pressure distribution, the pressure distribution is petal shaped, which is caused by the unique working properties of full radial centrifugal fan. When the centrifugal fan is working, the gas is drawn in from the axial direction, and the centrifugal force is used to throw it out from the circumferential direction. There is a wake at the leading edge of the leaf, so the petal type pressure distribution is formed. From the pressure distribution Cloud Figure 3 (b) of the central section, it can be seen that there is a pressure gradient in the drainage basin inside the wind guide hood, which rises rapidly from the negative pressure area to the positive pressure area, and the pressure change area is an important source of noise.



（a） Cross section pressure distribution（b） Central section pressure distribution

Fig.3 pressure distribution

Figure 4 shows the distribution of axial speed. The velocity near the outlet is large, which can cool and heat the motor components. The velocity near the gap between the fan blades and the corner of the shroud is small, and there may be large vortices here.

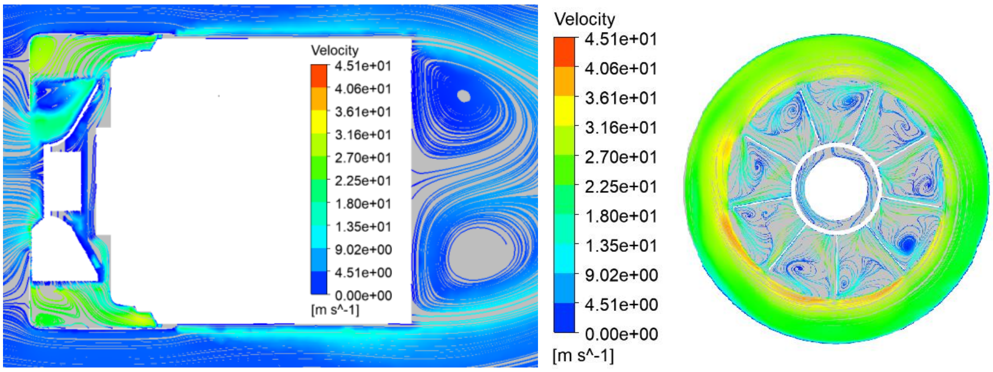


(a) Cross section distribution of velocity（b） Central section distribution of velocity

Fig.4 Distribution of velocity

ISSN: 2414-1895 DOI: 10.6919/ICJE.202004_6(4).0005

Figure 5 is the sectional streamline diagram and cross-sectional streamline diagram. It can be seen from the figure that eddy current is generated at the corner of the hood and the blade gap. This is because the centrifugal fan draws in the gas from the axial direction and then uses centrifugal force to throw it out from the circumferential direction. When the air flow is blocked, the original flow direction changes, so eddy current is formed at the chamfering of the hood. At the same time, there is a large negative pressure on the suction surface of the blade, which is easy to form eddy current at the blade gap. According to the theory of turbulent eddy current [10-11], the aerodynamic noise is closely related to the tension and fracture of eddy current. It can be seen that there are a lot of vorticity in the chamfering and blade gap of the shroud, which is one of the main sources of eddy noise in the motor model.



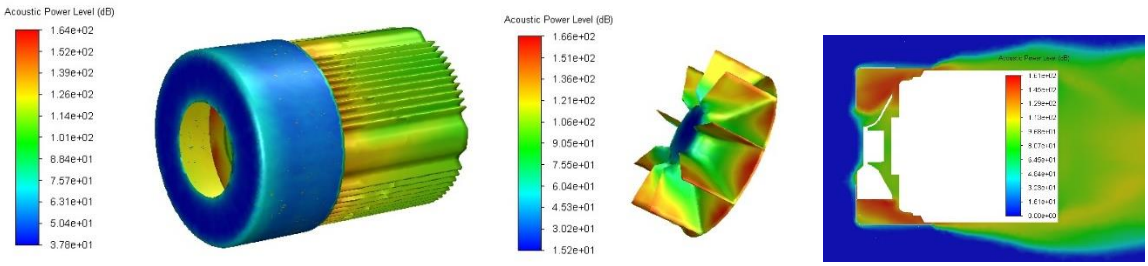
(a) Cross section sectional streamline (b) Central section sectional streamline

Fig.5 Velocity streamline

2.2.2 Analysis of aerodynamic noise characteristics

1) Analysis of aerodynamic noise source

Fig. 6 is a cloud chart of the distribution of the sound power level of the motor model. It can be seen from Figure 6 (a) cloud chart of sound power level on the surface of the wind guide cover that the dipole noise sound power level on the surface of the wind guide cover is small, and the noise source is mainly concentrated at the air outlet. This is because the structure of the air outlet is complex, and the gas mainly flows out from the gap of the radiator, which destroys the original gas flow path and easily produces gas dynamic noise. It can be seen from Fig. 6 (b) cloud chart of sound power level on fan surface that the sound power level of centrifugal fan blade is mainly distributed at the tip position of pressure surface and the hub of blade clearance. Figure 6 (c) shows the axial sound power level distribution nephogram of the central section of the motor model. The maximum noise area is mainly distributed between the leading edge of the centrifugal fan blade and the inner wall of the shroud, which is related to vortex shedding and reorganization.



(a) Surface sound power level of wind guide cover (b) surface sound power level of fan (c) center section sound power level

Fig.6 Acoustic power level of motor model

2) Spectrum analysis of aerodynamic noise

The noise measurement points are respectively arranged at the front, back, left, right and other 8 positions of the noise source, which are 1 m away from the sound source. The sound pressure level

ISSN: 2414-1895 DOI: 10.6919/ICJE.202004_6(4).0005

of each noise monitoring point in Table 2 is obtained through measurement, and the average noise value of 8 monitoring points is calculated according to formula (1) [12].

$$\overline{L}_p = 10\,\lg\left(\frac{1}{n}\sum_{i=1}^{n}10^{\frac{L_i}{10}}\right) \tag{1}$$

Where, n is the number of monitoring points, is the sound pressure value of each monitoring point, and the calculated average noise is 80.5 dB. It can be seen from the table that the noise of the monitoring points in the x-axis direction of the motor is relatively large. Therefore, this paper mainly analyzes the noise in the x-axis direction.

In the analysis of aerodynamic noise, the order analysis method is usually used. The relationship between order and speed can be expressed as [13]:

$$f_i = \frac{nZ}{60} i \tag{2}$$

Where, n is the number of fan revolutions, Z is the number of fan blades, and I is the medium. When I is equal to 1, this order is called the first order BPF (blade passing frequency). When I is an integer multiple, this order is called the first order BPF.

Table.2 Sound pressure level of each noise monitoring point

Noise monitoring point	X-axis monitoring point		Y-axis monitoring point		Z-axis monitoring point		45 °monitoring point	
	Positive	negative	Positive	negative	Positive	negative	Positive	negative
Sound pressure level	82.9	80.9	80.3	80.3	80.6	79.0	79.2	79.0

Figure 7 shows the spectrum of noise A-weighted sound pressure level of monitoring points in x-axis direction. It can be seen from the figure that the main order of the total noise of each measuring point is basically the same, which is composed of 1, 2, 5, 7 and other order components, and the amplitude of each order component is also relatively close. Due to the low speed of blade tip, the rotating noise is covered by eddy current noise, which is not prominent in the spectrum.

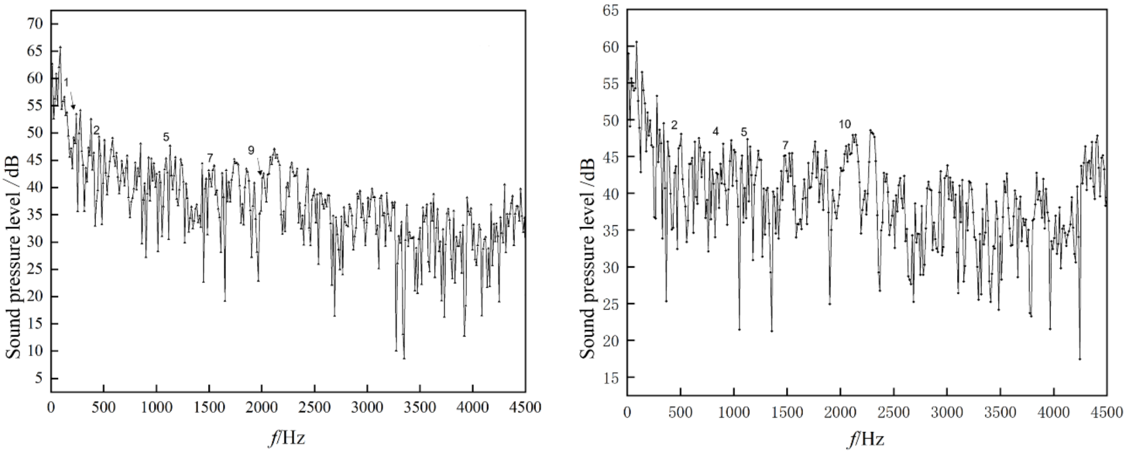


Fig.7 Sound pressure spectra of monitoring point

It can be seen from the analysis of the spectrum that the rotating noise is not prominent. In order to quantify the proportion of the rotating noise energy in the total energy of the whole frequency band, the concept of energy contribution rate is quoted in this paper [14]:

$$\eta_i = \frac{I_i}{I_A} \tag{3}$$

Where, η_iA is the energy contribution rate of the i-th order; I_i is the acoustic energy of the i-th order; I_A is the total acoustic energy of the whole frequency band. In practical engineering application,

ISSN: 2414-1895 DOI: 10.6919/ICJE.202004_6(4).0005

because the sound intensity is not easy to collect, it is generally calculated according to the relationship between sound intensity I, sound pressure P and sound pressure level SPL:

$$I = p^2/\rho c \tag{4}$$

$$SPL = 10lg(p^2/{p_0}^2) \tag{5}$$

According to formula (3) (4) (5):

$$\eta_i = \frac{I_i}{I_A} = 10^{\frac{SPL_i}{10} - \frac{SPL_A}{10}} \tag{8}$$

In the formula, $\rho c$is the characteristic impedance, which is the fixed value under normal temperature and pressure; $p_0$isthe reference sound pressure, which is the fixed value.

The contribution rate is based on the power spectrum of the x-axis forward monitoring point. Select the sound pressure level at the order frequency, and calculate the percentage of the rotating noise energy corresponding to different orders in the total noise energy as shown in Figure 8. It can be seen from the figure that the BPF contribution rate of the 1st and 2nd order is the largest, which is the main rotating noise, consistent with the actual working condition. Through calculation, the total contribution rate of rotating noise is 1.3%, and the contribution rate of eddy current noise is 98.7%. As the most important part of noise energy contribution, eddy current noise is an important part of noise reduction research, which can be optimized from the vortex concentration. Although the contribution rate of rotating noise is only 1.3%, it can not be ignored, because the rotating noise will affect the acoustic quality, so the blade design of centrifugal fan can be improved in the subsequent optimization design.

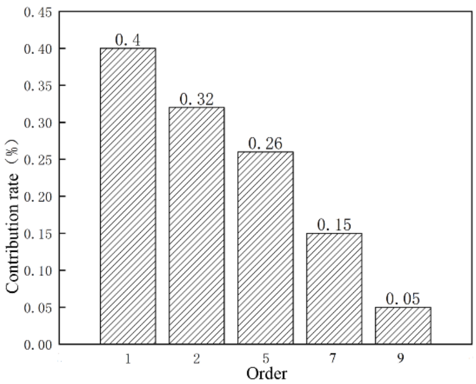


Fig.8 percentage of noise energy

3. Summary

In this paper, the large eddy simulation is used to calculate the flow field and sound field of the motor. Through the analysis, the following conclusions are drawn: there is obvious eddy flow at the chamfering and blade gap of the special motor guide cover for vibroseis. The aerodynamic noise source area is mainly located between the leading edge of the fan blade and the inner wall of the shroud. The frequency spectrum of motor far-field aerodynamic noise is wide, its main energy is concentrated in the frequency range of 450-3000 Hz, and the main order is 1-9. Based on the concept of energy contribution rate, the total contribution rate of fan order is 1.3%, and the total contribution rate of eddy current noise is 98.7%. In order noise, the first order BPF and the second order BPF are the most important.

References

[1] SHEN Yan-you, JIA Min-ping, ZHU Lin. Noise analysis of a centrifugal leaf vacuum based on Latin hypercube sampling [J]. Journal of Vibration and Shock, Vol. 35 (2016) No.15, p. 93-97.

[2] ZHANG Ya-dong, DONG Da-wei, YAN Bing, et al. Numerical simulation analysis for aerodynamic noise of a vehicle alternator [J]. Journal of Vibration and Shock, Vol. 35 (2016) No. 01, p. 174-182+187.

ISSN: 2414-1895 DOI: 10.6919/ICJE.202004_6(4).0005

[3] KANG Qiang, ZUO Shu-guang, HAN Hui-jun, et al. Experimental and simulation studies on the aerodynamic noise of regenerative flow compressor for fuel cell vehicle[J].Automotive Engineering, Vol. 36 (2014) No. 02, p.236-242..

[4] Kyoung-Yong Lee, Young-Seok Choi, Young- Lyul Kim, Jae-Ho Yun .Design of axial fan using inverse design method [J].Journal of Mechanical Science and Technology, Vol. 22 (2008) No. 10, p. 1883-1888.

[5] Taehoon Kim, Feng Gue, Cheolung Cheong. Development of low- noise axial cooling fans in a house hold refrigerator [J].Journal of Mechanical Science and Technology, Vol. 25 (2011) No. 12, p. 2995-3004.

[6] SHAO Wei, HUANG Zhi-liang, DENG Xi-shu, et al. Noise reduction study and experimental verification for the cooling system of a construction machine[J].Noise and Vibration Control, Vol. 37 (2017) No. 01, p. 113-116.

[7] ZHANG Jian-hua, CHU Wei-li, ZHANG Hao-guang, et al. Numerical investigation of unsteady aerodynamics and aero-acoustics in a centrifugal fan[J].Journal of Aerospace Power, Vol. 30 (2015) No. 08, p. 1888-1899.

[8] ZHOU Xiang. Aerodynamic noise analysis and noise reduction design of axial flow fan based on CFD/CAA[D].School of Mechanical and Electrical Engineering,China,2016,p.40

[9] YANG Wei-ping, HOU Liang, CAI Hui-kun,et al. Noise reduction of excavator cooling fan and wind scooper based on CFD[J]. Journal of Mechanical ＆ Electrical Engineering, Vol. 32 (2015) No. 05, p. 585-590.

[10] Menter F R. Two-equation eddy-viscosity turbulence models for engineering applications [J]. AIAA Journal, Vol. 32 (1994) No. 08, p. 1598-1605.

[11] Williams J E F, Hawkings D L. Sound Generation by Turbulence and Surfaces in Arbitrary Motion [J]. Trans of the Royal Society, Series A, Mathematical and Physical, Vol.264 (1969) No. 1151, p. 321-342.

[12] SUN Cheng. Numerical simulation of aerodynamic noise of axial fan based on fluid-acoustic coupling [D]. School of Mechanical and Electrical Engineering,China,2018,p.45.

[13] LIU Jian-wei, ZHANG Ya-dong, ZHANG Shu-ming, et al. Experimental and simulation analysis for aerodynamic noise of an EMU traction transformer cooling fan[J].Journal of Mechanical engineering, Vol.55 (2019) No. 24, p.153-161+171.

[14] ZHANG Hai-bing, JIANG Wei-kang, WAN Quan. Experimental investigation on noise radiation characteristics of an urban transit train at moderate and low speeds [J]. Journal of Vibration and Shock, Vol.29 (2010) No. 11, p.83-86.