Experimental and numerical analysis on noise reduction in a multi-blade centrifugal fan

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Abstract. In this work, analysis on noise source and reduction in a multi-blade centrifugal fan used for air-conditioners was carried out by experimental and numerical methods. Firstly, an experimental system using microphone mounted on volute surface for measuring surface pressure fluctuations of volute was designed and introduced, then surface pressure fluctuations of the whole volute for a multi-blade centrifugal fan were measured by this system, and the inlet noise for this fan was also obtained. And then, based on the experimental results, the aerodynamic noise source of the studied fan was analysed. The surface pressure fluctuations of the volute showed that there were largest surface pressure fluctuations near the volute tongue, and peaks appeared at the Blade Passing Frequency (BPF). The spectra of fan inlet noise showed that the peaks also appeared at BPF, and noise levels in a wide range of frequency were also larger. Secondly, the internal flow of the fan was simulated by commercial software under the same conditions with the experiment, and then the fluid flow and acoustic power field were obtained and discussed. The contours of acoustic power level showed that the larger noise was generated at the impeller area close to the outlet of scroll and at the volute tongue, which is same as that from experiment. Based on all of the results, we can find that the vortex noise is an important part of fan noise for the studied fan, and the rotation noise also cannot be neglected. Finally, several reduction methods that are thought to be effective based on experimental and numerical results were suggested.

1. Introduction

The quality of air conditioner is very important for people’s life, which should not only meet to the requirement of temperature and humidity of environment but also generate as small noise as possible when it works. The multi-blade centrifugal fan is widely used in the air conditioner system because of its smaller size and lower noise level. Since the multi-blade centrifugal fan is the main source of aerodynamic tonal noise in the air conditioner system, it is necessary to study the noise source of the fan and to reduce the noise.

Many numerical simulations and experimental analysis on noise reduction for the multi-blade centrifugal fan have been done. Technology of one step-tongue volute was introduced and applied to a centrifugal fan for discharging lampblack by Li D and Gu JM, and by simulation analysis, they found that the impact of airflow on volute tongue was weakened by the step-tongue and the step-tongue volute was effective to reduce the fan noise [1]. Qin GL investigated the noise and performance of one multi-blade centrifugal fan equipped with inclined volute tongue by experiment method, and the results showed that the inclined volute tongue was very effective to reduce the rotation noise of centrifugal fan [2]. Sandra VS studied the effects of the geometry and position of volute on the noise
of a forward-curved centrifugal fan, and the volute geometry to reduce the aerodynamic tonal noise of the fan with the same performance was obtained [3].

The pressure fluctuation of volute surface is main source of the aerodynamic noise of the centrifugal fan, which was used to analyze the position and type of the noise source [4-6]. Pressure fluctuation measurements on the volute surface and acoustic pressure measurements at the fan exit duct in a centrifugal fan with backward-curved blades were made in reference [6]. A correlation study of both pressure signals showed that a strong source of noise was mainly caused by the interaction between the fluctuating flow leaving the impeller and the volute tongue. However, there is little study on noise analysis for a multi-blade centrifugal fan with forward-curved blades by pressure fluctuation measurements on the volute surface. Therefore, an approach based on microphone is applied to measure the pressure fluctuation on the volute surface and the inlet noise for a multi-blade centrifugal fan with forward-curved blades, and the numerical simulation on the fan is also carried out to analyze the flow fields and noise source. Then by analyzing and comparing the spectrums of surface pressure fluctuations and fan inlet noise, the source of the fan noise is analyzed. Finally several noise reduction methods that are thought to be effective based on experimental and numerical results were suggested.

2. Experiment setup

The fan studied in this paper is a double-suction multi-blade centrifugal fan which is widely used in air conditioner system. The fan has two impellers with 41 forward-curved blades; the diameters of inlet and outlet of impeller are 113.6 mm and 135 mm, respectively. Figure 1 shows the schematic diagram of impeller of this fan. Two fans are mounted on two sides of a DC electric motor with a DC power supply.

![Figure 1. Impeller of the test fan.](image1)

![Figure 2. Photograph of the experiment setup for pressure fluctuation measurement.](image2)

Figure 2 is the photograph of the experiment setup for pressure fluctuation measurement. The microphone was mounted on the surface of the volute. Signals of pressure fluctuation enter into signal conditioner through cables, and through filter and data acquisition equipment the signals pass into computer. The microphone’s model is PCB-377B11, which is a pressure microphone, and its sensitivity is about 55mV/Pa, and its dynamic range is 15dB-146dB. The filter’s model is PF-1U-16FA. The data acquisition equipment’s model is DEWE-51-PCI-16.

As Figure 3 shown, there are 4 sections in axis direction, named section a, b, c and d. Section a is in the middle of volute, section d was 7 mm away from the edge of volute, section b and c divide equally between section a and d. And there are 11 points along peripheral direction on each section of volute surface, named position 1, 2… 11. Position 1 is at the volute tongue, the radian of adjacent position is about 30 degree. With 11 positions and 4 sections, 44 test points are obtained, which are named as 1a, 1b, 1c, 1d, 2a…11d.
3. Experiment results

3.1. Repeatability of the test equipment

In order to verify the repeatability of the test equipment, two test points, point 2a and 6a were tested by nine times separately. Table 1 shows the sound pressure level measured at point 2a and 6a, in which the sound pressure level is defined as $SPL = 10 \log \left( \frac{p}{p_{ref}} \right)^2$, where $p$ is the pressure, and $p_{ref}$ is the reference pressure, $p_{ref} = 2 \times 10^{-5} \text{Pa}$. From the table, it is found that the maximum difference of sound pressure level was 1.8 dB and 0.9 dB for point 2a and 6a, respectively, and relative error compared to average sound pressure level was 1.6% and 0.9% for point 2a and 6a, respectively. The repetitive measurements show good repeatability of the test system.

| Test time | 1   | 2   | 3   | 4   | 5   | 6   | 7   | 8   | 9   |
|-----------|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Point 2a  | 109.9 | 109.4 | 110.0 | 108.7 | 109.3 | 108.9 | 110.0 | 110.3 | 108.5 |
| Point 6a  | 96.9 | 97.0 | 97.2 | 96.9 | 97.6 | 97.4 | 96.8 | 96.7 | 96.7 |

3.2. Pressure fluctuation on the volute surface

Figure 4 shows the measurement results of pressure fluctuation of 4 sections on the volute surface, in which vertical coordinate shows the magnitude of pressure fluctuation, and other two coordinates show the frequency and measurement point respectively. From the results shown in the figures, it is found that there are peaks at position 1 for each section at blade passing frequency (BPF) which is about 750 Hz ($BPF = 1095 \times 41/60 \approx 750 \text{Hz}$), and that the magnitudes of pressure fluctuation at other positions are much lower than that at position 1. The results indicate that the volute tongue is the main position of the fan noise and the rotation noise is the main part of the noise near the volute tongue.

3.3. Measurement results of fan inlet noise

In order to determine if the rotation noise is dominant in the fan noise, the inlet noise for the studied fan is measured in a hemi-anechoic chamber and the spectrum of inlet noise is analyzed. Figure 5 shows the spectrum of inlet noise for the fan. From the figure, we can find that there is small peak at
BPF, and the magnitude of noise at wide range of frequency is high, which indicates that the noise of studied fan is mainly caused by vortex noise and rotation noise can't be ignored.

Figure 4. Pressure fluctuation of 4 sections on volute surface.

Figure 5. The spectrum of inlet noise for the fan.

4. Numerical simulation

4.1. Simulation models and boundary conditions

Governing equations for incompressible turbulent flows, such as continuity and Reynolds-averaged Navier-Stokes equation, are solved with a standard turbulence model. A central-difference scheme is used for the diffusion terms while a second-order upwind difference scheme is used for the convection terms. The SIMPLEX algorithm is applied to match the pressure and velocities. A computational grid with 5420000 elements for all computation domains is applied for the fan. The reasonability of the grid is checked by comparing the current results with results obtained by using a grid with 7040000 elements. The computed results are almost the same with a maximum error less than 1%.
For the boundary conditions, the mass flow rate on the inlet surface is applied, which is 0.0575 kg/s. And the static pressure on the outlet surface is applied, which is 10 Pa. On the walls of blades and scroll, no-slip conditions are imposed for velocity.

4.2. Simulation results

Figure 6 is absolute velocity streamlines of section b and c. Here, the section b and c are same sections as used in pressure fluctuation measurement shown in Fig. 3. From the figures, most of streamlines which flow out the impeller hit on the cut-off and flow back to blade passages and scroll. Airflow from inlet does not flow into impeller uniformly, thus air inlet angle is different between blade passages. The flow condition below volute tongue may be influenced by the deflection of inlet flow. Thus eccentric mounting of inlet may be optimal method to improve the inlet flow and reduce the noise.

Figure 6. Absolute velocity streamlines at section b and c of impeller.

Figure 7 shows relative velocity streamlines of section b and c. The reference velocity is impeller rotational speed. As the figures shown, there is backflow close to cut-off and vortex in blade passages. In some parts of impeller, the air flow which enters the impeller hits the leading edge of blade and generates vortex at suction surface because airflow angle doesn’t match with blade inlet installation angle. Thus some changes of blade leading edge may improve flow condition and help to reduce noise. From the figures, it also can be found that the volute tongue clearance may generate poor flow, which
is backflow in volute tongue clearance and deflection of air flow flowing into impeller. Therefore, to increase tongue clearance may be one method to improve the flow and reduce the noise.

Figure 8 is contours of acoustic power level of section b and c. The acoustic power level is defined as

\[ L_p = 10 \log \left( \frac{P_A}{P_{ref}} \right), \]

where \( P_A = \alpha \rho_0 \left( \frac{u^3 l}{l} \right) u^5 / a_0^5 \), and \( P_{ref} \) is reference acoustic power which is \( 10^{-12} W/m^3 \), and \( u \) and \( l \) are turbulent velocity and length scales, respectively, \( a_0 \) is the speed of sound, \( \alpha \) is a model constant, \( \rho_0 \) is far field density. The contours of acoustic power level show that the impeller especially the area vicinity to outlet of scroll generates larger noise, and that the area near volute tongue also generates higher noise, which is in accord with the experiment results of pressure fluctuations described above.

![Figure 8. Contours of acoustic power level at section b and c of impeller.](image)

5. Conclusions

Based on all of the numerical and experimental results, we can conclude that the vortex noise is an important part of fan noise for the studied fan, and the rotation noise also cannot be neglected. Therefore, increase of tongue clearance, eccentric mounting of inlet and some changes of blade leading edge can be used to improve the inner flow and reduce the noise for the studied fan.

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References

[1] Li D and Gu JM 2004 Chinese Fluid Machinery 32 10-12
[2] Qin G L, Wen S P and Li J Y 1997 Chinese Fluid Machinery 6 8-10
[3] Sandra V S and Rafael B T 2008 Applied Acoustics 69 225-232
[4] Mao Y J, Qi D T and Liu Q H 2005 Journal of Xi'an Jiaotong University 39 989-993
[5] Liu Q H, Song Y H and Tang Y G 2011 Science Technology and Engineering 11 1405-10
[6] Suarez S V, Rafael B T, Juan P H C and Carlos S M 2006 Journal of Sound and Vibration 295 781-796
[7] Liu Y Z, Ke F and Sung H J 2005 Journal of Shanghai Jiaotong University 39 1371-74