NOISE REDUCTION ANALYSIS OF INTAKE DUCT FOR SMALL HIGH-SPEED FAN
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More and more fans have been used in industry. Miniaturization and high speed are the main development direction of the current fan. The small high-speed fan has the characteristics of small volume and high efficiency. However, the noise problem of the small high-speed fan is more prominent, especially for the intake port, which seriously affects the quality of the product. In this paper, the noise of the intake duct of the small high-speed fan is studied. By designing effective noise elimination devices, analysing of transmission loss and pressure loss of muffler and selecting the optimal structure form, the purpose of reducing noise can be achieved. Keywords: noise elimination device, transmission loss, noise reduction, pressure loss

1. Introduction

More and more fans have been used in industry. Miniaturization and high speed are the main development direction of the fan. The small high-speed fan has the characteristics of small volume and high efficiency. The noise problem of the small high-speed fan is very prominent, which seriously affects the quality of the product.

The noise of fan can be divided into four parts: the aerodynamic noise, the noise generated by the interaction of gas-solid elastic system, namely the coupling noise, the mechanical structural noise and the motor noise. The aerodynamic noise generally occupies the main part, and it is the most difficult to eliminate. There are two ways to reduce aerodynamic noise of the fan: one is to use the principle of aeroacoustics to design the low noise fan, and the two is to use the measures of noise elimination, sound insulation or sound absorption. The former way is very difficult, and many research institutions and enterprises have already carried out a lot of work, but it is not yet mature enough. The latter can effectively solve the noise problem of the fan by adding a muffler or other silencing device without changing the structure of the fan[1]. Excessive pressure loss of mufflers or other silencers will directly increase the power loss [2-4], so we must consider and balance the effects of pressure loss and noise reduction.

In this paper, we do some research on the noise of small high-speed fan inlet, design effective muffler, analyse the transmission loss and pressure loss of muffler, select the best structure form, so as to achieve the purpose of noise reduction.

2. Transmission loss theory of muffler

The transmission loss of the muffler is defined as the difference between the incident sound power level at the inlet of the muffler and the transmission sound power at the exit when the outlet is the non-reflective end of the muffler[5]. As shown in the following
Among them, $W_i$ and $W_t$ are the incident sound power at the inlet of the muffler and the transmission sound power at the outlet, as shown in figure 1.

![Figure 1 Schematic of transmission loss of muffler](image)

When the sound wave in an import and export pipeline is a plane wave, the incident and transmission sound power can be expressed as

$$W_i = S_i I_i = \frac{S_i (1 + M_1)^2 |p_i|^2}{\rho_1 c_1}$$

(2)

$$W_t = S_2 I_t = \frac{S_2 (1 + M_2)^2 |p_t|^2}{\rho_2 c_2}$$

(3)

$I_i$, $p_i$, $I_t$, and $p_t$ are the incoming sound intensity and sound pressure at the inlet of the muffler, and the sound intensity and sound pressure at the outlet. $S_i$, $\rho_i$, $c_i$, $M_1$ and $S_2$, $\rho_2$, $c_2$, $M_2$ are the cross section area of the muffler inlet and outlet, the medium density, the sound speed and the Mach number of the air flow, respectively.

So the transmission loss of the muffler can be expressed as

$$TL = 20 \log \left( \frac{p_t}{p_i} \right)$$

(4)

If the temperature at the inlet and outlet of the muffler is the same, the characteristic impedance of the medium is also the same. If the cross section area of the inlet and outlet is also same, the expression of the transmission loss can be simplified as follow

$$TL = 20 \log \left( \frac{p_t}{p_i} \right)$$

(5)

It can be seen from the above formula (equation 5) that we can calculate the transmission loss of muffler by means of experiment or simulation to measure the sound pressure at the inlet and outlet of muffler.

3. Transmission loss analysis of muffler

Transmission loss is an important characteristic parameter of muffler's acoustic performance. It is the inherent characteristic of a muffler itself, and its numerical value can be used as an evaluation criterion of muffler performance.

3.1 Structure design of muffler

Aiming at noise reduction for the high-speed fans, three kinds of mufflers are designed in this paper, and three-dimensional solid models of mufflers are built by using Pro/E software, as shown in Figure 2.
3.2 Simulation results of transmission loss

The geometric model of the muffler is processed and the mesh is divided in the finite element software. Different surface mesh numbers are set on the intake and exhaust ports and external surfaces of the mufflers, respectively, to prepare for adding different boundary conditions, the finite element analysis models of each model are obtained.

![Structure design of three kinds of mufflers](image)

**Figure 2** The structure design of three kinds of mufflers

![Transmission loss of three different mufflers](image)

**Figure 3** Transmission loss of three different mufflers

It can be seen from Figure 3, comparing with muffler 1, the transmission loss effect of muffler 2 and muffler 3 are much better than that of muffler 1. Especially at the middle and high frequency section, muffler 3 has the best effect. For the noise reduction of high-speed fans, both muffler 2 and muffler 3 can achieve better effect.

4. Pressure loss analysis of muffler

The computational fluid dynamics (CFD) method is used to study the pressure loss of the muffler. The eddy viscosity model includes zero equation model, one-equation model and two-equation model. The two-equation model ensures a good calculation precision in the case of small calculation cost, so it is the most widely used in the project. In this paper, the most basic two-equation $k - \varepsilon$ model is used as the calculation model.

Turbulent kinetic energy ($k$) equation:

$$\frac{\partial (\rho k)}{\partial t} + \frac{\partial (\rho u_j k)}{\partial x_j} = - \frac{\partial}{\partial x_j} \left[ \left( \mu + \mu_t \right) \frac{\partial k}{\partial x_j} \right] + \mu_t \left( \frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} \right) \varepsilon - \rho \varepsilon$$  \hspace{1cm} (6)

Turbulent energy dissipation rate ($\varepsilon$) equation

$$\frac{\partial (\rho \varepsilon)}{\partial t} + \frac{\partial (\rho u_j \varepsilon)}{\partial x_j} = - \frac{\partial}{\partial x_j} \left[ \left( \mu + \mu_t \right) \frac{\partial \varepsilon}{\partial x_j} \right] + C_1 \frac{\varepsilon}{k} \left( \frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} \right) \varepsilon - C_2 \frac{\varepsilon^2}{k}$$  \hspace{1cm} (7)

Turbulent viscosity coefficient:

$$\mu_t = \frac{\rho C_k k^2}{\varepsilon}$$  \hspace{1cm} (8)
Among them, $\mu$ is turbulent viscosity, $\overline{\rho}$ is the mean of the density of the fluid medium, $x_i$, $x_j$ is a position coordinate component, $\overline{u_i}$, $\overline{u_j}$ is the mean value of the velocity component of the fluid along the $x_i$, $x_j$ direction, $i=1,2,3$ represents the 3 coordinates of $x, y, z$, respectively, $C_1$, $C_2$, $\sigma_k$, $\sigma_\varepsilon$, $C_\mu$ are empirical constants, the general adoption of the recommended values of Launder and Spalding[6], as shown in Table 1.

Table 1. Recommended values of empirical constants in the $k-\varepsilon$ model

<table>
<thead>
<tr>
<th></th>
<th>$C_1$</th>
<th>$C_2$</th>
<th>$\sigma_k$</th>
<th>$\sigma_\varepsilon$</th>
<th>$C_\mu$</th>
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</thead>
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<td>1.92</td>
<td>1.00</td>
<td>1.30</td>
<td>0.09</td>
</tr>
</tbody>
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4.1 Boundary conditions of computational model

The CFD software Fluent is used to solve the $k-\varepsilon$ model. In order to improve the comparability of data, the fluid state of model inlet is simplified to steady flow, and the fluid model is selected as the ideal model of turbulence and incompressible flow. The wall of the tube is smooth and without slip, that is, the velocity of the fluid on the wall boundary is set to zero. The average velocity of 50 m/s is applied to the inlet, the standard atmospheric pressure is applied at the exit, and the time step is set as the adaptive time step. The temperature of the whole analysis process is set at 25 degrees, without the effect of temperature change on the physical parameters of flow.

4.2 Simulation results of pressure loss

The CFD software Fluent is used to solve the equations in the two-equation $k-\varepsilon$ turbulence model for each model, the corresponding results are analysed.

Figure 4 Pressure loss of three different mufflers

Figure 5 Velocity field and turbulent kinetic energy diagram of muffler 1
The pressure loss of three different mufflers is calculated. From figure 4, we can see that the pressure loss of muffler1 is the largest, muffler2 is second, and the pressure loss of muffler3 is the smallest. Large pressure loss will bring great power loss to high-speed fans. Judging from this factor, muffler3 has the best effect. Compared with muffler1 and muffler2, we can see from figure 4, the flow field distribution of Muffler3 is more uniform, the velocity gradient tends to be gentle, the turbulent kinetic energy in the cavity decreases gradually, and the pressure loss decreases.

5. Experimental verification of the high-speed fan with muffler3

According to the analysis of the transmission loss of the muffler in section 3 and the analysis of the pressure loss in section 4 of this paper, the comprehensive performance of the muffler3 is the best among the three mufflers. Muffler3 can not only bring better noise reduction effect, but also bring no great pressure loss. It will not bring much power loss to the high-speed fan.

In this paper, we use 3D printing technology to make the designed muffler3 into actual model, connect it to the intake port of the high-speed fan, and carry out verification experiments in semianechoic room. In order to exclude the effect of outlet noise on the experimental results, we guide the noise of the air outlet to the distance by means of a catheter, so that the experimental results will not be affected by outlet noise.

Figure 6 Velocity field and turbulent kinetic energy diagram of muffler 2

Figure 7 Velocity field and turbulent kinetic energy diagram of muffler 3

Figure 8 Fan noise reduction experimental diagram (left side is fan, right side is fan with muffler3)
The experimental results are shown in the figure 9, the green histogram is the result of the noise test of the fan, and the blue histogram is the result of noise test of the fan installed muffler3 at its inlet. It can be clearly seen from figure 9 that the noise reduction effect of intermediate frequency band in 600hz-2000hz is especially obvious, which is consistent with the analysis result of transmission loss in section 3.2. The noise reduction effect is very good in the whole high frequency range, and there is a general decrease in 10~20dB.

6. Summary

The noise problem of small and high-speed fans is prominent, which seriously affects the quality of products. In this paper, the inlet noise of small high-speed fan is studied. The following conclusions are drawn:

1. According to the noise characteristics of small and high-speed fans, three mufflers are designed. By calculating its transmission loss, the three mufflers all have better noise reduction effect. The effects of muffler2 and muffler3 are better in middle and high frequency band.
2. By calculating the pressure loss of three different mufflers, the pressure loss of muffler1 is the largest, followed by muffler2, and the pressure loss of muffler3 is the smallest.
3. Comprehensive analysis of muffler transmission loss and pressure loss, muffler3 is optimal. By analysing the experimental results of fan noise, the muffler3 has a better noise reduction effect on the fan noise, especially in the middle and high frequency band.

REFERENCES