Study on Noise Reduction of Fans with Uneven Blade Spacing

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Abstract. The CFD simulation model of unequal and equidistant blades is established, and the aerodynamic performance and aerodynamic noise of the model are analyzed. The noise spectrums of the unequally and equally spaced fan are compared and studied. The conclusion is as follows: the unequal distribution of blades leads the fan modulation phenomenon at the passage frequency, so the unequally spaced fan can reduce the discrete noise in the sensitivity range of human ear. By comparing the performance curves of the unequal fan and the equidistant fan, we can see that as long as the relative change value of the uneven distribution of the blades is within a certain constraint range, the unequal fan will not have a great impact on the aerodynamic performance. Even in some flow areas, the aerodynamic performance of fans has been slightly improved, and it is necessary to reasonably design the distribution of unequal blades.

1. Introduction
Urban noise mainly comes from traffic noise, and traffic noise mainly comes from car noise. Car noise is mainly composed of the noise source generated by the engine, the interaction between the body and the air, the role of the tire and the ground, and the transmission system. Therefore, the car is a comprehensive noise source containing different types of car noise\cite{1}. The research shows that the characteristics of noise and the percentage of total acoustic energy are different in different properties of cars, and the most influential one is the noise generated by the engine. The noise sources generated by the engine include inlet and exhaust noise, dielectric combustion noise, vibration radiation noise of various parts of the body, noise from cooling fans, and noise generated by other accessories. In the past long period of time, due to the late start of the technology of autonomous brand automotive companies, the cooling fan technology in China has been greatly insufficient compared to foreign countries, and the development model is still reverse development. The serious lag in technology makes the quality of the cooling fan also have certain defects. In order to ensure the cooling effect of the engine and extend the service life of the engine, major manufacturers and engineers are constantly studying the effective noise reduction measures and performance improvements of the cooling fan.

Reducing the aerodynamic noise of the cooling fan is nothing more than starting from the following three aspects: the first aspect is to prevent or reduce the occurrence of noise from the sound source; The second aspect is to absorb the sound after it is produced, which is to use a muffler or silencer to suck sound; The third aspect is to directly reduce the noise at the sound reception. Practical studies have shown that the aerodynamic noise generated by fan blades is much greater than the mechanical noise and the electromagnetic noise of fans. If the fan sound transmits the inlet and outlet connections and the blade structure can be improved, the aerodynamic noise can be greatly reduced when passing through the fan. From the aspect of leaf structure characteristics, it is relatively easy to
break through and there is a lot of research spaces[2]. The frequency of the flapping air of the blades of the unequal fans is different, and the gas pressure pulsation generated is also different. The phase difference of the flapping air of the adjacent two blades is not the same[3]. In terms of spectral curve characteristics, the value of the unequal distance fan at the peak value is distributed at the base frequency and its multiplier frequency, and the total acoustic pressure level performance of the unequal distance fan is also significantly reduced[4].

Akaike[5] expounded the mechanism of fan noise in the propulsion cooling system, and puted forward the method of reducing fan noise by using unequal distance blade design. An objective function optimization method was proposed by A. Cattanei[6]. Based on the structure of cooling fan, the simulation model of CFD blade fan is established, and the aerodynamic performance and aerodynamic noise are analyzed. This paper describes the principle that the noise can be reduced in the range of human ear sensitivity to noise.

2. Model establishment
The research object of this paper is an unequal pitch 7-blade fan, and an isometric blade fan. The model software UG is used to model the wind pipe test bed of the unequal fan and equal fan in 3D. The blade surface of the fan is divided into small size grids, while the fan hub is transitioned with large size grids. By using Hypermesh software for grid division, the entire pipeline flow field grid model is transitioned 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.

3. Analysis of Results
Using the FW-H model to perform a fast Fourier transform (FFT) on the sound pressure at each monitoring point over time, then the spectral curve of the sound pressure at each monitoring point can be obtained, which is the relationship between the sound pressure level(SPL) and the frequency(f). Under the condition of operating speed of 2100 rpm, the total acoustic pressure spectrum curve obtained by calculating the aerodynamic noise of the equal-pitch fan is shown in figure 1, and the local magnification in the low-frequency part is shown in figure 2. The relationship between acoustic pressure and frequency obtained by simulation of the equidistance fan is shown in figure 3, which is compared horizontally with the rotational noise of the equidistance fan.

Figure 1. Diagram of acoustic pressure and frequency of isometric fan(2100rpm)
For an equal-pitch fan, the frequency of its rotating noise can be obtained according to the formula
\[ f_i = \frac{n \cdot z}{60}, \]
and the base frequency and harmonic frequency of the fan are calculated to be 245Hz, 490Hz, 735Hz, and 980Hz, respectively as shown in figure 1, figure 2. For an isometric fan, the pulse strength of each blade flapping air is the same, and the phase difference between the adjacent two blades and the air interaction is \( 2\pi/\pi \), the fan's rapid rotation will make this periodic excitation especially obvious. The coherence of the harmonics enhances the pulse strength at the frequency, so the peak appears at the fundamental frequency and harmonic values in its discrete noise spectrum as shown in figure 2.

The total acoustic pressure level (SPL) of the equal-pitch blade fan is 90.93 dB. As can be seen from figure 1 and figure 2, the base frequency has an obvious peak, and the double frequency peak is also more obvious. At frequencies other than the base frequency and frequency multiplier, the total acoustic pressure level (SPL) is continuous broadband. However, the high frequency discrete noise does not clearly indicate the corresponding main order. This is because the internal flow field generated by the cooling fan is more complex, so that the performance parameters such as wind pressure, speed, flow and other changes are also relatively large and the eddy current noise with different discrete noise characteristics is also generated.
The total acoustic pressure level (SPL) of an unequal blade fan was 88.64 dB with a decreasing of 2.28 dB. As can be seen from the noise spectrum diagram and the local magnification of the low-frequency part of the unequal distance fan in figure 3 and figure 4, the total acoustic pressure level peaks of the unequal pitch fan have been reduced at 245Hz (the base frequency) and 490Hz (the double frequency). However, at the same time, other obvious peaks of acoustic pressure levels have also appeared near 245Hz, indicating that the unequal pitch layout blades can modulate sound pressure level frequency at fan base frequency and its frequency multiplier, so that the noise energy at the base frequency is distributed within the frequency bands on both sides of the base frequency and the peak noise energy of the blade corresponding to the double frequency is distributed on both sides of the double frequency [7] [8] [9]. For any harmonic, the distribution of the unequal distance blade does not produce the significant frequency peak like the equidistance fan, but has a nearly symmetrical frequency band, which means that the distribution of the unequal distance blade modulates the frequency.

From the spectrum diagram, although it can be seen that there are several peaks in the curve, it is not enough to accurately analyze the fan noise characteristics, so we obtain a frequency segment with a more obvious discrete noise peak, an acoustic frequency curve with a horizontal coordinate of 1/3 frequency range has been drawn as showed in figure 5. In figure 5 the longitudinal coordinate represents the acoustic pressure level with unit of dB(A) after the A-weight. The different pitch distribution of the blades makes the fan produce the minimum total A sound level noise, and the interference force of the fan pitch noise is reduced. Interference is evaluated by the subjective auditory sensitivity of the human ear, and the A-sound scale power network is closest to the auditory characteristics of the human ear[10].

As can be seen from figure 5, the pitch noise source frequency band of the isometric fan rotational noise is mainly concentrated in the middle and low frequency segment, and the highest A-weight pressure occurs at 245 Hz, which is 80.01 dB(A). There are also several concentrated discrete noise high frequency segments in the middle and low frequency segments. In the 245Hz - 1000Hz frequency segment with more concentrated rotational noise, the discrete noise distribution of the A sound level of the unequal distance fan is relatively uniform, and the maximum A-weight sound pressure is 76.8 dB(A), which is reduced compared to the discrete noise of the isometric fan 3.2 dB(A), the effect of the decrease is more significant than that of the total acoustic pressure level(SPL). The discrete noise value of the equidistant fan is relatively large at the passing frequency, and the pitch noise value of the frequency segment on both sides of the fundamental frequency is relatively small. Because that the maximum peak of the discrete noise is assigned to other frequency segments by the unequal distance fan, thus achieving noise reduction.

![Figure 5. A comparison of weight acoustic pressure levels](image-url)

The unequal arrangement destroys the periodicity of flapping air in the blades, which will inevitably change the flow of fluid in the field and may affect the performance of the fan. If you blindly pursue the reduction of discrete noise regardless of the aerodynamic performance of the fan, it is obviously incorrect. Therefore, it is necessary to study the aerodynamic performance of the unequal distance fan and the equidistance fan in order to provide sufficient basis for subsequent theoretical analysis.
4. Concluding
Pneumatic noise of equal-distance fans and unequal fans is calculated. By comparing the noise spectrum of unequal fans and equidistant fans, it is known that the unequal distribution of blades causes the fan to modulate at the frequency. That is to say, the peak of the sound energy corresponding to the fundamental frequency is symmetrically distributed on both sides of the fundamental frequency, and the first few harmonics are also the same, so the unequal distance blade fan can reduce discrete noise within the sensitivity of the human ear to noise. The aerodynamic performance of the equidistant fan is also calculated. By comparing the performance curves of the unequal fan and the equidistant fan, it can be seen that as long as the non-uniform distribution of the blade relative change value is within a certain constraint range, unequal distance fans will not have a great impact on aerodynamic performance. Even in some flow areas, the aerodynamic performance of fans has been slightly improved. It is necessary to reasonably design the distribution of unequal distance blades.

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