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The Study of Owl's Silent Flight and Noise Reduction on Fan Vane with Bionic Structure[1]

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Abstract: In light of the bionics engineering point of view, we use the biological non-smooth surface in the surface design of the fan blade in order to reduce the fan noise and improve air flow and efficiency .We design several kinds of Sawtooth-shaped distribution, and apply the non-smooth form on the fan model. We analyzed the acoustic performance of various non-smooth fan blades that was reflected when the fan was rotating. Through the wind tunnel test, we obtained the spectrum map, wind comparison chart, efficiency curve and other important parameters that came from the comparison between smooth and non-smooth models and the noise of the fan. This paper will reveal that the non-smooth shape practically is good for preventing formation of off-body vortex, which is caused by turbulent boundary layer on the vane surface, and it will have reference significance for exploring the mechanism of noise reduction on fan vane.
Key words: Owl; Bionic; Noise Reduction; Optimization Test

INTRODUCTION

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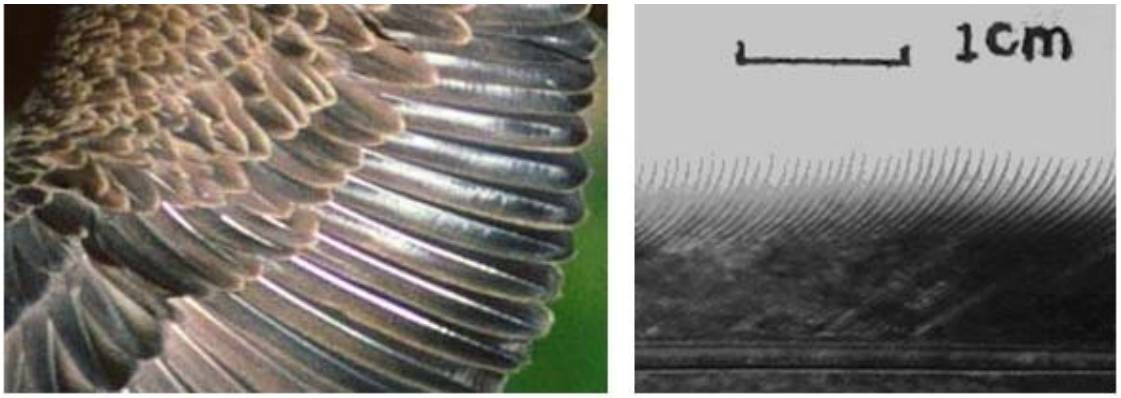
When the axial fan is running, the noises include aerodynamic noise, mechanical noise and gas-solid coupling noise that is generated by the interaction between gas and solid elastic system noise. Aerodynamic noise accounts for 45% of all noise, which is the main source (ZHI, 1985) of making noise. However, aerodynamic noise is composed of rotation noise and vortex noise. The noise of rotation is due to the adhesion of the air and leafs, resulted in velocity gradient, formed on turbulent boundary layer noise by the vane's surface boundary layer pulse, and it will decline gradually with in increase of the fan speed; The vortex noise is a kind of strong noise which is made by the local pulse power (SHEN & XIE, 2004) with a more narrow frequency characteristics, and the power is made by the Karman Vortex Street of vane trailing. When the air is flowing, the fan vanes cut the air periodically, so that airflow becomes unstable, and thus form a pulse wake momentum of Karman Vortex Street. The noise would be much greater when the vortex separated from trailing.

Edge is impacted by the back vanes. When air flows through the axial fan channel, the differential pressure will be formed between the vane's Convex and Concave. It will form secondary vortex (Canwen, 1994) noise when the air flows from the concave to the convex on the end face of vane.

People have developed many methods and techniques that can reduce the aerodynamic noise of the impeller through the long-term production practice. We adopted a method of perforating the vane to reduce the vortex noise (ZHANG & GU, 1989; WU & LI, 2001) that can make the air on the pressure side flow to the suction surface, prevent the fluid breakdown, and even reduce and inhibit the tail vortex shedding. However, this method would reduce the differential pressure too fast. If we choose the method of Bent-Swept Vane to reduce the noise, the bending direction could cause the phase difference of acoustic signal, which come from every sound source on the radial blade. But it has much bad influence on sound pressure level (SPL). We sharpened the trailing edge of vane (HUANG, 1998) and reduce the thickness of trailing edge that will make the acoustical power decrease. Unequal pitch distribution could spread the noise in a wider frequency range by arranging vanes unequally, and then the fan's base frequency and its harmonic wave noise will be reduced together (YANG & CHEN, 2002; SUN, 1986).If we choose the soft edges to reduce the noise, there will be some problems concerning the strength, high-temperature and corrosion resistance of the material. The method of adding serrated vanes on the surface of vane (CHENG, 1989) can achieve the effect of noise reduction by transforming laminar boundary layer into turbulent boundary layer.

1. THE MECHANISM OF OWL'S SILENT FLIGHT

Owl can almost fly silently when it is hunting at night, and it has been known as the natural nighttime "stealth craft". Biologists have found three reasons why the owl can fly silently. The first one, the primary feather of the owl's wings was separated from each other，and the feather's edges was serrated（Fig.1）.



Owl's striate and serrated structure　　Serrated shape of owl's feather

Fig.1: Owl's feather morphology and Wing configuration

In flight, the wings resolved the sound wave, which was produced after air passed the wings，changed the air flow status of its surface boundary layer, and inhibited the formation of air turbulence. This form has excellent performance in noise elimination; The second, the smear feather at the end of wings are spiciform and have no regular arrangement; the third one，the soft feather on owl's wings can absorb surplus sound whose rate was over 2000 Hz. That is why prey cannot hear the owl.

It was just because of the surface of owl's body have a lot of coupling interaction such as special surface morphology, unique wing configuration, special internal structure and highly flexible material. They can delay the separation of turbulent boundary layer around the airfoil profile, reduce pulsating pressure of the surface of wings, and reduce the production of Sound energy. Above all the feature make the surface have a function of noise elimination.

2. TEST METHODS AND NOISE REDUCTION TECHNOLOGY

2.1 Test equipment, Measuring points, Methods and Materials

Using a special test bionic fan impeller constitutes the test equipment and adding other necessary gauges in Fig.2，which are based on the fan test rig. We have tested the rotating noise of fan vanes. We put the noise measuring points at an angle of about 45 degrees to the exit centerline of fan and one meter away, and put the noise measurement conditions in high-speed range of fans intensively, because that the background noise was too high and the fan noise was not obvious when the blower was spinning at a low speed. We tested the value of acoustic pressure level under two working conditions such as 1700r/min and 2000r/min，and then we had a spectral analysis. At the same time，we tested the air flow and efficiency performance. We measured three times for each condition and had some average values as the test data. We had the spectral analysis three times for each crossover frequency and then get their average values.

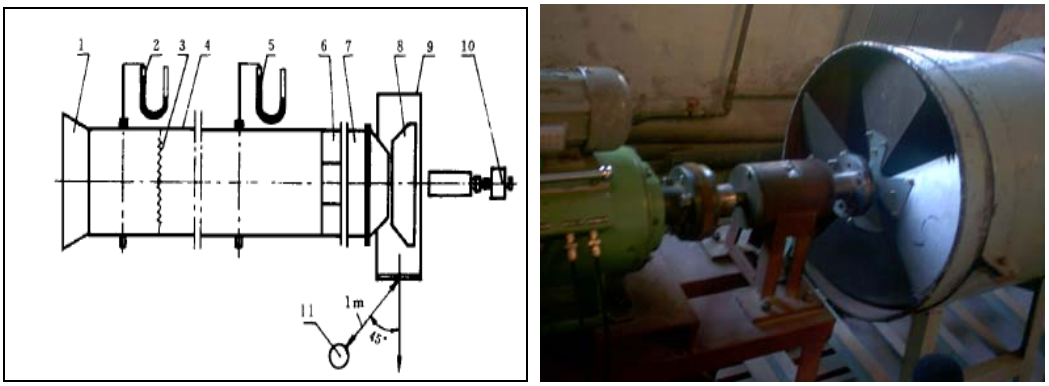


Fig.2: Test equipment

1. collector-shoe gear; 2,5. Micromanometer; 3. Grid restrictor; 4. **Blowdryer; 6. Diffuser grid; 7.** Joint; 8. Tailor-made vane; 9. Enclosure; **Dynamometer** motor**; 10.** Sound meter.

2.2 Design of bionic axial fan

Based on the owl wings' characteristics of structure and shape and its distribution law, and also accounting to the practical processes when the fan vanes were working, we created a real bionic fan type shown in Fig.3 and Fig.4. By using wind tunnel test, we explored the law of noise elimination of non-smooth surface morphology and found out the main and minor factors which have impacted SPL, air flow and efficiency. Because the hole diameter of wind tunnel test device is ϕ=500mm, having the bionic design of surface with that the fan vane diameter is D=480mm, the Material of vane is Q235-A and the sheet thickness was 1.0 mm. The jagged design of bionic jagged fan was made at the end of vane inlet edge, and the vane was

processed by WEDM. The factors and standards of bionic jagged fan vanes were shown in Table 1. The testing index was the rate of the reducing noise, component and efficiency, adopting orthogonal test program L_4（2^3）(LIANG, 2005) shown in Table 2.

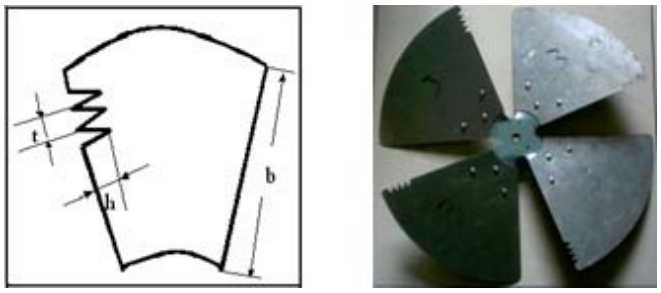
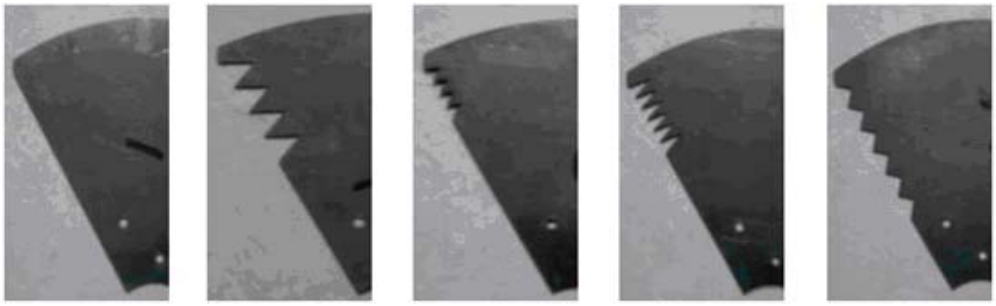


Fig.3: Bionic blade, impeller



Fan vane F1 Fan vane F2 Fan vane F3 Fan vane F4 Fan vane F5

Fig.4: Bionic fan vane model

Table 1: Factors and Standards

Factors / standards	height of teeth (mm)	circular pitch (mm)	number of teeth
1	10	10	3
2	20	20	5

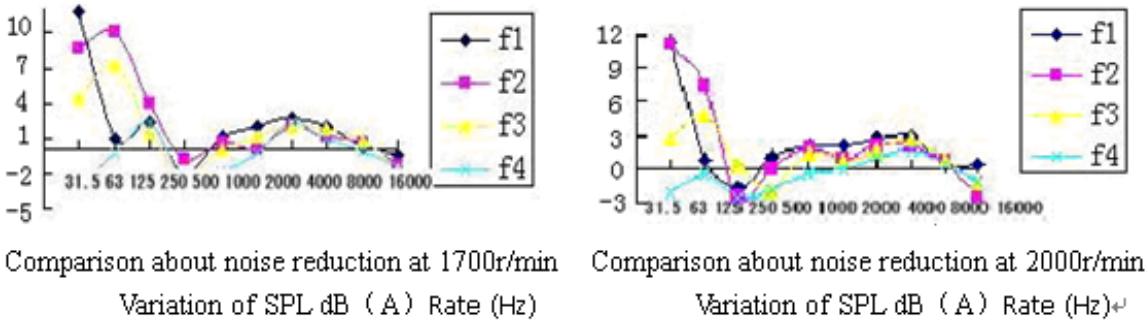
Table 2: Analysis of discrete data of fan noise

NO.	A number of teeth	B circular pitch	C height of teeth	Y_i (rate of noise reduction)
1	3	20	20	2.5%
2	3	10	10	1.4%
3	5	20	10	1.3%
4	5	10	20	0.6%
Y_{j1}	3.9%	3.8%	3.1%	$\sum_1^4 y_i$ =1.45%
Y_{j2}	1.9%	2.0%	2.7%	
$0.5y_{j1}$	1.95%	1.9%	1.55%	
$0.5y_{j2}$	0.95%	1.0%	1.35%	
R_j	1.0%	0.9%	0.2%	
Good level	A_1	B_1	C_1	
Primary and secondary factors	A > B > C			
Optimum combination	A_1 B_1 C_1			

3. TEST RESULTS AND ANALYSIS

3.1 Tate of noise reduction

The SPL of non-serrated vanes was indicated by the letter A，and the SPL of serrated vanes was indicated by the letter A^1. $\gamma^{A} = \frac{A - A^1}{A} \times 100\%$ was used as the rate of noise reduction. The larger rate we got, the more obvious noise reduction was. There was a comparison about noise reduction between a fan with common vane and a fan with bionic vane in Fig.5.



Comparison about noise reduction at 1700r/min　　Comparison about noise reduction at 2000r/min

Variation of SPL dB （A） Rate (Hz)　　Variation of SPL dB （A） Rate (Hz)

Fig.5: Noise reduction rate contradistinction between common vanes and bionic vanes

3.2 Analysis of test results

Results have showed that: all serrated vanes were effective to a certain extent, and the effects were proportional to revolving speed. Accounting to Fig.5, all bionic serrated blades had some effect of noise reduction in different paragraphs. Since the peaks of SPL were mostly in 1kHz to 3kHz, it indicates that the noise reduction of high-frequency eddy current was better. In the peak frequency domain, the effect of fan F1 was the best, and rate was 2.5%. By analyzing the discrete data of fan noise(Table.2)，we can reach a conclusion that the main factor that influence a fan voice one by one in order was the number of teeth, height of teeth and the circular pitch. At the same time, their efficiency, air flow, total pressure and other index had been increased (Fig.6, Fig.7). Changes in air flow and efficiency of fan F1 were perfect. The air flow was increased 11.2%, the efficiency was improved by 5.3 percentage points, and the total pressure also increased 17.21Pa. That can explain that this fan's power exportation ability was also increased.

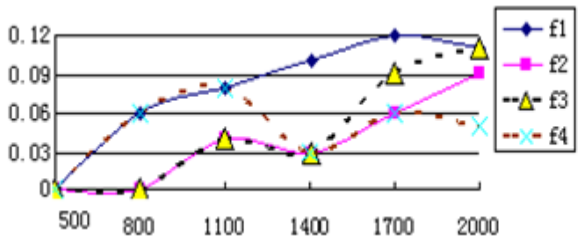


Fig.6: Comparison of air flow (m^3/min)

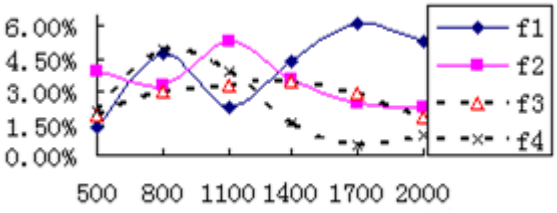


Fig.7: Comparison of efficiency in different rate

4. ANALYSIS OF NOISE REDUCTION MECHANISM

According to the above spectral analysis, we have known that the fans with bionic serrated blade mainly reduced the noise of high frequency eddy current. There were two major reasons to form vortex noise. One

was the pressure fluctuation on the vane, which was generated by turbulent boundary layer produced at the time when the air flows through the vanes (LIANG & WU, 1999). The other one was the pressure fluctuation on the Blade edge, which was generated by the shedding of trailling vortex when the boundary layer was developed to a certain extent (Sharland, 1964). Based on the above analysis, the noise could be reduced if we can change the parameters of vane's boundary layer, delay the separation of boundary layer and prevent vortex shedding, or change the energy of trailling vortex.

(1) Delaying the separation of boundary layer (LIU & WANG, 2001)

When the fan was rotating, the moving direction and velocity of air flow in fan length direction were constantly changing. That produced pressure gradient on both sides of the vane grid. The effect of air on the vane produced fluctuate lift forces , and the acoustic radiation pressure was produced by which could caused turbulence noise (LI et al., 2006). Serrated vanes changed their pressure distribution. That made the high pressure stream flow to the low-voltage side (LU, 2001), decreased the area of separating zone on the export section of vane, reduced the vortex intensity on the area of separating zone, and improved turbulence intensity of vane's trailing edge. Meanwhile, the noise was reduced.

(2) Segmentation of discrete vortex (SUN et al., 2001)

Serrated vanes separated the trailling vortex concentrating on the vane into some small-scale vortices. These small trailling vortexes crashed into the shell at different times, parts and directions, which could make the strong interference in continuous strikes of high frequency and low amplitude. As the speed in the direction of motion of dispersed trailling vortex was uncertain, the viscous dissipation effect was enhanced further in the course of the campaign, and the intensity of concentrated vortex was weakened. That made the alternating aerodynamic loads acting on vanes decrease, thus reducing thevortex noise

5. CONCLUSION

1. The jugged vane structure, which is made of trailing edge of axial fan vane, changes the distribution of pressure on the vanes, delays the separation of boundary layer, disperses the vortex strength and improves turbulence intensity of vane's trailing edge. Meanwhile, the noise is reduced.

2. When the structures of blade profile are different, the effects on noise reduction and operating characteristics are also different. All serrated vanes are effective to a certain extent .Changes in air flow and efficiency of fan F1 is perfect. The air flow is increased 11.2%, the efficiency is improved by 5.3 percentage points, and the total pressure also increases 17.21Pa. That is all explained that this fan's power exportation ability is also increased.

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