The Noise Radiation Characteristics of Axial Fan by Experimental Method

실험적 방법에의한 축류형 팬의 소음 방사 특성에 관한 연구

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ABSTRACT

Blade passage frequency tone of fan is the most obvious component among the overall noise spectrum. It is generally the most annoying component and thus needs to be reduced. Therefore, to reduce the noise level, the noise source and noise radiation characteristics identification of axial fan need to be studied in detail.

In this study, noise source mechanism and noise radiation characteristics of axial fan was identified. In noise source analysis by sound pressure and sound intensity method, we carried out triggering of axial fan by photo sensor. The determination of recording time to identify the exact location of noise source on the fan blade was presented. The location of noise source exists between trailing edge of each blade and leading edge of the following blade respectively, when axial fan is rotating. We determined the noise radiation pattern of axial fan through directivity pattern and also visualized the flow of sound by vector energy flow mapping. The rotating vibration characteristics on the fan blade surface was identified by strain gauge and the coherence of structure-borne sound to sound pressure was measured as well. The possibility of static pressure measurement on the fan blade surface by piezo film was presented.

요 약

팬의 익면 통과 주파수 소음은 총괄 소음 스펙트럼중에서 가장 명백한 성분이다. 그 소리는 일반적으로 가장 불쾌한 성분이므로 저감이 요구된다. 따라서 그 소음치를 저감시키기 위해서는 정확한 축류형 팬의 소음원과 소음 방사 특성 규명이 요구된다.

본 연구에서는 축류형 팬의 소음원과 소음 방사 특성을 정의하였다. 음압 및 음향인텐시티를 이용한 음원 해석에서, 광센서를 이용한 축류형 팬의 동기화가 수행되었고, 팬 날개에서의 정확한 소음원의 위치를 결정하기 위해 Recording time의 결정이 제안되었다. 팬 회전시, 소음원의 위치는 각 날개의 후단과 그 다음 날개의 선단사이에 각각 존재한다. 지향성을 통하여 축류형 팬의 소음 방사 형태를 결정하였고, 벡터 에너지 흐름도로 음의 흐름을 가시화하였다. 팬 익면에서의 회전 진동 특성을 스트레인 게이지에 의하여 규명하였고, 또한 구조진동음의 음으로의 기여도를 측정하였다. 또한 압전필름에 의한 팬 익면에서의 정압측정 가능성이 제시되었다.

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Ⅰ. Introduction

Recently, on account of development in design and manufacturing technique for rotating machine, it is possible to manufacture rotating machine with high performance at low cost. But the noise and vibration problems due to increase of rotating speed are newly appeared. Blade passage frequency tone of fan is obvious in the overall noise sprectrum and the tone is generally the most annoying component and thus needs to be reduced. Therefore, it is necessary to identify the noise source mechanism and noise transmission path for reducing the noise level.

In this study, several approaches were carried out to identify the noise source mechanism and noise radiation characteristics of axial fan. Sound pressure and sound intensity method are presented for the purpose of analyzing noise source, sound propagation and sound radiation pattern of axial fan. And the mesurements of structure-borne and air-borne sound by strain gauge and piezo film are presented.

Ⅱ. Theory

2.1 The characteristics of axial fan tone

Generally, in all cases, the rotor noise spectra are assumed to be generated by random, periodic, or steady blade forces. For all axial fan, blade passage frequency(BPF) which is characterized by low frequency is the dominant component of noise spectrum and is defined as follow.

$$f_{bpf} = V_r \cdot N / 60 \tag{1}$$

where, f_{bpf} : blade passage frequency [Hz]
V_r : the rotating speed of fan [rpm]
N : number of blades

2.2 Sound intensity

Sound intensity is a vector quantity with both magnitude and direction. The vector indicates the amount of acoustic power transported through a unit area and the direction of this energy transportation. While sound pressure is used to quantify the received sensation, many practical measurements are based upon energy flow principles. The power P transmitted from the air on the one side of this surface to the that of the other side is,

$$P = F \cdot V = S \cdot p \cdot V \tag{2}$$

where, S is the area of the surface, p is pressure on the surface and V is the resulting particle velocity. The intensity I is the power per unit area.

$$I = P / S = p \cdot V \cdot \tag{3}$$

In practical, the intensity is measured by the two microphones of intensity probe. The pressure on the surface is calculated as the mean pressure, and the air particle velocity V normal to the surface can be calculated from the pressure differences. And the intensity I can be obtained by measuring the imaginary part of cross spectral function of two sound pressures.

$$I_r(f) = \frac{1}{2\pi\rho \triangle r} \int \frac{Im[G_{12}(f)]}{f} df \tag{4}$$

2.3 The principle of piezo film

The equation (5) is a fundamental expression about piezo film. Its strain is determined by electrical pressure or existing force, and generates the moment of structures. Subscripts indicate each axial direction of piezo film.

$$S_{ij} = \overset{E}{s}_{ijkl} \cdot T_{kl} + d_{kij} \cdot E_k \tag{5}$$

where, S_{ij} : Strain,
$\overset{E}{s}_{ijkl}$: Elastic compliance constant
T_{kl} : Stress, d_{kij} : Electricity constant
E_k : Electric field

Ⅲ. Experiment

In this experiment, the axial fan has six blades and its diameter is 31.4 cm. When axial fan is rotating, the measuring system of sound pressure and sound intensity for the purpose of identifying noise source mechanism is shown in Fig.1. Inten-

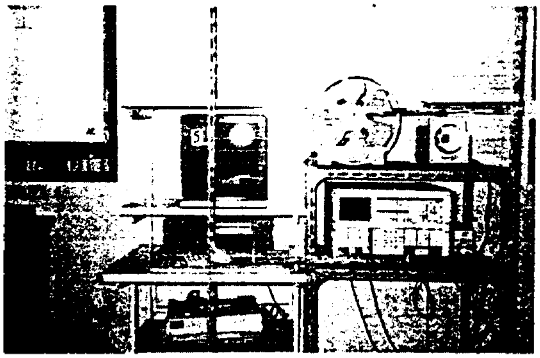
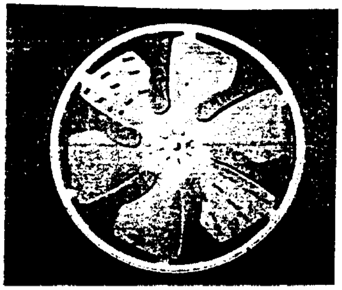
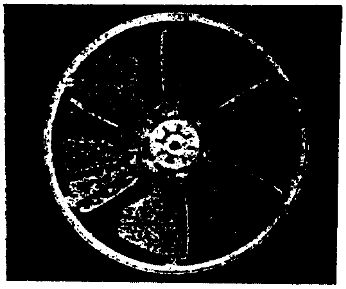


Fig. 1. Instrumentation used for sound intensity.
1. stroboscope, 2. axial fan system
3. intensity probe, 4. FFT analyzer, 5. IBM-AT

sity probe used in this measurement was face-to-face type (B & K 3519). As rotating condition of axial fan is 800 ~ 2000 rpm in this experiment, the peak frequency (BPF) range is from 80 Hz to 200 Hz. Thus, the measurement of sound intensity utilized the 50 mm spacer of which effective frequency range is from 50 Hz to 1250 Hz. And in this experiment, as the axial fan was rotating, we carried out triggering by photo sensor to execute time and spatial synchronization. For the measurement of axial fan-self noise, we used strain gauge and piezo film, and axial fan blade on which each of them was adhesive was shown in Fig.2. The experimental schematic diagram was shown in Fig.3, and detected signals were analyzed by FFT(Fast Fourier Transform) analyzer and micro-computer.



(a) The case of strain gauge



(b) The case of piezo film

Fig. 2. The adhesive point of each sensor on the fan blade

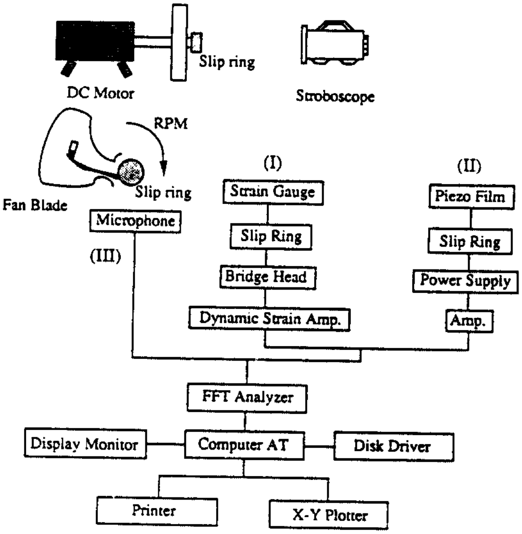


Fig. 3. The experimental schematic diagram of strain gauge, piezo film, and coherence estimation

Ⅳ. Experimental result and consideration

4.1 Sound source analysis by sound pressure and sound insensity

(1)The characteristics of axial fan according to the change of rotating speed

Fig.4 indicates the spectrum of sound pressure according to the change of rotating speed. In this measurement, rotating condition is from 800 rpm to 2000 rpm. The spectrum of sound pressure at each rotating speed has each dominant blade passage frequency. In the direction of low frequency, the influence of surrounding's back ground noise are eminent and smooth.

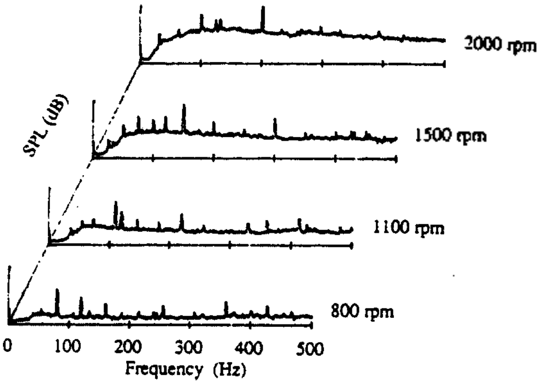


Fig. 4. The spectrum of axial fan according to the change of rotating speed

(2)The measurements of sound pressure and sound intensity

The contour mapping of sound pressure is shown in Fig.5, when the rotating speed of axial fan is 1100 rpm. According to the contour about sound pressure, the noise sources are located in each blade. The exact location of noise source is between the blade tip and the middle of blade.

On the other hand, Fig.6 indicates the contour mapping of sound intensity at same condition. From there we can see the noise source and sink. And the vector mapping of energy flow which can be estimated to intensity measurement on X-Y plane(measureing plane) causes sound radiation patterns to be visible. Fig.7 indicates the vector flow mapping at the same condition.

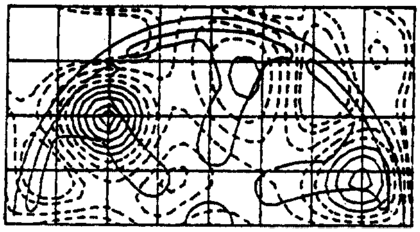


Fig. 5. The contour mapping of sound pressure at 1100 rpm

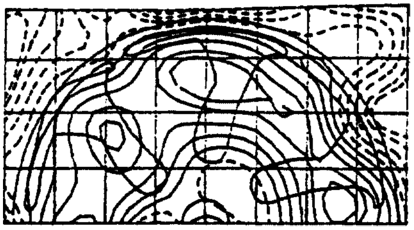


Fig. 6. The contour mapping of sound intensity at 1100 rpm

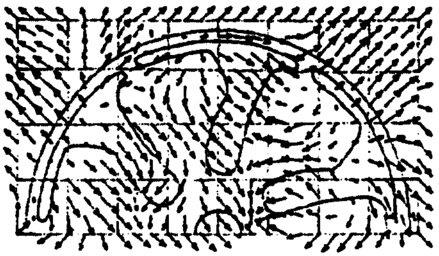


Fig. 7. The vector energy flow mapping at 1100 rpm

4.2 The measurements of structure-borne and air-borne sound of axial fan

Each rotating characteristics on the blade surface, i.e., structure-borne and air-borne sound are investigated by using strain gauge and piezo film adhesive on the blade surface. Fig.8 indicates the spectrum of rotating speed by strain gauge. It is the characteristics caused by pure rotating vibration and structure-borne sound. Its tendency is dominant at first fundamental frequency and it corresponds to one sixth(1/6) of BPF. Each fre-

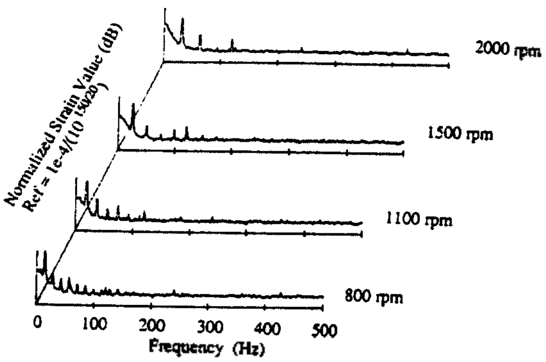


Fig. 8. The spectrum of rotating characteristics according to the change of rotating speed by strain gauge

quency is shown in Table1., and Fig.9 is in the case of piezo film. The type of peak frequency is the same that of strain gauge, but we can measure structure-borne and air-borne sound by piezo film. The characteristics of each adhesive point are shown in Fig.10, and its level is large at trailing edge and leading edge. On the other hand, the coherence of structure-borne sound to sound pressure is investigated by introducing coherence function. The coherence of the signal measured by strain gauge to sound pressure means the that of structure-borne sound to sound pressure. It is shown in Fig.11, and the case of piezo film is in Fig.12. In the coherence to sound pressure, the second harmonic component of the first fundamental frequency is superior to others. In comparison of each case, the coherence of piezo film to sound pressure is superior to that. Thus, we can see that piezo film measures structure-borne and air-borne sound at the same time.

Table 1. The frequency due to the change of rotating speed.

Rotating speed(rpm)	1 st harmonic (Hz)	2 st harmonic (Hz)	blade passage freq
800	13.75	27.5	80
1100	18.75	36.25	110
150	25	50	150
2000	31.25	62.5	200

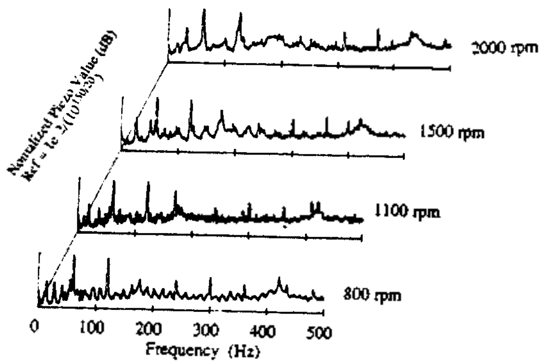


Fig. 9. The spectrum of the rotating characteristics according to the change of rotating speed by piezo film

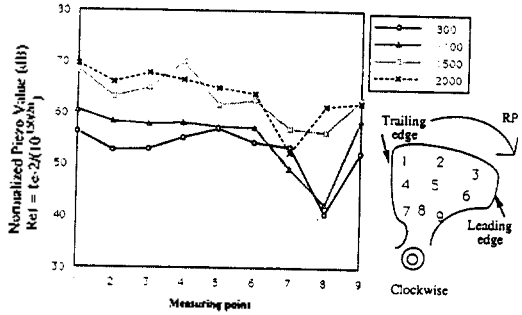


Fig. 10. Piezo value of each point at the first fundamental frequency

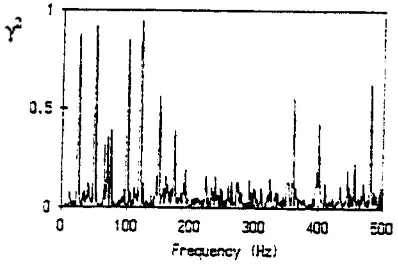


Fig. 11. The coherence of the signal measured through strain gauge to sound pressure

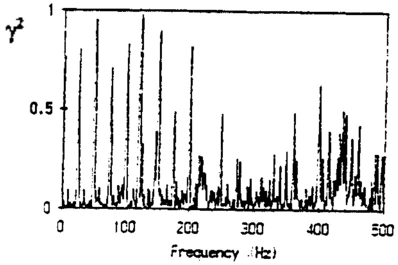


Fig. 12. The coherence of the signal measured through piezo film to sound pressure

V. Conclusion

(1)The noise source exists among the blades respectively, when axial fan is rotating. And the location of the noise source is between the blade tip and the middle of blade.

(2)We determined the noise radiation pattern of axial fan and caused the flow of sound to be visible through the vector energy flow mapping.

(3)The rotating vibration characteristics of the axial fan stood for the frequency corresponding to one sixth(1/6) of BPF. Blade passage frequency was the first fundamental frequency, and its second harmonic frequency contributed to sound pressure highly.

(4)The possibility of static pressure measurement on fan blade surface was presented by using piezo film.

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