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BASIC STUDY FOR A LOW-NOISE FAN USING ACTIVE NOISE CANCELLATION

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1. INTRODUCTION

Noise from cooling fans in electronic devices has long been a serious problem. Many passive techniques such as the use of sound absorbing material and sound isolation are used to reduce the noise. However, these techniques are not very effective in low frequency regions and it is difficult to apply them to electronic devices with limited size and weight. Recently, active noise cancellation (ANC) systems have been put to practical use in a number of cases. Most of these systems use an adaptive control system with digital signal processing. As a result, they tend to be very large and high in cost. In applying ANC systems to small electronic devices, what is needed is a small and low cost noise reduction system which achieves efficient noise reduction rather than a major lowering of the noise level. This paper describes a basic study we carried out for the development of a low noise cooling fan for installation in ANC equipment. In this study, we attempted to reduce blade passing noise of a typical cooling fan by analog signal processing.

2. CHARACTERISTICS OF COOLING FAN NOISE

Cooling fan noise includes wide frequency components generated by exfoliation or eddy of air flow and discrete frequency components caused by fan rotation. Blade passing noise, which is one of the discrete frequency components, in particular contributes greatly to the sound pressure level of the overall frequency. Figure 1 shows a noise spectrum of a fan set up in a non-acoustic room. This fan is a typical cooling

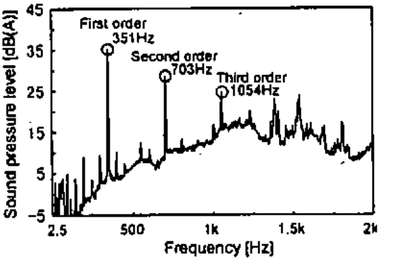

Fig.1 Noise spectrum of a typical cooling fan in a free sound field.

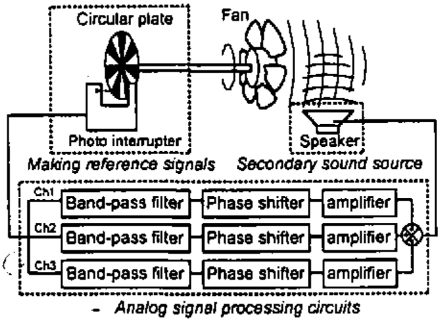

Fig.2 Basic experimental system.

fan (width/height 80 mm) and was used throughout this study. It has seven blades and operates at a speed of 3000 rpm. Therefore, blade passing frequency is 351 Hz and noise peaks appear at 351 Hz, 703 Hz and 1054 Hz. The contribution of the first order frequency of 351 Hz to blade passing noise is 17 % of the overall frequency. Those of the second and third order frequencies are 5 % and 1 % for a total of 23 %. If the components of these three peaks are eliminated, fan noise drops by 1 dB.

3. EXPERIMENTAL SETUP AND FAN NOISE REDUCTION METHOD

Figure 2 shows our basic experimental system. The system consists of three parts, a photo interrupter for making reference signals, analog circuits for processing signals, and a speaker for generating anti-sound waves. We decided to use a combination of a photo interrupter and a circular plate to obtain a reference signal from the rotation of the fan. By using a circular plate with seven shaded patterns (equal to the number of fan blades), we can obtain an output signal which includes blade passing frequency. Figure 3 shows a spectrum of the photo interrupter output signal. The output signal is a rectangular wave with harmonic components at odd-number multiples of the blade passing frequency in principle. However, the actual output signal also includes harmonic components at even-number multiples of the blade passing frequency due to overshoot occurring as the signal rises and falls. Figure 4 shows the coherence between the fan noise and the photo interrupter output signal. This coherence, which is the average value for 40 measurements, is very good in regard to the harmonic components of the blade passing frequency, and thus the signal can be used as a reference signal.

The analog signal processing circuits have three channels so that the three peaks of the blade passing noise will be eliminated. One of the advantages of analog signal processing is that the signal processing time is very short and therefore the cost is low. The reference signals output from the photo interrupter include not only harmonic components of the blade passing frequency but also many undesirable harmonic components of the fan rotation frequency caused by a discrepancy between the rotation center of the fan and that of the circular plate. Therefore, band-pass filters which have steep isolation characteristics are used to pick up the harmonics components of the blade passing frequency. The magnitude and phase of each signal passed to the band pass filter are adjusted in an amplifier/phase shifter. These signals are then combined by an adding circuit and drive the speaker, and the blade passing noise is eliminated by the sound generated from the speaker.

Since the purpose of this study is to develop a small low-noise fan for installation in an ANC system, the speaker is located as near the fan (80 mm) as possible. The measuring point at which the noise reduction is evaluated is the intake side of the fan; this avoids undesirable influence from surrounding wind. We carried out separate experiments in a non-acoustic room. The first involved noise reduction in a fan located in a free sound field. The other involved noise reduction in a fan located in a long duct 1.23 m in length.

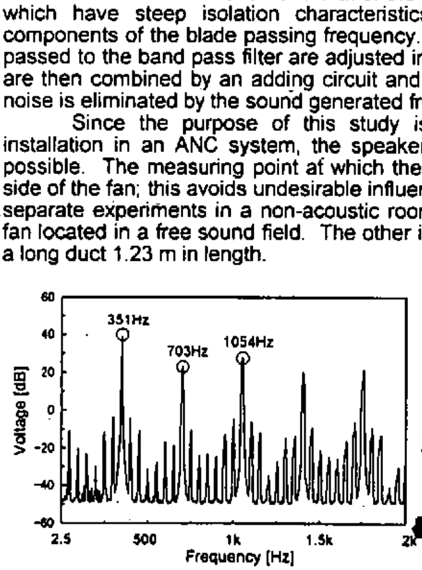

Fig.3 Spectrum of photo interrupter output signal.

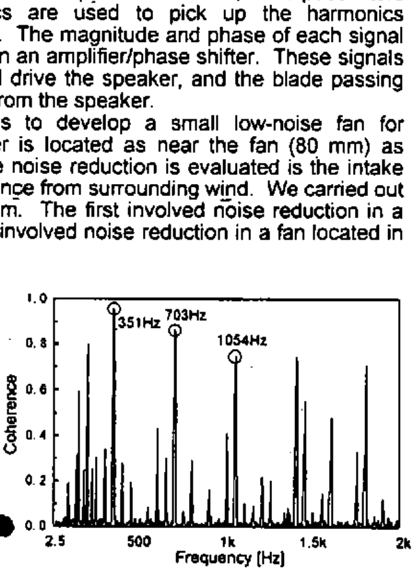

Fig.4 Coherence between fan noise and photo interrupter output signals.

4. EXPERIMENT RESULTS AND DISCUSSION

First, we tried to reduce noise from a fan located in a free sound field. In this case, the speaker was located 0.15 m from the fan. Figure 5(a) shows the sound field around an inoperational fan. The noise of overall frequency has no particular direction of its own. However, the frequency components of the blade passing noise move in different directions. This result indicates that even if one sound source is located near the fan, no fan noise reduction is expected in a wide space. Therefore, the magnitude and phase of sound waves generated from the speaker were adjusted so that the fan noise is lowest at point A. Figures 5(b) and 5(c) show sound pressure distribution for the components of the blade passing noise. Though both of these components attain a sound reduction value of 6 dB at point A, the sound pressure level tends to increase at many other points. One reason for this is that the distance of 0.15 m between the fan and the speaker is not sufficiently smaller than sound wave length of the blade passing noise components. When the frequency is 704 Hz, the sound wave length is about 0.5 m. Next, the experiment was carried out using a long duct 1.23 m in length to achieve stable sound interference between the fan noise and the sound of the speaker. Duct height and width was 85 mm. The fan was located in the center of the duct. The magnitude and phase of the sound waves were adjusted so that the fan noise is lowest at the end of the duct inlet side. Figure 6 shows the noise spectrum we obtained (the value shown is an average of 80 measurements). The solid line shows

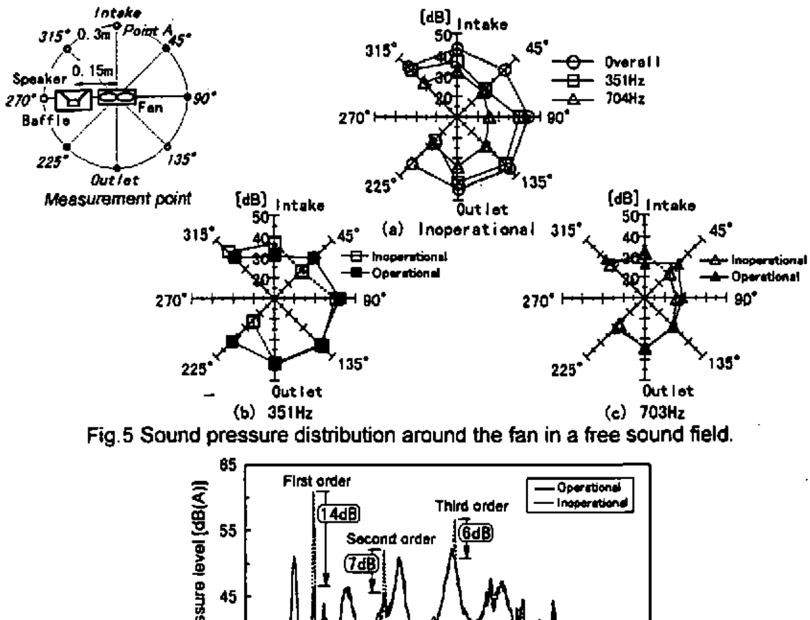

Fig.5 Sound pressure distribution around the fan in a free sound field.

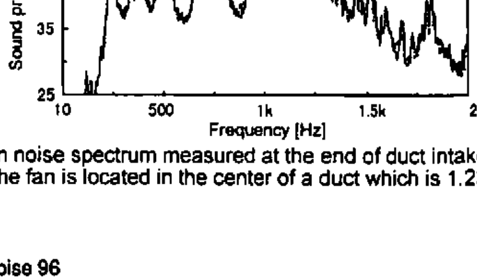

Fig.6 Fan noise spectrum measured at the end of duct intake side.
(The fan is located in the center of a duct which is 1.23 m in length.)

the values obtained when the system was not operating; the dotted line shows those attained when it was operating. The wide frequency components of fan noise are amplified by resonance in the duct, but blade passing noise clearly appeared as peak components. By putting the system into operation, sound reduction value from the first order to the third was 14, 7 and 6 dB respectively. The noise reduction value for the overall frequency was 2 dB. Generally, however such a long duct is not applied to small electronics devices. Figure 7 shows the sound field at the end of the duct intake side for different values of X, the distance between the fan and the end of the duct intake. The direction of the blade passing noise component becomes symmetrical when X is 90 mm. This tendency is very important to eliminate noise distributed over a wide space. Figure 8 shows the sound field measured for 351 Hz, when X is 90 mm. The sound reduction value is 10 dB at the end of the duct. The reduction value at 0.3 m is from 5 dB to 6 dB for every direction. These sound reduction values are smaller than 10 dB because sound propagated from the end of the duct outlet negatively effects the sound fields at the duct intake side.

5. CONCLUSIONS

Using a normal cooling fan and a small speaker, we carried out basic experiments to eliminate blade passing noise. We found that the signals picked up from the rotation of a fan can be used as reference signals to make anti-sound waves, and that a speaker can be located near a fan. Furthermore, we found that when the distance between the fan and the end of the intake side of a duct is 90 mm (≒diameter of a fan), this system attains a 10 dB sound reduction value for the first order component of blade passing noise. These results indicate that development of a small low-noise fan for installation in an ANC system is possible.

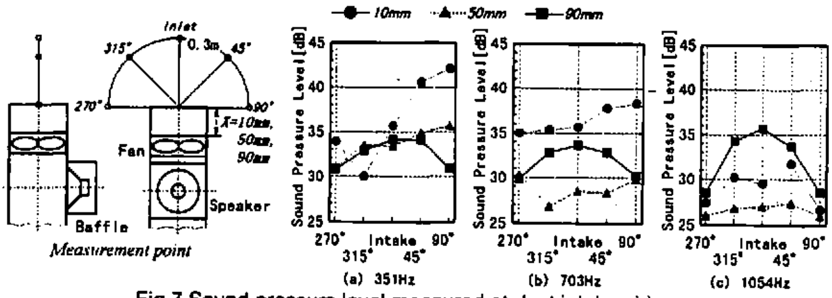

Fig.7 Sound pressure level measured at duct intake side.

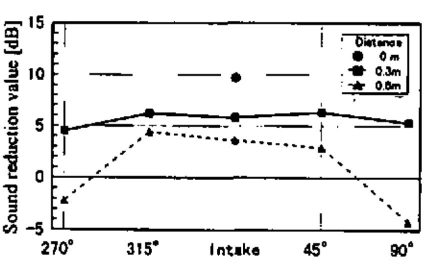

Fig.8 Sound reduction values at the duct intake side obtained with the system. (When the distance from the fan to the duct intake side is 90 mm.)

REFERENCES

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