Study on evaluation method of the pure tone for small fan

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ABSTRACT

In the field of audio, visual and information technology equipment, small fan noise which includes many pure tones becomes annoying components. Pure tones are caused by the electromagnetic force of motor, the flow interference between blades and spokes, the acoustic modes of the structure and so on. These tones become not only the main contribution to the overall sound pressure level, but also unpleasant component. Some metrics for the pure tone have been presented, however the one which specified for small fan noise has not been developed. In this study, evaluation of multiple pure tones generated by small fan was attempted and examined by using sensory test.

Keywords: Small fan, Fan noise, Tonal components, Tone to noise ratio, Prominence ratio, Sound Quality
I-INCE Classification of Subjects Number(s): 12.3.4 63.7

1. INTRODUCTION

Recently, performance improvement and downsizing of information technology or audio and visual equipment have been accelerated, the installation density of electric devices has also been increasing and as a result, the cooling fans are required so as to exhaust the big amount of heat. The usage of fan makes the heat design much easier, on the other hand, the fan noise is getting big problem. Especially, the tonal components of the noise are annoying even though the level is low. In the standards such as the ISO 7779, ECMA 74 and ANSI S1.13., the judgment methods of the certain prominent discrete tone in information technology devices are presented as the Tone to Noise Ratio (TNR) and the Prominence Ratio (PR). On the other hand, a psychoacoustic approach to detect the tonal feeling has been developed and the metrics such as the Tonality has been used for the evaluation of the tonal feeling. In the present study, the sound quality evaluation for the small fan was done by using the metrics based on the TNR and PR.

2. Noise characteristics of small fan

2.1 Fan noise generation mechanism

The Aerodynamic noise generated from fan can be classified into the rotating noise and the turbulent flow noise. The former is produced by the periodic pressure fluctuations due to the rotation of the impeller and has the discrete components at the blade passing frequency which is the product of the number of blades Z and rotating speed n and its harmonics. It is so peaky that the contribution to the overalls noise level is large and is annoying.

The rotating noise is caused by two types of unsteady flow, one is so called the potential interference noise caused by the pressure distribution around the impeller and another is so called wake interference noise induced by the separated flow from the trailing edge of the impeller. In case of the small axial fan, when the obstacles such as stators and spokes are located just behind the impeller, the unsteady flow interfere the obstacles and large noise will be generated.

On the other hand, the turbulent noise is caused by the random turbulent flow in the fan. The noise source consists of the pressure fluctuations induced by the turbulent boundary layer on the surface of

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the impeller, the fluctuation of lift caused by the vortex shedding from the trailing edge of the impeller and so on. It has broadband frequency components, the energy is smaller than the rotating noise and the contribution to the overall sound pressure level is secondary.

2.2 Tonal components of centrifugal fan

The rotating noise from centrifugal fan is caused by the interference between the periodic flow from the impeller blade and the tongue of the fan casing. The frequency of tonal components f_r are shown as,

$$f_r = i \cdot Z_r \cdot n \tag{1}$$

Where,

i : Number of frequency components

Z_r : Number of blades

n : Rotating speed [rps]

2.3 Tonal components of axial fan

The rotating noise from axial fan is caused by the interference between the periodic flow from the impeller and the stator or the spoke which supports the motor. In general, the number of the blades and the spokes should be the prime number so as not to occur the interference of the blades and the spokes at the same time, so the frequency components are more complicated matter than that of centrifugal fan. The frequency of tonal components f_r are shown as the following formula,

$$f_r = \frac{j \cdot Z_r \cdot n}{j \cdot Z_r + k \cdot Z_s} \tag{2}$$

Where,

j, k : Integer index(…-2, -1, 0, 1, 2…)

Z_r, Z_s : Number of blades and spokes

n : Rotating speed [rps]

On both cases, the shape of the wake is not exact sinusoidal, so the harmonics components are appeared at the same time in FFT. In addition, these components are influenced by the frequency response function of the fan system. The typical noise spectrum of the small axial fan is shown in Figure 1.

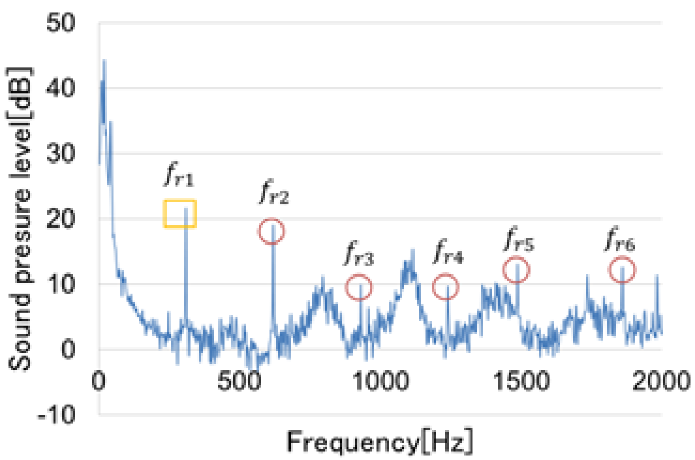


Figure 1 – Noise spectrum of small axial fan

3. Evaluation methods of tonal components

3.1 Tonality

Tonality provided by Terhardt or Aures is known as the metrics that indicate the tonal feeling of the sound. It is calculated as the product of the various weighted functions to the tonal components such as the influence of masking by other tones, the ratio of tonal components and noise, the influence of hearing threshold and is applicable to the evaluation of subjective tonality of total sound.

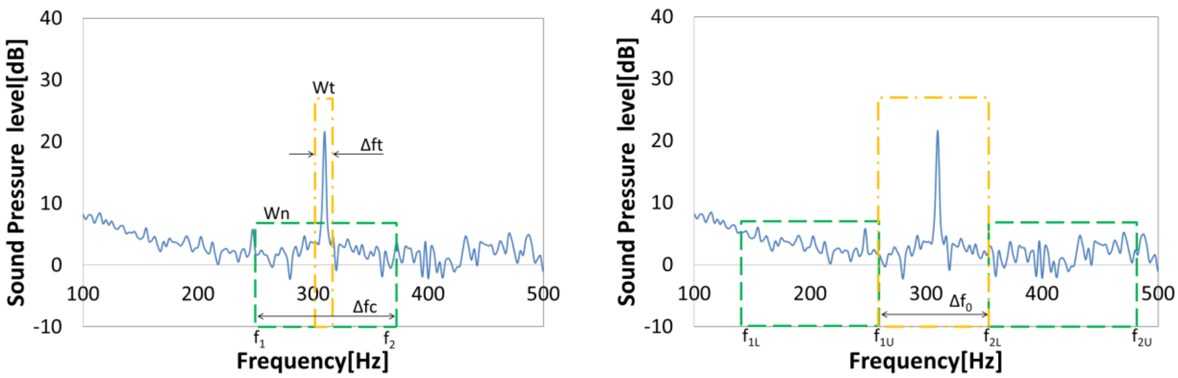
3.2 Tone to Noise Ratio (TNR) and Prominence Ratio (PR)

In the standard, the DIN 45681 “Acoustics - Determination of tonal components of noise and determination of a tone adjustment for the assessment of noise immissions” defines how to determine the tonal component to the noise. But this method shows only the excess of the level and does not include the psychoacoustic consideration.

In general, the audible threshold or the prominence of a tonal component is decided by the relationships between the tonal component level and the surrounding band noise level which is masking the tonal component. The frequency bandwidth is so called the critical band that is centered at the frequency of the tone. In the standards such s as the ISO 7779, ECMA 74 and ANSI S1.13., the judgment methods of the certain prominent discrete tone in information technology devices are presented as the Tone to Noise Ratio (TNR) and the Prominence Ratio (PR).

The TNR is defined as the decibel value of the ratio of the power of tonal component and other noise component in the critical band. In the ECMA-74, when the TNR exceeds by 6dB, the tonal component is regarded as the prominent discrete tone. In case that multiple peaks exist in the same critical bandwidth or the noise level next to the critical bandwidth is considerable, the TNR vales tends to show bigger or smaller.

The PR is defined as the decibel value of the ratio of the critical bandwidth power including the tonal component and the critical bandwidth power on both sides. In the ECMA-74, when the PR exceeds by 7dB, the tonal component is regarded as the prominent discrete tone. Figure 2 is the schematic view of calculating the TNR and PR.



Tone to Noise Ratio Prominence Ratio

Figure 2 – Schematic view of TNR and PR calculation

3.3 Total TNR(T-TNR) and Total PR(T-PR)

In fan noise evaluation, it is important to quantify the tonal components for the product quality control, the identification of noise source and the noise reduction. The Tonality is a little bit complicated and isn’t good at the evaluation of the individual tonal component. On the other hand, the TNR and PR are the indicators for the prominent discrete tone and don’t care for the multiple tonal components. Here, the new evaluation parameters so called TTNR and TPR are presented, in which the excess levels for multiple tonal components are calculated by the method of the TNR and PR and summed up the TNRs and PRs.

$$T \cdot TNR = 10\log_{10}\left(\sum_{i=1}^{n} 10^{\frac{TNR_i}{10}}\right)$$
$$T \cdot PR = 10\log_{10}\left(\sum_{i=1}^{n} 10^{\frac{PR_i}{10}}\right) \tag{3}$$

Where,

$T \cdot TNR$: Total tone to noise ratio [dB]

TNR_i : Tone to noise ratio for ith peak component [dB]

$T \cdot PR$: Total prominence ratio [dB]

PR_i : Prominence ratio for ith peak component [dB]

4. Sensory test

4.1 Noise source

As the noise source, a small axial fan (The Orientalmotor MD825B-12) was chosen. The fan was driven by 3740rpm without flow restriction and the noise was measured in front of the fan by the noise level meter (Rion NL-31) set at 0.5m apart from the fan. The noise signal was recorded by the PC as wav file.

The recorded noise was cut by 3sec duration and regarded as the Sound 1 which was original one. Then, the Sound 2 to Sound 5 were made by amplifying the peak components under 4000Hz by 2 to 5times as the Sound 1. Finally, the sound pressure of the sounds was adjusted so as the overall sound level were the same.

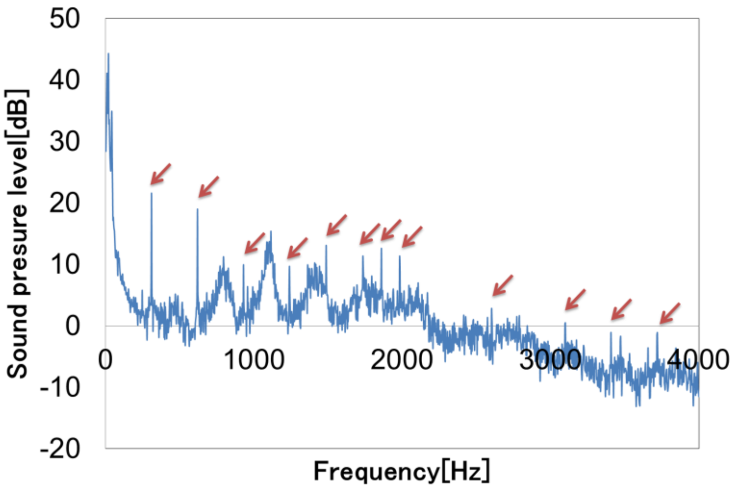


Figure 3 – Spectrum of test sound

4.2 Jury test

For the jury test, the PC (Paired Comparison) method was chosen and 20 college students with the normal hearing attended the test as juries. The adjective of “Annoying – Not annoying" was used for the evaluation. In each test set, two sounds were chosen at random out of five sounds and the jury judged the impression of the first sound to the following sound by five steps. In order to reject the influence of the presentation order, all combination patterns were proposed. By using the results, the correlation between the subjective annoyance and the sound quality evaluation parameter as presented in this paper was calculated.

5. Results and discussion

Figure 4 shows the relationships between the presented metrics and the subjective annoyance. TTNR and TPR showed high correlation coefficients over 0.99. Comparing the TTNR and TPR, TPR has higher sensitivity.

In this case, since the frequency structure of the sample sounds was same and only the level of the tonal components was varied, the level of the tones might decide the annoyance even the overall level were standardized. As the next step, it is required the test with sample sounds which frequency structure of tones or each level of tones are varied. In addition, by standardizing the loudness level, the effect of tonal component will appear more significantly.

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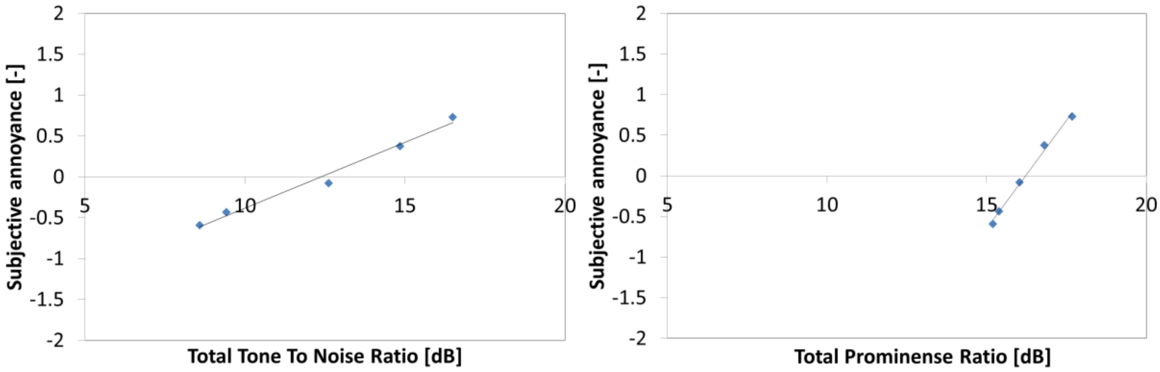

Figure 4 – Relationships between TTNR or TPR and subjective annoyance

6. SUMMARY

For the evaluation of the sound quality of small fan, new metrics based on the TNR and PR were presented and investigated the relationship to the subjective annoyance by the jury test. The presented metrics showed high correlation with the subjective annoyance.

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