Mechanical Active Noise Control for Cross Flow Fan

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Abstract

In this study, a new method of noise reduction for cross flow fans, the mechanical active noise control, was developed. The study was conducted by using many types of plate tongues, stepped tongues and oblique tongues. And, the sound levels along the leading edge of the stepped tongues or the oblique tongues were measured to investigate the mechanism of the mechanical active noise control,

Keywords: noise reduction, active noise control, cross flow fan, rotation sound

1 Introduction

The main noise of cross flow fans is the rotation noise generated by the interference between the blade of impeller and the tongue or the partition plate in the casing. So the fan noise can be reduced by removing or separating the tongue from the impeller or cancelling the rotation noise by the method of active noise control.

In a very recent analysis, Cho and Moon [1] have shown through unsteady CFD and unsteady aeroacoustic pressure calculations that "the interaction between the stabilizer and rotating impeller generates tonal sound. Also, it is found that the trailing edge of blade generates more acoustic pressure than the leading edge." Meanwhile, Fukano *et al*. [2], [3] examined the effects of impellers, tongues and a casing configuration on the noise performance of a cross flow fan. Hayashi *et al*. [4-6] revealed that the fan noise could be reduced by changing the blade shape. H.M.Koo *et al.* [7] and Hyoung [8] conducted experiments on the effects of blades and tongues configuration on noise reduction.

In our previous study, we developed the noise reduction method of cross flow fan by using step tongues and oblique tongues.

However, conventional studies have not been considered about new method of noise reduction for cross flow fans, the mechanical active noise control, where the noise with inverted phase from the original noise is generated.

In this study, the mechanical active noise control was developed. Usually, in the idea of active noise control, noise reduction is completed by interfering the original noise and the inverted noise generated by complicated electrical devices. However, with this electrical active noise control, it is very difficult to bring the source of inverted noise close to that of the original noise. In this study, stepped tongues and oblique tongues were used to generate the original noise and the inverted noise, which sources were placed at almost the same position.

Characteristic of total pressure coefficient to flow rate coefficient is used to evaluate the fan performance. Specific noise level K was the most important parameter to evaluate the effect of noise reduction.

At the first, the experiment was carried out using many types of plate tongues, stepped tongues and oblique tongues where the fan performance characteristics including noise level and total pressure output were measured. Specific noise level K was calculated as the most important parameter to evaluate the effect of noise reduction. As the experimental results, it was made clear that the mechanical active noise control was very useful to reduce rotation noise level.

Secondly, the experiment was conducted to investigate the mechanism of mechanical active noise control. The sound levels along the leading edge of the stepped tongue or the oblique tongue were measured where the phase angle of its sound wave was calculated. In conclusion, the mechanism of mechanical active noise control was clarified from the phase angle of noise signal.

2 Experimental apparatus and procedure

Figure 1 shows the experimental apparatus of the cross flow fan used in this study. The fan had 27 blades with an outside pitch of 10 mm and 0.8 mm blade thickness. The impeller had a 90 mm outside diameter and was 127 mm in axial length. A 66.5 mm diameter hole was bored in one of the end plates to permit the insertion of the one-hole yaw-meter. The tongue was flat and the casing was composed of an arc joined to a flat duct. The experimental apparatus conforms to JIS B 8330 for the configuration of air blowers. The clearance between the impeller and the tongue was 3 mm in the radial direction, and the clearance between the leading edge of casing and the impeller was fixed at 11 mm. The flow rate was controlled by changing the aperture ratio of the duct outlet. The pressure transducers, the fan tachometer and the microphone were used to determine the fan performance parameters and the noise level. The rotational speed of fan was maintained at 1400 min^{-1}. A digital monometer was used to record the static and total pressures in the duct. The noise measuring method was based on the noise level measurement standard JIS B 8346 for air blowers. The A-weighting fan noise was measured by a sound level meter, the data from which were input into a PC and processed via the FFT contained in the LabVIEW8.0 software.

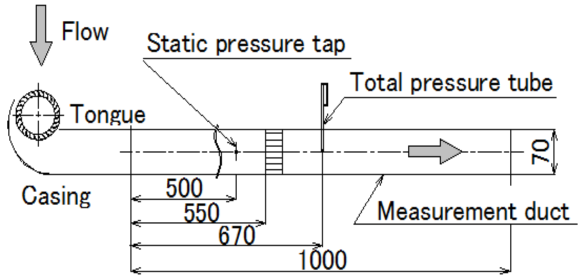


Fig. 1 Experimental apparatus

The fan performance was characterized in terms of the above-mentioned three parameters, Eqs. (1) ~ (3).

(1) Total pressure coefficient ψ_t,

$$\psi_t = \frac{2p_t}{\rho u^2} \tag{1}$$

where p_t is total pressure at the outlet of the fan [Pa], ρ is density of air [kg/m^3] and u is outside speed of the impeller [m/s]

(2) Flow coefficient φ,

$$\varphi = \frac{Q}{DLu} \tag{2}$$

where Q is flow rate [m^3/s], D is outside diameter of the fan impeller [mm], and L is width of the fan impeller [m]

(3) Noise level (Specific sound noise level) K,

$$K = SPL - 10\log_{10} QP_t \tag{3}$$

where SPL is Sound pressure level [dB(A)]

3 Development of Noise Reduction Method

In our previous study, the fan noise could be reduced by alteration of the tongue shape. Unfortunately, a detailed mechanism of the fan noise reduction is not known yet. In this section, we mention about noise reduction caused by the alteration of tongue shapes.

Figure 2 shows the principal position of the edge of tongues. The nine different dividing tongue geometries investigated in this study are shown in **Figure 3**. These geometries can be summarized as follows: Tongue A affords the reference condition (default tongue position, taken as the reference datum). The shaded regions in **Figure 3** show those portions of the dividing tongue geometry that are at the default reference position. Tongues B and C are both still flat tongues, but positioned one-half blade pitch above or below the datum. Tongues D, E, F and G have a half pitch offset over half of tongue (and vary only with regard to which half is up and which half is down. D is left or right mirror image of E. Tongues F and G are rotation of E and D about tongue centerline). Tongues H and I are slanted on the face perpendicular to a flow from the fan outlet.

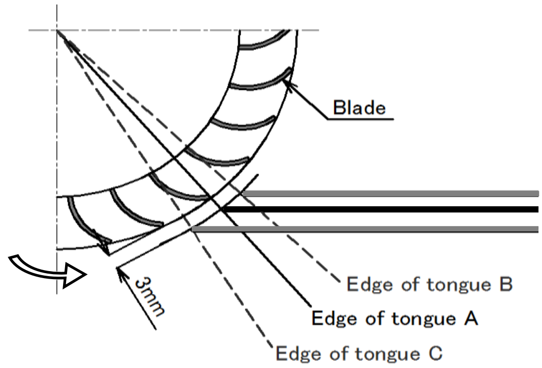


Fig. 2 Principal positions of the edge of tongues

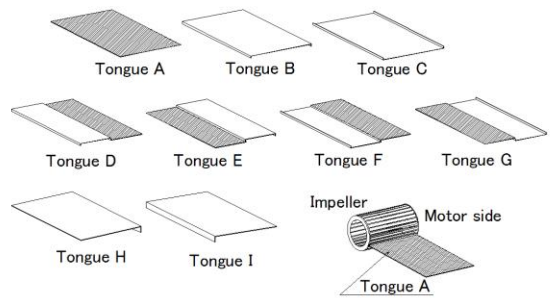


Fig. 3 Nine configurations of the tongues in experiment

4 Experimental results and discussion

The fan performance is essentially unaffected, or very slightly improved, by modifications to the dividing tongue from the comparison of the performance of the modified tongues (step tongue D, oblique tongue I) with that of flat tongue A in **Figure 4**. Meanwhile, **Figure 5** shows a relatively significant decrease in the SPL and K, especially for tongues D and I. The SPL are reduced except for high flow rate ($\varphi \geq 0.7$).

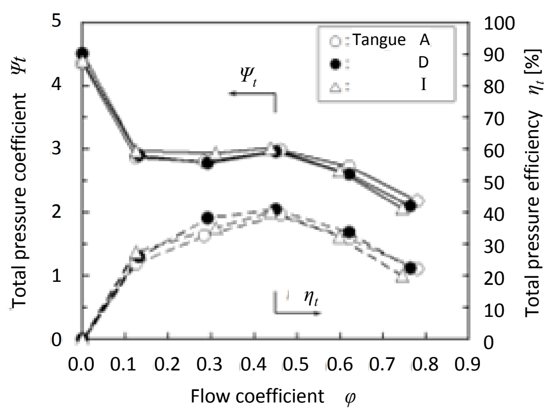


Fig. 4 Relation between total pressure coefficient ψ_t and total pressure efficiency η_t for tongues A, D and I

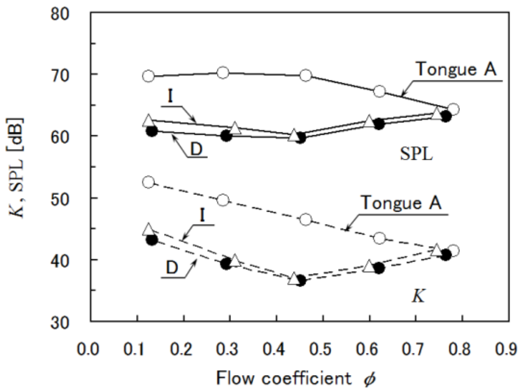


Fig. 5 SPL and specific noise level *K* for tongues A, D and I

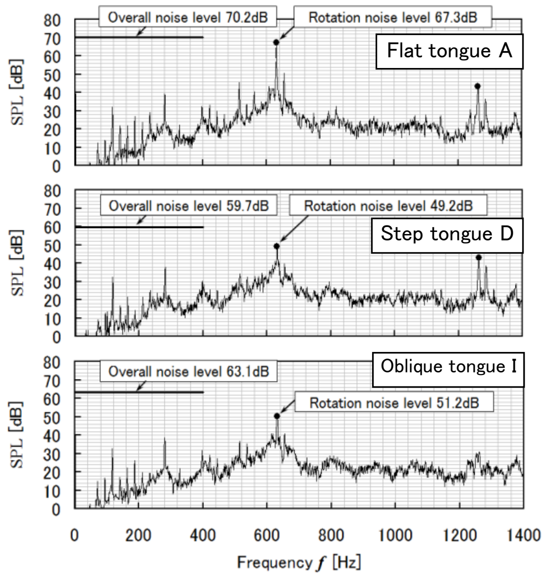
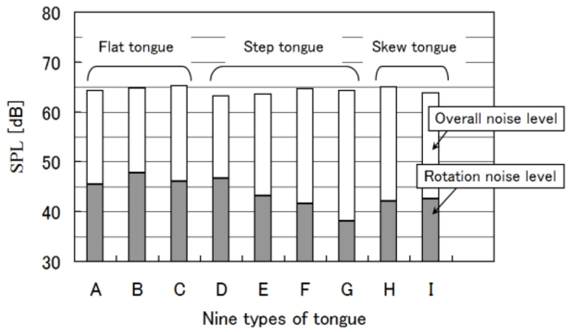


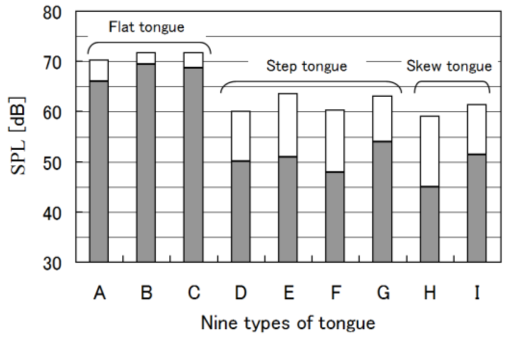
Fig. 6 Comparison of spectra of acoustic signal for tongues A, D and I (low flow rate region for φ= 0.3)

The spectral analysis of the acoustic signals from dividing tongues D and I for φ= 0.3 are shown in **Figure 6**. Tongues D and I result in almost 17 dB noise reduction at the blade passing frequency relative to that of tongue A in **Figure 6** (middle). The overall noise level for tongue D was 59.7 dB and that for tongue I was 63.1 dB. There was some reduction in SPL for the other tongues as well. The oblique tongue I reduced not only the rotation noise level but also second rotation noise level as shown in **Figure 6** (bottom).

The relationship between the overall noise level and the rotation noise level for the 9 different tongues are shown in **Figure 7**. **Figure 7 (a)** shows the overall noise level for φ=φ_{max} differs more than 17 dB from rotation noise level. At this flow rate, turbulence noise (sometimes called the broad band noise) is the main noise source. Meanwhile, **Figure 7 (b)** shows the noise data for a low flow rate of ψ= 0.3. The rotation noise levels of flat tongues A, B and C are nearly equal to the overall noise level. However, the rotation noise levels of the tongues E to I are vastly reduced. Accordingly, in this case the rotation noise is the main noise source. The alteration of tongue shapes therefore is very effective.



(a) φ=Max



(b) φ=0.3

Fig. 7 Overall noise level and rotation noise level for 9 types of tongue

5 The mechanism of mechanical active noise control

The experiment was conducted to investigate the mechanism that the noise of stepped tongues and oblique tongues are smaller than flat tongues. The sound levels, pressure and velocity along the leading edge of typical tongues of stepped tongues or oblique tongues shown in **Figure 3** were measured using micro-phone, pressure sensor and flow velocity meter where the phase angle of its signal wave were calculated.

Figure 8 shows the impeller and the tongue used in experiment. **Figure 9** shows the five tongues used in experiment. **Figure**.**10** shows the three mounting points of sensors for measuring sound, pressure and velocity.

Fig. 8 Impeller and tongue used in experiment

Table 1 shows the frequency and the SPL level of rotation sound for each tongue where tongue E and D are for stepped tongue, and tongue H and I are for oblique tongues. It shows that the rotation sound is the same frequency regardless of the shape of the tongues.

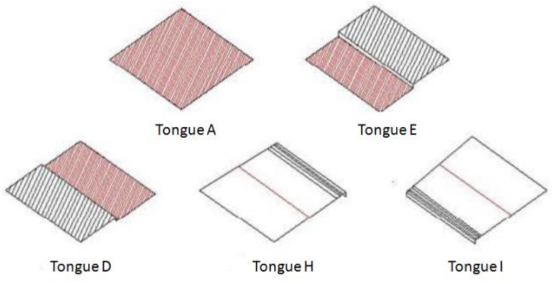


Fig. 9 Five tongues used in experiment

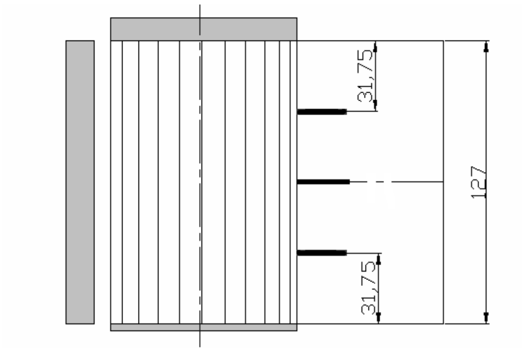


Fig. 10 Mounting points of sensors for measuring sound, pressure and velocity

Table 1 Frequency and SPL of Rotation sound for each tongue

Tongue	Rotation Sound [Hz]	SPL [dB]
A	631	56.2
D	631	51.7
E	630	52.26
H	627	49.81
I	629	49.87

Figures 11, 12 and 13 show the comparison of sound waves, pressure waves and velocity waves for mounting point 1/4 and 3/4 of stepped tongue E, respectively. It shows that the frequency of the rotation sound are same on the two measuring points that are of 1/4 and 3/4 of the axial length from the axial edge of the fan, and that the phase of the 1/4 point is deviated from the phase of the 3/4 point by 180°, for the stepped tongue E.

Figure 14 shows the comparison of sound waves for mounting point 1/4 and 2/4 of oblique tongue H. It shows that the phase of the 1/4 point is deviated from the phase of the 2/4 point by 90°. **Figure 15** shows the comparison of sound waves for mounting point 1/4 and 3/4 of oblique tongue H. It shows that the phase of the 1/4 point is deviated from the phase of the 3/4 point by 180°, It is supposed by the figures that the phase difference of the rotation sound become larger according to length from the axial edge of the fan for the oblique tongue H.

The mechanism of restraint of the noise by the shape change of the tongue, that is the mechanical active noise control, was clarified from the phase angle of noise signal.

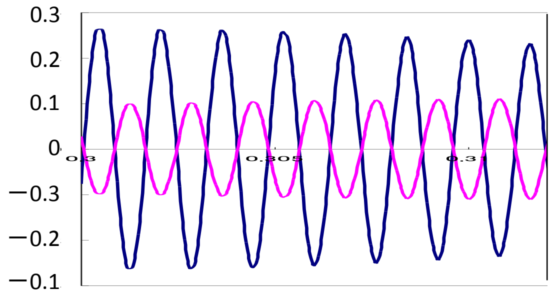


Fig. 11 Comparison of sound waves for mounting point 1/4 and 3/4 of stepped tongue E

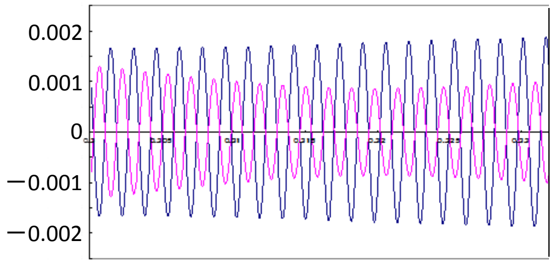


Fig. 12 Comparison of pressure waves for mounting point 1/4 and 3/4 of stepped tongue E

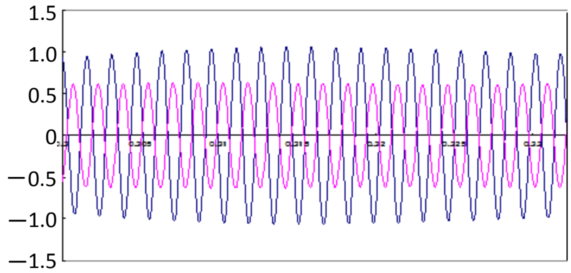


Fig. 13 Comparison of velocity waves for mounting point 1/4 and 3/4 of stepped tongue E

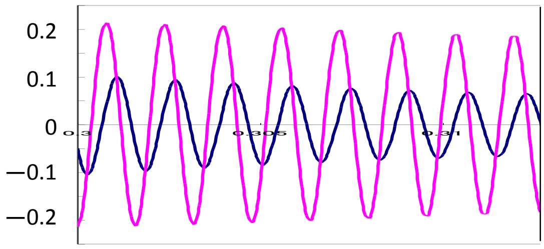


Fig.14 Comparison of sound waves for mounting point 1/4 and 2/4 of oblique tongue H

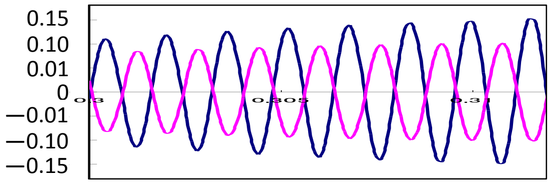


Fig.15 Comparison of sound waves for mounting point 1/4 and 3/4 of oblique tongue H

6 Conclusions

The rotation noise is the main noise force in the low flow rate regime, while the turbulence noise is the main noise source in the high flow rate regime. This paper shows the followings for the low flow rate generated by cross flow fans.

(1) The modified tongues, step tongues or oblique tongues, show the smaller SPL and Specific Sound Noise level K ;
(2) The modified tongues reduced the rotation noise level, especially the oblique tongue reduced not only the rotation noise level but also second rotation noise level;
(3) The noise reduction by the modified tongues is caused by the phase deviation by 180°.

The mechanical active noise control was clarified from the above results.

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