Use of rectifying meshes for active noise control in an air flow duct

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At the application of an Active Noise Control (ANC) for a duct with high speed flow whose velocity is around 12.0 m/s (Reynolds number of 1.0×10^5), the following results for the use of the meshes, as the simplest method for rectifying the flow, were given. The effect of ANC depends on the disturbance velocity attenuation factor of the rectifying meshes. The meshes should not be installed closer to the detection sensor than half the diameter of the duct. The meshes are more effective than the use of thicker sound absorbent materials on the sensors, although the numerical aperture of duct cross-section can be decreased both. The noise reduction effect by use of the meshes were around 3 to 4 dB, without ANC under 200 Hz, and 13 dB of noise control effect at 500 Hz with the ANC system with the meshes (These effects were measured 100 mm from the duct outlet).

Keywords: Active noise control, Air flow, Duct, Rectifying meshes, Filtered-X algorithm

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1. INTRODUCTION

Recent office automation equipment is generally designed for high-density packaging and dissipates much heat. It has, therefore, air from blowers, fans and a duct leading to outside of the equipment. Especially, for high speed flow in the duct, additional turbulent noise uncoherent from the original noise can be produced. This decreases the estimation precision of an Adaptive Digital Filter when ANC is applied to the duct.

Ordinary countermeasures against the problem can mainly be divided into two ways. One is the taking only the coherent components as the primary noise with plural detection sensors.¹⁾ The other is the putting the meshes²⁾ or the grid³⁾ in the duct for flow rectification. The use of the meshes is suitable because of its simplicity, low cost, and well proven principles.^{4,5)}

Though criteria about the effect of the meshes

have already existed,^{4,5)} the relationship between the criteria and the effect of ANC has not been clarified. In this report, the relationship between them have been examined. Furthermore, a suitable position for settling the meshes, the effective flow range for adapting the meshes, the noise control effect due to the meshes, and a comparison with the meshes with sound absorbent material on the sensors to reduce the additional noise, have been reported.

2. EQUIPMENT USED IN EXPERIMENT

Figure 1 shows the layout of the equipment which imitates the cooling system of a large printer in the experiment. Details are as shown below.

- Maximum air velocity at outlet 12.0 m/s
- Reynolds number inside the duct 1.0×10^5
- Pressure loss factor ζ at the connection of the duct 0.59
- Algorithm Improved filtered-X⁶⁾
- DSP 5 chips of Fujitsu MB86224 (75 ns)⁷⁾

- Sampling frequency 9120 Hz
- Thickness of sound absorbent material inside duct 10 mm (bottom is 20 mm)

- Attenuation with sound proof box 30 dB(A)

3. RECTIFYING MESHES

Before selecting the meshes, several samples in terms of their rectifying effect on the duct were evaluated. Table 1 indicates values for a few samples prepared in order of the disturbance velocity attenuation factor⁴⁾ which gives a measure for the rectifying effect. Table 1 indicates that 22 mesh (type b) would be the most effective.

4. WORST MESH POSITION

The sensors were installed at a fixed position as shown in Fig. 1. Mesh b was settled at distance D from the duct inlet, while the coherence function between the detection sensor and the error sensor was measured under a flow speed of 6 m/s and 12 m/s, as shown in Fig. 2. The flow speeds were controlled by voltage supplied to the blower.

Consequently, the coherence function soon deteriorated irrespective of flow speed when D was 300 mm, where the meshes were positioned closer to the detection sensor. The meshes should not be installed at the close area to the detection sensor by a half the diameter of the duct because the meshes need the area for completion of their rectifying effect.⁸⁾

Strictly speaking, variation of the positions of the meshes had simultaneously changed not only the distance D but also the positions of the meshes relative to the detection sensor. These simulta-

Fig. 1 Equipment layout for experiment.

Table 1 Varieties of the rectifying meshes.

Mesh type	Numerical aperture [%]	Mesh/1 inch	Wire diameter [mm]	disturbance velocity attenuation factor
a	45.8	10	0.45	— ^{#1}
b	48.5	22	0.35	0.10
c	49.7	5	1.50	0.31
d	55.2	10	0.35	— ^{#2}
e	58.4	12	0.50	0.36
f	67.7	10	0.45	0.7 ^{#3}
g	74.3	10	0.35	0.8 ^{#3}
h	78.0	3	1.00	0.8 ^{#3}

^{#1} Two type f meshes (They were placed 140 mm apart.)

^{#2} Two type g meshes (They were placed 140 mm apart.)

^{#3} Some errors have been contained because figures of meshes are outside the range for approximation.

Fig. 2 Coherence function between detection sensor and error sensor at each distance D for flow velocity of 12 m/s and 6 m/s.

Fig. 3 A-weighted frequency characteristic at each mesh. $D=50$ mm, flow velocity of 12 m/s.

neous factors were absolutely negligible because wider variation of the positions in the case of $D=0$ to 250 mm were not critical for deterioration of the coherence function than the narrower some in the case of $D=250$ to 300 mm.

5. NOISE CONTROL EFFECT DUE TO MESHES

Figure 3 shows frequency characteristics measured at a point 100 mm from the duct outlet. The maximum static pressure of the blower is so high (60 mm H₂O) that the flow speed of 12 m/s could be maintained regardless of the variety of mesh. Actually, mean error accompanying each measured flow speed, scattered as the same extent as the slight changes of the flow speed caused by the variety of meshes.

The noise reduction effect by meshes without ANC were under 200 Hz for mesh b (see the plots ○ in Fig. 3). The reduction at around 3 to 4 dB was possible in comparison with the case with no meshes (see the plots × in Fig. 3), even without ANC. Furthermore, a reducible sound pressure level (SPL) of around 13 dB at 500 Hz was accomplished with ANC (see the plots ● in Fig. 3).

6. THE EFFECT OF ANC WITH MESHES

6.1 Relationship between Effect and Type of Meshes

ANC was applied, when each of different mesh was set inside the duct in turn. The effect of ANC was measured after adapting coefficients of all digi-

Fig. 4 Reducible SPL with ANC at each mesh. A-weighted characteristic, $D=50$ mm.

tal filters. The flow speed of the blowers, and the amplifier gain for sensors and a secondary source were all kept constant so that the measured data could be compared despite different rectifying meshes. Figure 4 shows the effect of ANC at each mesh measured at a position 100 mm from the duct exhaust port under a flow velocity of 12 m/s. The results may be summarized as follows. First, reducible SPL depends more on the numerical aperture than the size of mesh hole. Second, the smaller the mesh holes, the more reducible the SPL, is for almost the same numerical aperture. Finally, these factors also reflect the disturbance velocity attenuation factor which decides the reducible SPL.

6.2 Flow Range for Adapting Meshes for ANC

The flow range for adapting the meshes has been

Fig. 5 Effect of change in flow velocity on ANC ($D=50$ mm).

described in Fig. 5. The data was measured at each flow speed which was set with voltage supplied to blower, using mesh type b after setting the gain of the amplifier for the sensors and secondary source, and each coefficient of all digital filters so that measurement data could be compared despite different flow speeds. The effect of ANC deteriorated at 6 m/s because dominant periodic noise synchronized with blower rotation corresponded to the 1 kHz of cut-on frequency.

7. THICKER SOUND ABSORBENT MATERIAL ON SENSORS V/S. MESHERS

Two selections must be realistic for gaining high coherency under these experimental condition without the evident loss in the air pressure. One is use of the sound absorbent material of more than 20 mm in thickness, on the surface of sensors without the rectifying meshes, and the other is the use of the rectifying meshes with the sound absorbent material of just 20 mm in thickness, on the surface of sensors. Both methods were compared. First, flow speed was set as 12.0 m/s without the rectifying meshes, and the numerical aperture of the duct cross-section was defined as 100%. Next, the thickness of sound absorbent material on the sensors was gradually increased like these.

Thickness of sound absorbent material	Flow velocity	The numerical aperture of duct cross-section
20 mm	12.0 m/s	100.0%
30 mm	13.0 m/s	92.3 %
40 mm	14.2 m/s	84.6 %

Figure 6 shows the A-weighted reducible SPL with ANC for various thickness of sound absorbent

Fig. 6 A-weighted reducible SPL with ANC at each thickness of sound absorbent material on the surface of sensors.

material on the surface of sensors, and for 3 mesh (type h) with a 20-mm-thick sound absorbent material (plotted with same data as in Fig. 4). It is unnecessary to increase the thickness of sound absorbent material to more than 30 mm since this reduces the numerical aperture of the cross-section.

8. CONCLUSION

13 dB of noise control effect (measured 100 mm from the duct outlet) was obtained at 500 Hz with the ANC system with meshes, applied to an exhaust duct with a flow velocity of 12.0 m/s (Reynolds number of 1.0×10^5). The effect of ANC depends on the disturbance velocity attenuation factor of the meshes, which gives a measure of the rectifying effect. The mesh should not be installed closer to the detection sensor than half the diameter of the duct because this would destroy the point of adopting the meshes.

The noise reduction effect without ANC, which the meshes bring by themselves, was under 200 Hz by the use of an ideal mesh. At around 3 to 4 dB (measured 100 mm from the duct outlet), the effect was observed in comparison with the result for no meshes.

The mesh is more effective than the use of thicker sound absorbent materials on the sensors, although the numerical aperture of duct cross-section can be decreased both. The effective flow range worth for adapting the meshes were observed at flow speed of more than 6 m/s.

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