Series of Experiments for SPVG analysis

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ABSTRACT

A previous study, the authors have presented a concept of manufacturing and theoretical analysis a ventilation grille called SPVG which is capable of ventilating and reducing the noise heard inside houses. To maximize the soundproofing ability, various shapes of inlet and outlet are determined by an investigation of the distribution of higher order mode waves formed inside the SPVG. The acoustic characteristics of SPVG are experimentally considered in present work.

1. INTRODUCTION

A previous study [1], the authors have presented a concept of manufacturing and theoretical analysis a ventilation grille called SPVG (Soundproofing ventilation grille) which is capable of ventilating and reducing the noise heard inside houses. Due to the fact that SPVG must have a large volume to attenuate the low frequency range of noise, while sound propagates through SPVG is a combination of a plane wave and the higher order mode waves. The higher order mode waves are reviewed in numerous experimental and analytical studies [2-4]. It generates very high levels of sound pressure, especially at resonance frequency. Therefore, in order to enhance the soundproofing capability, it is necessary to reduce sound pressure levels or prevent the generation of higher order mode waves in any technique. To maximize the soundproofing ability, various shapes of inlet and outlet are determined by an investigation of the distribution of higher order mode waves formed inside the SPVG. In present work, the acoustic characteristics of SPVG are experimentally considered based on the reverberation chamber method.

2. ATTENTION TO THE SHAPE OF SPVG

Model of the ventilation grille is shown in Fig.1. A section area $S_w = a \times a$ and depth L of rectangular cavity that has N inputs and M outputs at both sides. The theoretical calculation of the sound pressure inside the ventilation grille is based on the wave equation in term of the velocity potential. Let $V_x = -\partial\phi\ /\partial x$, $V_y = -\partial\phi\ /\partial y$ and $V_z = -\partial\phi\ /\partial z$ be the velocity components in the x, y and z directions, respectively. The boundary conditions are:

$$[1]\ V_x = 0 \text{ at } x = 0 \text{ and } x = a \tag{1}$$

$$[2]\ V_y = 0 \text{ at } y = 0 \text{ and } y = a \tag{2}$$

$$[3]\ V_z = V_0^{(1)}\ F_0^{(1)}(x,y) + V_0^{(2)}\ F_0^{(2)}(x,y) + \cdots + V_0^{(N)}\ F_0^{(N)}(x,y) = \sum_{i=1}^{N} V_0^{(i)} F_0^{(i)}(x,y) \text{ at } z = 0 \tag{3}$$

$$[4]\ V_z = V_L^{(1)}\ F_L^{(1)}(x,y) + V_L^{(2)}\ F_L^{(2)}(x,y) + \cdots + V_L^{(M)}\ F_L^{(N)}(x,y) = \sum_{i=1}^{M} V_L^{(i)} F_L^{(i)}(x,y) \text{ at } z = L \tag{4}$$

where the symbols in Eq. (1)-(4) are given in [1]. According to these boundary conditions the sound pressure at the outside becomes:

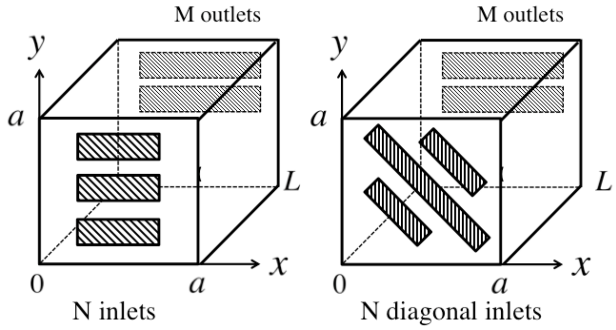

Figure 1 Model calculation of SPVG

$$\bar{P}_L = j\,\frac{4k\rho c}{S_w}\left[\frac{1}{\sin(kL)}\left(-\sum_{i=1}^{N}U_0^{(i)} + \cos(kL)\sum_{i=1}^{M}U_L^{(i)}\right) + \sum\left\{\frac{\theta_{m,n}\Delta_{m,n}}{\mu_{m,n}\sinh(\mu_{m,n}L)} + \frac{\cosh(\mu_{m,n}L)}{\mu_{m,n}\sinh(\mu_{m,n}L)}\lambda_{m,n}\Delta_{m,n}\right\}\right] \quad (5)$$

where $$\theta_{m,n} = \sum_{i=1}^{N}\int_{a_{0,0}^{(i)}}^{a_{0,1}^{(i)}}\int_{b_{0,0}^{(i)}}^{b_{0,1}^{(i)}} V_0^{(i)}\cos\left(\frac{m\pi x}{a}\right)\cos\left(\frac{n\pi y}{a}\right)dx\,dy$$

other symbols are defined in [1]. In order to maximize the soundproofing ability of the SPVG, it is necessary to reduce the sound pressure level or to prevent those waves from even occurring. For these purposes, low values of $\theta_{m,n}$, $\lambda_{m,n}$ and $\Delta_{m,n}$ in Eq. (5) are required. In the case of the left model of Fig.1, the calculation to find a low value of $\theta_{m,n}$ is performed as follows. To simplify, let we consider the case where SPVG has only one inlet and outlet, namely when M=N=1. Let $a_{0,0} = a/2 - \Delta a$, $a_{0,1} = a/2 + \Delta a$, $b_{0,0} = a/2 - \Delta b,\ b_{0,1} = a/2 + \Delta b$ as shown in Fig. 2. Thus, $\theta_{m,n}$ becomes:

$$\theta_{m,n} = V\int_{a/2-\Delta a}^{a/2+\Delta a}\int_{a/2-\Delta b}^{a/2+\Delta b}\cos\left(\frac{m\pi x}{a}\right)\cos\left(\frac{n\pi y}{a}\right)dx\,dy$$

$$= \frac{4a^2}{mn\pi}\cos\left(\frac{m\pi}{2}\right)\sin\left(\frac{m\pi}{a}\Delta a\right)\cos\left(\frac{n\pi}{2}\right)\sin\left(\frac{n\pi}{a}\Delta b\right) \quad (6)$$

This demonstrates when m = 1, 3, 5, … or n = 1, 3, 5, … $\theta_{m,n}$ becomes zero. Furthermore, if $\Delta a = a/2$ is selected, for m=2, 4, 6, … $\theta_{m,n}$ also becomes zero. On the other hand, if $\Delta b = a/2$ is selected, $\theta_{m,n}$ becomes zero when n=2, 4, 6, …. Therefore, to avoid many higher order mode waves, the shape of the inlet must be in the form of $\Delta a = a/2$ or $\Delta b = a/2$ as shown in Fig. 2. The remaining higher order modes that we have to consider are (0, 2), (0, 4), (0,6), …. when using $\Delta a = a/2$ and (2, 0), (4, 0), (6,0), …when using $\Delta b = a/2$, respectively. Note that, as shown in Eq. (6) when select $\Delta a = a/2$ value of $\theta_{m,n}$ will be changed by Δb. Similarly, a low level of $\lambda_{m,n}$ could be selected in the same manner. From the above considerations, the resonable shape of inlet or oulet is shown in Fig. 2 as Shape-A and Shape-B, respectively.

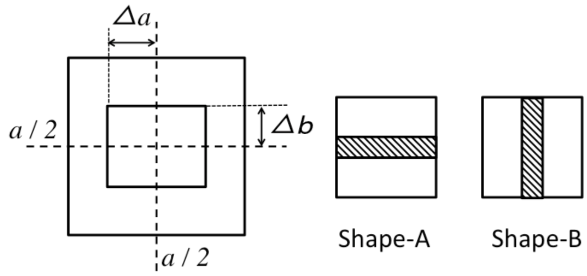

Figure 2 Coordinate system to find a reasonable shape of inlet and outlet

3. EXPERIMENT AND RESULTS

An experiment was conducted using the reverberation chamber method to verify the actual sound attenuation characteristics of SPVG. Figure 3 shows the experimental setup. The volumes of reverberation chambers were 98m^3 and 179 m^3, respectively. The SPVG was installed at the aperture by a casing composed of a plank. The sound source was a loudspeaker fed by pink noise, and five microphones located in each chamber measure the spatially averaged sound pressure. The pressure level in the sending chamber was 100 -105 dB to achieve a pressure level of 70 – 80 dB in the receiving room. The actual sound attenuation of the SPVG is estimated by the differences of the measurement results of with and without the SPVG inserted between the two reverberation chambers.

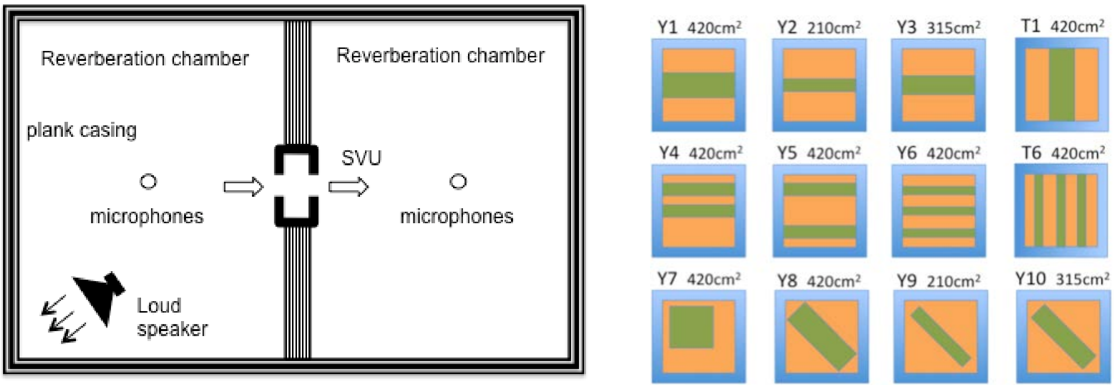

Figure 3 Measurement system and samples

Several SPVGs with various shapes of inlet and outlet were used in the experiment. The shapes and positions of inlets and outlets are shown in the right of Fig. 3. Measured results are shown in Fig. 4- Fig. 6.

Figure 4 is the measured results of SPVG with outlet Y1 and Y7. Y1 is the reasonable shape that we consider in our theoretical analysis and Y7 was use to validate our prediction. Good agreement with our theoretical prediction was confirmed. Figure 5 is the measured results that show differences when using 1 or 2 or 3 outlets. Additionally, in the case of using 2 outlets, the difference is the installed location. The number in parentheses indicates sound attenuation obtained, which means the differences of the measurement results with and without the SPVG inserted between the two reverberation chambers. Figure 6 demonstrates the case of changing a shape of outlet. Noticably, the diagonal outlet form Y8 resulted in greater attenuation effect.

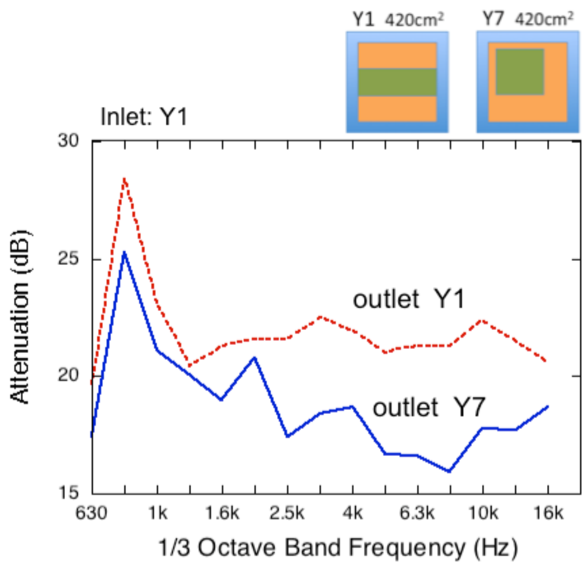

Figure 4 Measured results of SPVG with outlets Y1 and Y7. Good agreement with our theoretical prediction.

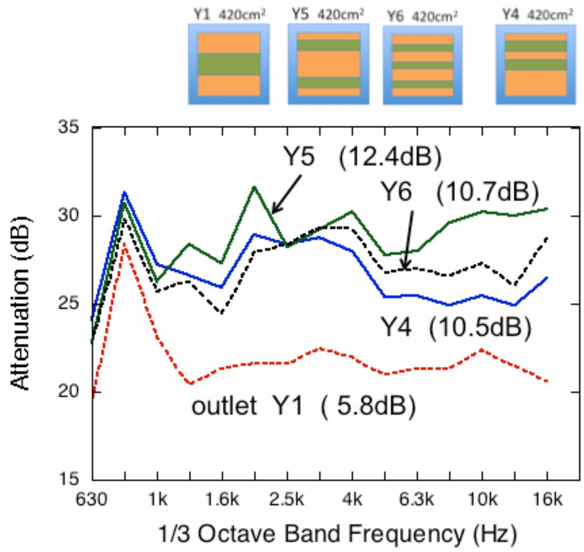

Figure 5 Measured results of SPVG with change of outlet's number

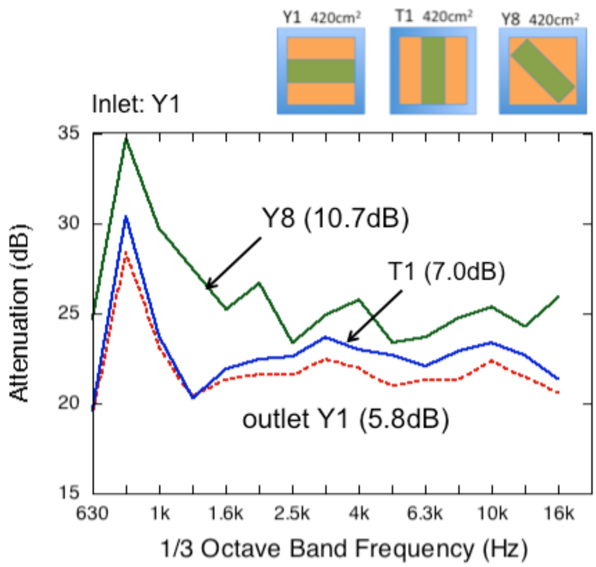

Figure 6 Measured results of SPVG with change of outlet's direction

4. CONCLUSIONS

Experiments were conducted using the reverberation chamber method with 16 shapes of inlet and outlet obtained from the theoretical analysis to verify the actual sound attenuation characteristics of SPVG. Measured results indicated that a combination of different shapes between inlet and outlet is very important. In order to further increase the soundproofing capability, the introduction of sound absorbing materials and complex structures inside the SPVG are required. This technologies will be presented in an upcoming report.

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