DEVELOPMENT OF SOUND PROOF WINDOWS FOR HOUSE IN VIETNAM

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ABSTRACT

This study aims to develop a new type of casement windows (NCW) for house in Vietnam to prevent a traffic noise. The NCW composes of a lighting part and ventilation part which consists of several rectangular sound absorber. In order to have a great muffling effect, the resonance frequencies inside the sound absorber and the location of input and output are also theoretically considered. A good correlation between the prediction and experiment result is observed.

KEYWORDS

Resonance frequency, sound absorber, higher-order mode, muffling

INTRODUCTION

Under the tropical climate condition, majority of houses in Vietnam or other countries in the Southeast Asia have the traditional entrance doors and windows with ventilation holes for fresh air circulation and natural light. Unfortunately, these ventilation holes also allow traffic noises which increase year by year to reach indoors.

This study aims to develop a new type of casement windows (NCW) is more suitable for house in Vietnam without requiring any reform construction. The NCW composes of a lighting part and ventilation part, which consists of several rectangular sound absorber. In the present work, a theoretical formulation describes the acoustic field in a sound absorber with consideration of the higher-order mode effects is suggested. In order to have a great muffling effect, the resonance frequencies inside the sound absorber and the location of input and output are also taken into consideration.

MATERIALS AND METHODS

The NCW composes of a lighting part and ventilation part is shown in Fig.1. As for the illumination part diagonally set up with one glass between the ventilation parts, the noise reduction effect of 20dB-30dB is expected. The ventilation part is composed of several rectangular sound absorber which has a entrance located in downside to prevent a rain. Here, in order to have a great noise reduction effect for the sound absorber, let we consider the resonance frequencies inside the sound absorber and the location of input and output. There are a variety of design methods for the structure of the sound absorber, the simpless model for analysis is shown in Fig. 2, in a similar way to a study by Ih [1]. No loss is assumed in the present work.

The general solution of the wave equation in Cartesian co-ordinate is as follows

$$\phi = \left(Ae^{\mu z} + Be^{-\mu z} \right)\left(C\sin\alpha x + D\cos\alpha x \right)$$

$$\left(E\sin\sqrt{s^2-\alpha^2}\,y + F\cos\sqrt{s^2-\alpha^2}\,y \right) \qquad (1)$$

where A, B, C, D, E and F are arbitrary constants determinable from the boundary conditions. Other symbols are constants. The boundary conditions are:

$$[1]\ \text{at}\ x=0,\quad -\partial\phi/\partial x=0 \qquad (2)$$
$$[2]\ \text{at}\ x=a,\quad -\partial\phi/\partial x=0 \qquad (3)$$
$$[3]\ \text{at}\ y=0,\quad -\partial\phi/\partial y=0 \qquad (4)$$
$$[4]\ \text{at}\ y=b,\quad -\partial\phi/\partial y=0 \qquad (5)$$
$$[5]\ \text{at}\ z=0,\quad -\partial\phi/\partial z=V_i\,F_i(r,\theta) \qquad (6)$$
$$[6]\ \text{at}\ z=\ell,\quad -\partial\phi/\partial z=V_0\,F_0(r,\theta) \qquad (7)$$

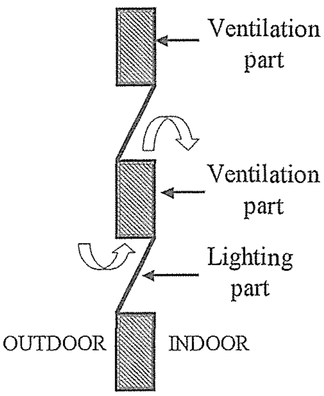

Fig. 1 Sideview of NCM

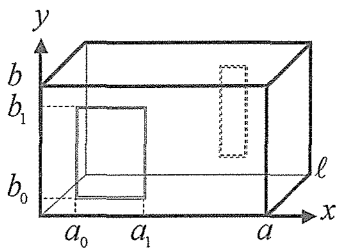

Fig. 2 Ventilation part and its coordinates

where V_i and V_0 are the driving velocity at the input and output, $F_u(r,\theta)=1$ at the input/output and $F_u(r,\theta)=0$ elsewhere.

In order to find ϕ, let ϕ_a be the solution of Eq.(1) obtained for the following boundary conditions:

$$[1]\ \text{at}\ x=0,\quad -\partial\phi_a/\partial x=0 \qquad (8)$$
$$[2]\ \text{at}\ x=a,\quad -\partial\phi_a/\partial x=0 \qquad (9)$$
$$[3]\ \text{at}\ y=0,\quad -\partial\phi_a/\partial y=0 \qquad (10)$$
$$[4]\ \text{at}\ y=b,\quad -\partial\phi_a/\partial y=0 \qquad (11)$$
$$[5]\ \text{at}\ z=0,\quad -\partial\phi_a/\partial z=V_i\,F_i(r,\theta) \qquad (12)$$
$$[6]\ \text{at}\ z=\ell,\quad -\partial\phi_a/\partial z=0 \qquad (13)$$

and let ϕ_b be the solution of Eq.(1) obtained for the following boundary conditions:

$$[1]\ \text{at}\ x=0,\quad -\partial\phi_b/\partial x=0 \qquad (14)$$
$$[2]\ \text{at}\ x=a,\quad -\partial\phi_b/\partial x=0 \qquad (15)$$
$$[3]\ \text{at}\ y=0,\quad -\partial\phi_b/\partial y=0 \qquad (16)$$

[4] at $y=b$, $-\partial\phi_b/\partial y=0$ (17)

[5] at $z=0$, $-\partial\phi_b/\partial z=0$ (18)

[6] at $z=\ell$, $-\partial\phi_b/\partial z=V_0\,F_0(r,\theta)$ (19)

then ϕ can be obtained as $\phi=\phi_a+\phi_b$. According to the above boundary conditions, velocity potential ϕ can be obtained as

$$\phi=\sum_{m=0}^{\infty}\sum_{n=0}^{\infty}e^{\mu_{m,n}\ell}\cosh\left(\mu_{m,n}(z-\ell)\right)V_0\,\Delta_{m,n}\cos\left(m\pi x/a\right)\cos\left(n\pi y/b\right)$$
$$+\sum_{m=0}^{\infty}\sum_{n=0}^{\infty}\cosh\left(\mu_{m,n}z\right)V_\ell\,\dot{\Delta}_{m,n}\cos\left(m\pi x/a\right)\cos\left(n\pi y/b\right) \tag{20}$$

where

$$\mu_{m,n}=\sqrt{(m\pi/a)^2+(n\pi/b)^2-k^2} \tag{21}$$

According to the above boundary conditions, ϕ can be determined and the sound pressure corresponding to ϕ becomes

$$P=jk\rho c\phi=jkZ_w\left[\sum_{m=0}^{\infty}\sum_{n=0}^{\infty}e^{\mu_{m,n}\ell}\cosh\left(\mu_{m,n}(z-\ell)\right)U_0\frac{S_w}{S_0}\Delta_{m,n}\cos\left(m\pi x/a\right)\cos\left(n\pi y/b\right)\right.$$
$$\left.+\sum_{m=0}^{\infty}\sum_{n=0}^{\infty}\cosh\left(\mu_{m,n}z\right)U_\ell\frac{S_w}{S_\ell}\dot{\Delta}_{m,n}\cos\left(m\pi x/a\right)\cos\left(n\pi y/b\right)\right] \tag{22}$$

The sound pressure on the output is given by the following equation

$$P_\ell=jkZ_w\left[\sum_{m=0}^{\infty}\sum_{n=0}^{\infty}e^{\mu_{m,n}\ell}\,U_0\frac{S_w}{S_0}\Delta_{m,n}\cos\left(m\pi x/a\right)\cos\left(n\pi y/b\right)\right.$$
$$\left.+\sum_{m=0}^{\infty}\sum_{n=0}^{\infty}\cosh\left(\mu_{m,n}z\right)U_\ell\frac{S_w}{S_\ell}\dot{\Delta}_{m,n}\cos\left(m\pi x/a\right)\cos\left(n\pi y/b\right)\right] \tag{23}$$

The average sound pressure acting on the output can be expressed as

$$\bar{P}_\ell=\frac{1}{S_\ell}\int_{a_{\ell 0}}^{a_{\ell 1}}\int_{b_{\ell 0}}^{b_{\ell 1}}P_\ell\,dx\,dy$$
$$=jkZ_w\sum_{m=0}^{\infty}\sum_{n=0}^{\infty}\left(e^{\mu_{m,n}\ell}\,U_0\frac{S_w}{S_0}\Delta_{m,n}-\cosh\left(\mu_{m,n}\ell\right)U_\ell\frac{S_w}{S_\ell}\dot{\Delta}_{m,n}\right)\bar{Q}_{m,n} \tag{24}$$

where

$$\bar{Q}_{m,n}=\frac{1}{S_\ell}\int_{a_{\ell 0}}^{a_{\ell 1}}\int_{b_{\ell 0}}^{b_{\ell 1}}\cos\left(\frac{m\pi}{a}x\right)\cos\left(\frac{n\pi}{b}y\right)dx\,dy \tag{25}$$

The insertion-loss can be expressed as $IL=20Log(D/D')+10Log(R/R')$ [2], where $D=(\cos k\ell_1)(C_w)(\sin k\ell_2)$, C_w is the open-circuit transfer admittance defined as

$$C_w = \frac{U_0}{\overline{P}_\ell}\bigg|_{U_\ell=0} = \frac{1}{\overline{P}} \tag{26}$$

where

$$\overline{P} = jkZ_w U_0 \left(-\frac{1}{\sin k\ell} + k\sum_{n=1}^{\infty} \frac{\overline{G}_{0,n}}{\mu_{0,n}\sinh(\mu_{0,n}\ell)} + k\sum_{m=1}^{\infty} \frac{\overline{G}_{m,0}}{\mu_{m,0}\sinh(\mu_{m,0}\ell)} + k\sum_{m=1}^{\infty}\sum_{n=1}^{\infty} \frac{\overline{G}_{m,n}}{\mu_{m,n}\sinh(\mu_{m,n}\ell)} \right) \tag{27}$$

in which

$$\overline{G}_{0,n} = \frac{1}{n^2\pi^2}\frac{b^2}{(b_1-b_0)(b_{\ell 1}-b_{\ell 0})}\left[\sin(n\pi b_1/b)-\sin(n\pi b_0/b)\right]\left[\sin(n\pi b_{\ell 1}/b)-\sin(n\pi b_{\ell 0}/b)\right] \tag{28}$$

$$\overline{G}_{m,0} = \frac{1}{m^2\pi^2}\frac{a^2}{(a_1-a_0)(a_{\ell 1}-a_{\ell 0})}\left[\sin(m\pi a_1/a)-\sin(m\pi a_0/a)\right]\left[\sin(m\pi a_{\ell 1}/a)-\sin(m\pi a_{\ell 0}/a)\right] \tag{29}$$

$$\overline{G}_{m,n} = \frac{1}{m^2n^2\pi^4}\frac{S_w^{\ 2}}{S_0\,S_\ell}\left[\sin(m\pi a_1/a)-\sin(m\pi a_0/a)\right]\left[\sin(m\pi a_{\ell 1}/a)-\sin(m\pi a_{\ell 0}/a)\right]\left[\sin(n\pi b_1/b)-\sin(n\pi b_0/b)\right]\left[\sin(n\pi b_{\ell 1}/b)-\sin(n\pi b_{\ell 0}/b)\right] \tag{30}$$

RESULTS AND DISCUSSION

Figure 3 shows the measured result of Eq. (26) when a=48cm, b= 7.5cm, ℓ=29cm. In order to obtain a great noise reduction effect C_w should have a great value, in other words the low level of Eq. (25) is preferable, especially at the frequencies where the resonance of higher-order modes occurred. Figure 4 shows a calculation result of those resonance frequencies when the denominators of Eq. (26) are zeros. Agreement observed between Fig. 3 and Fig.4 is acceptable.

The locating of input and output with considering of those cross-sectional area ratios to the absorber is very importance to obtain a great noise reduction effect. An example of $\overline{G}_{2,0}$ from Eq. (29), a factor related to the level of higher-order mode (2, 0), depending on the moving of ouput location is shown in Fig.5.

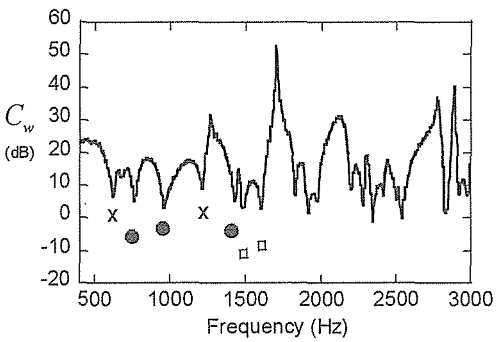

Figure 3: Measured results of Eq.(26)

The symbols R_{cb} and R_{io} illustrate the ratio of cross-section area between the input and the sound absorber, and between the input and output, respectively. Dimensions of sound absorber are a=48cm, b= 7.5cm, ℓ =29cm.

CONCLUSIONS

A simple sound absorber of NCW has been presented by solving the equations, considering the higher-order modes effects. Based on the results obtained, the cause and mechanism of resonance frequencies of the open-circuit transfer admittance C_w was discussed in detail. A good correlation between the prediction and experiment of C_w is observed. Application of the acoustic material according to the resonance levels is a subject of future study.

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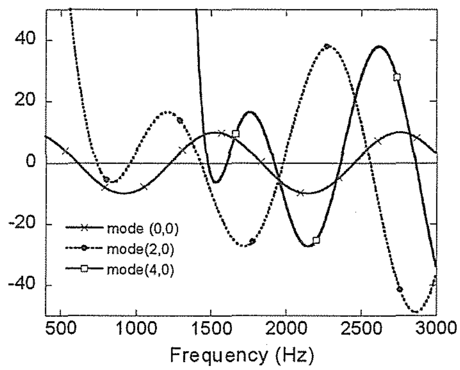

Figure 5: Calculated results of Eq.(29)

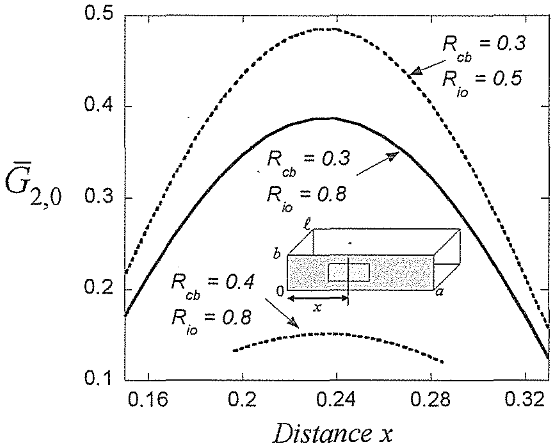

Figure 5: Calculated results of Eq.(29)