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Estimation method for parameters of construction on predicting transmission loss of double leaf dry partition

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ABSTRACT

For improving sound insulation of a double leaf dry partition, each leaf is often consisted of more than one panel. Previous study on predicting a transmission loss of double leaf partition, treats with the leaf varied just two kinds of panels and restricted to a leaf having same kind and same thickness. These restrictions are unfit for variety of current building materials and constructions. This study makes a prediction formula for a transmission loss of the double leaf partition with laminated leaves by a theoretical analysis and an experiment, and will discuss the predicted value with measured value in previous studies and catalogs.

1. Introduction

The sound insulation through the double leaf partition has investigated both theoretically and experimentally by London [1]. He has obtained theoretical solution of transmission sound for an oblique sound incident by using wave equations and acoustic impedance of each leaf. The statistical energy analysis has been used for sound transmission through double leaf partition [2,3]. Although their predictions have shown good agreement with experiment, the leaf has been a homogeneous panel. On the other hand, a sound transmission through a sandwich panel with face sheets and a core (e.g. isotropic, orthotropic and honeycomb) has been discussed [4], but it has treated with a single leaf partition. Moreover, a practical estimation of transmission loss for the double leaf partition consisted with gypsum boards have been suggested by considering a sound insulation theory and measured results for various partitions [5]. However, its laminated leaf varies just two kinds of panels and is restricted to a leaf having same kind and same thickness. These restrictions are unfit for variety of current building materials and constructions.

In this study, a transmission loss of double leaf partition is formulated by based on Helmholtz–Kirchhoff integrals and motion equations of each leaf. And estimation formulas for Young's modulus and loss factor of a laminated leaf, which are made by a theoretical model and a measurement, are calculated by parameters of each panel. Finally, this study makes a prediction formula for a transmission loss of the double leaf partition with laminated leaves by combining above formulas. It will discuss the predicted value with measured value of a transmission loss of the partitions in previous studies and catalogs. As a result of the discussion, the prediction formula is modified to fit variety of constructions of a double leaf partition.

2. Theoretical considerations

2.1. Transmission loss of double leaf partition

Fig. 1 shows a theoretical model for the double leaf partition. Two infinite elastic plates are homogenous and their surfaces have acoustic admittance. A cavity is separated two layers filled with the air or an absorptive media with propagation coefficient γ_i. This partition has an oblique incident sound p_i with incident angle θ and a transmission sound p_t. Sound pressure on the plate of incident side in region [1] is described by Helmholtz–Kirchhoff integral as follows:

$$p_1(x,0) = 2p_i(x,0) + \frac{i}{2}\int_{-\infty}^{\infty} \frac{\partial p_1(\mathbf{r}_0)}{\partial \mathbf{n}} H_0^{(1)}(k_0|x-x_0|)dx_0. \quad (1)$$

Here, sound pressure on the plate of the incident sound is given by

$$p_i(x,0) = e^{ik_0 x \sin\theta}, \quad (2)$$

if its amplitude equals 1. And, its boundary condition is given as follows:

$$\frac{\partial p_1(\mathbf{r}_0)}{\partial \mathbf{n}} = \rho_0\omega^2 w_1(x_0) + iA_1 k_0 p_1(x_0,0). \quad (3)$$

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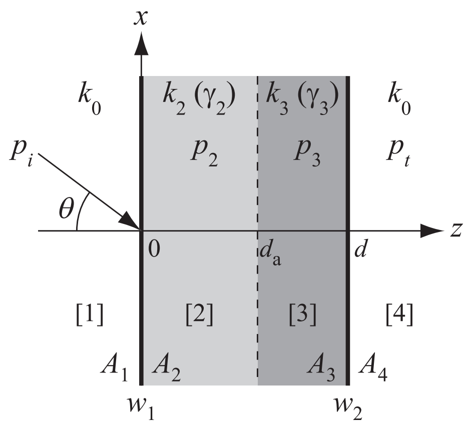

Fig. 1. Geometry of a theoretical model for a double-leaf wall filled with an absorptive layer and/or an air layer.

Here, w_1 is a vibration displacement of the plate of incident side, ω is a angular frequency, k_0 is a wave number, ρ_0 is a density of the air and A_1 is a specific acoustic admittance of the plate surface of incident side.

On the other hand, sound pressure on the plate of transmission side in region [4] is described by Helmholtz–Kirchhoff integral as follows:

$$p_t(x,d) = \frac{i}{2}\int_{-\infty}^{\infty} \frac{\partial p_t(\boldsymbol{r}_0)}{\partial \boldsymbol{n}} H_0^{(1)}(k_0|x-x_0|)dx_0. \tag{4}$$

And, its boundary condition is given as follows:

$$\frac{\partial p_t(\boldsymbol{r}_0)}{\partial \boldsymbol{n}} = -\rho_0\omega^2 w_2(x_0) + iA_4k_0p_t(x_0,d). \tag{5}$$

Here, w_2 is a vibration displacement of the plate of transmission side and A_4 is a specific acoustic admittance of the plate surface of transmission side.

When region [2] and [3] are filled with arbitrary media, sound pressure and particle velocity in their regions are described as follows:

$$p_j(x,z) = (p_j^+e^{-q_jz} + p_j^-e^{q_jz})e^{ik_0x\sin\theta}, \tag{6}$$

$$v_j(x,z) = \frac{\overline{q_j}}{Z_j}(p_j^+e^{-q_jz} - p_j^-e^{q_jz})e^{ik_0x\sin\theta}, \tag{7}$$

$$q_j = \gamma_{jz}\sqrt{1+\left(\frac{k_0\sin\theta}{\gamma_{jx}}\right)^2}, \tag{8}$$

$$\overline{q_j} = \frac{q_j}{\gamma_{jz}}. \tag{9}$$

Here, subscript j is a region number, and γ_{jx} and γ_{jz} are propagation coefficients to x-direction and z-direction respectively in region [2] and [3], and Z_j is a characteristic impedance of the media. In this paper, the propagation coefficients to x- and z-direction are assumed to have same value, then the propagation coefficients, γ_{jx} and γ_{jz}, and the characteristic impedance, Z_j, are given respectively as follows [6]:

$$\gamma_{jx} = \gamma_{jz} = k_0\{0.160(f/R_f)^{-0.618}\} - ik_0\{1+0.109(f/R_f)^{-0.618}\}, \tag{10}$$

$$Z_j = \rho_0c_0\{1+0.070(f/R_f)^{-0.632} + i0.107(f/R_f)^{-0.632}\}. \tag{11}$$

Here, R_f is a flow resistivity (MKSrayls/m) of absorptive media filled in the layer. When the layer is filled by the air, the flow resistivity R_f equals 0. Then, its propagation coefficient γ_{jx} and γ_{jz} becomes $-ik_0$, and the characteristic impedance Z_j becomes ρ_0c_0.

A particle velocity on the plate for $z = 0$ in region [2] is described as follows:

$$v_2(x,0) = -i\omega w_1(x) - \frac{A_2}{\rho_0c_0}p_2(x,0) \tag{12}$$

A_2 is a specific acoustic admittance of the plate surface in region [2]. The sound pressure and the particle velocity have continuity on a boundary between region [2] and [3] for $z = d_a$ as follows:

$$p_2(x,d_a) = p_3(x,d_a), \tag{13}$$

$$v_2(x,d_a) = v_3(x,d_a). \tag{14}$$

And, a particle velocity on the plate for $z = d$ in region [3] is described as follows:

$$v_3(x,d) = -i\omega w_2(x) + \frac{A_3}{\rho_0c_0}p_3(x,d) \tag{15}$$

A_3 is a specific acoustic admittance of the plate surface in region [3].

On the other hand, motion equations for leaves of incident side and transmission side are described respectively as follows:

$$D_1\nabla^4w_1(x) - \rho_{p1}h_1\omega^2w_1(x) = p_1(x,0) - p_2(x,0) \tag{16}$$

$$D_2\nabla^4w_2(x) - \rho_{p2}h_2\omega^2w_2(x) = p_3(x,d) - p_t(x,d) \tag{17}$$

Here, D_1 and D_2 are bending stiffness of leaves of incident side and transmission side respectively as follows:

$$D_n = \frac{E_n(1-i\eta_n)h_n^3}{12(1-\nu_n)} \quad (n = 1,2) \tag{18}$$

Fourier transforms of these equations are given respectively as follow. For sound pressure on the plate of incident side, Eq. (1), substituted the boundary condition, Eq. (3), its Fourier transform is described by

$$P_1(k;0) = 2P_i(k;0) + \frac{i\rho_0\omega^2}{\sqrt{k_0^2-k^2}}W_1(k) - \frac{A_1k_0}{\sqrt{k_0^2-k^2}}P_1(k;0). \tag{19}$$

Here, Fourier transform of the sound pressure on the plate of the incident sound, Eq. (2), is given by

$$P_i(k;0) = \delta(k - k_0\sin\theta). \tag{20}$$

$\delta(k)$ is the Dirac's delta function. For sound pressure on the plate of transmission side, Eq. (4), substituted the boundary condition, Eq. (5), its Fourier transform is described by

$$P_t(k;d) = -\frac{i\rho_0\omega^2}{\sqrt{k_0^2-k^2}}W_2(k) - \frac{A_4k_0}{\sqrt{k_0^2-k^2}}P_t(k;0). \tag{21}$$

Fourier transforms of sound pressure, Eq. (6), and particle velocity, Eq. (7), in the cavity filled with arbitrary media are respectively given as follows:

$$P_j(k;z) = (p_j^+e^{-q_jz} + p_j^-e^{q_jz})\delta(k - k_0\sin\theta), \tag{22}$$

$$V_j(k;z) = \frac{\overline{q_j}}{Z_j}(p_j^+e^{-q_jz} - p_j^-e^{q_jz})\delta(k - k_0\sin\theta). \tag{23}$$

Fourier transform of the particle velocity on the plate for $z = 0$ in region [2], Eq. (12), and $z = d$ in region [3], Eq. (15), are respectively given by

$$V_2(k;0) = -i\omega W_1(k) - \frac{A_2}{\rho_0c_0}P_2(k;0), \tag{24}$$

$$V_3(k;d) = -i\omega W_2(k) + \frac{A_3}{\rho_0c_0}P_3(k;d). \tag{25}$$

The continuity of the sound pressure and the particle velocity on the boundary between region [2,3], Eqs. (13) and (14), are respectively described as following Fourier transforms: