STUDIES OF SOUNDPROOFING CHARACTERISTICS OF SANDWICH PANEL WITH HONEYCOMB CORE AND ELASTIC POROUS ABSORBER

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Abstract

In this paper, some experimental data on soundproofing characteristic of triple sandwich partitions combined between ceramic bricks with holes with honeycomb core, elastic porous absorber and heavy weighted gypsum fiberboard is presented. The honeycomb core is widely used in automotive and aerospace industry in a variety of applications to reduce noise and vibrations and to improve sound quality. On the other hand gypsum fiber boards and porous absorbers are widely used in building constructions and the examination of the properties of combination between these tree type of cores will be useful.

Keywords: soundproofing, sandwich panel, honeycomb, porous absorber

1. INTRODUCTION

Sound insulation between two rooms is very important problem and there is a lot of well known methods for solving it. However, with the development of new materials and construction methods the interest of lighter, thicker and more efficient constructions grows.

Over the years, a great deal of research has been carried out in identifying the transmission loss (TL) characteristics of different panel constructions. Unique approaches to achieving high TL within mass limitations include a design developed by Watters and Kurtze [1], the “shear wall”, and the “coincidence wall” developed by Warnaka [2]. These designs are based on understanding of coincidence effects in the interaction of the incident sound field with the vibration response of the panel. Moore and Lyon [3] developed analytical model for calculating TL of sandwich panel with orthotropic honeycomb core. Dimino, Vitiello and Aliabadi [4] developed analytical model in transportation vehicles to predict sound transmission trough infinite sized triple panel partition placed in a rigid baffle. They also developed a numerical procedure to evaluate the transmission characteristics of finite partitions due to an incident diffuse field. The method is based on FEM/Rayleigh methodology and utilizes numerically calculated sound transmission loss of flat multipanel partitions and box like cavities with idealized boundary conditions.

Ballagh [5] developed a low frequency model for triple partitions that can predict the transmission loss relatively well up to about 250 Hz.

It is interesting to compare a double panel and triple panel system where the overall width and mass of the system is constrained. Ballagh [5] examine the behavior of double and triple partitions with same summarized mass and air cavity. The results are shown in Figure 1 where it can be seen that although the triple panel system has superior performance at higher frequencies, its performance at low frequencies is markedly inferior.

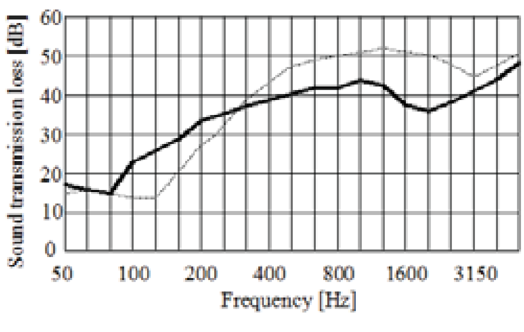

Fig. 1. Transmission loss comparison between:
double partition ——;
triple partition ▬▬

For residential buildings the most common sound sources are speech, sound generated from TV and small home music systems.

To achieve satisfactory levels of transmission loss of partitions and to receive unintelligible speech the frequency region of interest is between 400 and 5000 Hz. Sound waves striking such a panel are predominantly transmitted by travelling bending waves and the damping of banding waves reduces the transmission of intelligible speech trough the panel by interfering with the normal propagation of the sound radiating waves. The damping of bending waves is more effective than the damping of other vibrations with the result that by placing the critical frequency for bending waves at or near the upper end of the bass region, all frequencies above this region are effectively cut off. Cutting off all of the speech frequencies above bass essentially prevents transmission of intelligible speech trough the panel.

In this document is presented comparison of transmission loss between two types of sandwich partitions: first consist of heavy and light face sheets and elastic core; second consist of heavy and light face sheets and addition honeycomb structure placed in the center between two elastic layers. In both cases, face sheets and elastic cores are with same thickness and densities. This comparison validate that the introduction of additional layer with high bending stiffness and relatively small density has the potential to improve transmission loss of related structure in the desired frequency range.

2. ACOUSTIC MODELING OF TRIPLE PANELS

For modelling triple wall panels it is satisfactory to divide the frequency region into a low frequency region where a lumped parameter model is satisfactory, a mid frequency region where wave motion in the porous elastic absorbing layers is important, and a high frequency region where structural coupling between panels is important.

At low frequencies, where sound waves have very large wavelengths, it is found that it is the bulk properties of materials such as their mass are most significant.

The components in the wall can be regarded as masses or springs coupled. This is the classical lumped parameter model. Panels are described with their masses per unit area (surface mass) and filled air gaps with porous elastic absorber are modelled as springs. In its simplest form a triple panel wall would be represented by 3 masses connected by two springs (Fig. 2).

A simplified system of three masses attached to each other by springs with rigidity k_1 and k_2, eq. (1) can be defined, and this can be solved to give the natural frequencies of the system:

$$\begin{aligned}&[m_1 m_2 m_3](\omega^2)^2 - [k_1 m_3(m_1+m_2)+\\&k_2 m_1(m_2+m_3)](\omega^2)+\\&[k_1 k_2(m_1+m_2+m_3)]=0\end{aligned} \qquad (1)$$

With $k_1 = \dfrac{\rho c^2}{d_1}$ and $k_2 = \dfrac{\rho c^2}{d_2}$, where d_1 and d_2 are the thickness of the elastic layers and ω is a resonance frequency.

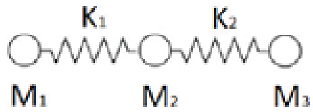

Fig. 2. Mechanical scheme of coupled triple panel

For the case of sound insulation of a structure (consisting of tree or more panels), the transfer function of interest is the ratio of the incident sound pressure to the velocity of the radiating panel.

Rindel [6] gives the transmission loss as:

$$R = 10\log\left(\frac{\langle\rho_s^2\rangle}{4(\rho c^2)\langle\nu_r^2\rangle}\right) \qquad (2)$$

and it can be seen that it is ratio of incident pressure $<\rho_s>$ to velocity $<\nu_s>$ of the radiating panel that is important.

By using standard Fourier transform methods the transfer function can be derived.

The sound transmission coefficient (τ) is defined as the square of the absolute value of the ratio of the transmitted to incident pressures:

$$\tau = |p_t / p_i|^2, \qquad (3)$$

Where for anti symmetric panels:

$$\frac{p_i}{p_t} = \frac{(1+\bar{z}'/2z_a)(1+\tilde{z}'/2z_a) - \alpha_2\alpha_5}{(\bar{z}'/2z_a)-(\tilde{z}'/2z_a)} \qquad (4)$$

In eq.(4) $\bar{z}'$ and $\tilde{z}'$ are impedances of symmetric and anti symmetric motions in the panel, z_a is the modified acoustic impedance of the acoustic field:

$$z_a = \rho_a c_a / \cos\theta \qquad (5)$$

Where $\cos\theta$ is angle of incidence of sound wave, ρ_a is the density of the air and c_a is the speed of sound in air.

In eq. (4) α_2 and α_5 are ratios of operators that appear as coefficients in the equations of Dym, Ventres and Lang [7].

The transmission coefficient is a function of the angle of incidence of the sound waves. To account for this distribution, an averaged form of the transmission coefficient is used. Conventionally this averaged form of equation is:

$$\bar{\tau} = \int_0^{\theta_{lim}} \tau \sin\theta \cos\theta d\theta \Big/ \int_0^{\theta_{lim}} \sin\theta \cos\theta d\theta , \quad (6)$$

where $\bar{\tau}$ being known as the field incidence averaged transmission coefficient. The limiting angle θ_{lim} is taken as equal to 78°, based on field and laboratory measurements. Finally, the field incidence averaged TL is:

$$TL = 10\log_{10}|1/\bar{\tau}| \quad (7)$$

In the observed triple partition, the middle panel is selected to be fabricated from recycled paper honeycomb structure laminated on both sides with elastic porous polyurethane foam. Such materials have different stiffness modules in planes perpendicular and parallel to the direction of the cells, and can be characterized as orthotropic with nine independent stiffness constants.

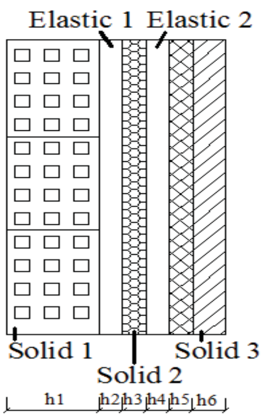

Fig. 3. Section of observed triple partition:
Solid 1 – ceramic brick with holes; Solid 2 – honeycomb structure; Solid 3 – laminated gypsum fiber board and gypsum board; Elastic 1 and 2 – PU elastic absorber

The honeycomb panel TL behaviour is conveniently explained in terms of coincidence effects associated with motions in the panel that are either symmetric or anti-symmetric in character. The decomposition into symmetric and anti-symmetric motions is exact for symmetric panel constructions with identical face sheets and a homogeneous core material.

When the wave speed for either motion in the honeycomb panel exceeds the sound speed, then a matching condition occurs between that motion in the panel and the incident acoustic wave that results in increased transmission trough the panel. For symmetric panel motions, these occur due to a double wall resonance and at higher frequencies where the motion is controlled by bending deformation in the face sheets. For anti symmetric panel motions panel motions, three regions exist with bending deformation of the entire panel cross section: the controlling factor at low frequencies; the core shear stiffness controls in the mid frequency transition region; and bending deformation in the face sheets is the limiting behavior at high frequencies. The wave speed for anti symmetric motions increases monotonically with frequency trough the three regions. Where coincidence first occurs is importantly dependent on the shear stiffness in the core. If the stiffness is too large, coincidence can easily be shifted to occur below the mid-frequency region at lower frequencies with the TL adversely decreased over the useful frequency range.

In Table 1 are given physical properties of the examined material:

Table 1. Physical properties of solid materials in observed triple partition

Type of material	Density	E Modulus	Coeff. of Poisson	Coeff. of internal loss
---	*kg./m³*	*GPa*	*ν*	*η*
Ceramic brick with holes	655	6,85	0,12	0,013
Gypsum fiber board	1130	3,9	0,3	0,012
Gypsum board	680	2,1	0,24	0,01
Honey comb structure	28	4.0	0.21	0.03
PU elastic absorber	150	0,7	0,35	0,15

The calculation of TL where done with software INSUL taking into account all the parameters described in Table 1.

3. EXPERIMENTAL PART

For the experiment was built a soundproofed chamber with test opening with dimensions of 185 x 132 cm and volume of 9.96 m^3. The receiving room is with volume of 265 m^3. The sound reduction index Rw of the partitions of the chamber, build from two layers of concrete bricks with air gap between them, filled with mineral wool is 65 dB. Tested specimen is separated from the other partition elements with a 10 mm rubber stripe. In the source chamber is placed a dodecahedron sound source connected with a generator of "pink noise". One microphone is placed in the source chamber, connected with a sound level meter and frequency analyzer. In the source, room at distance 100 cm from the specimen is placed a condenser microphone, connected with a sound level meter and a frequency analyzer. The generated sound pressure in the source room is SPL = 94 dB.

As the smallest dimension of tested partition is 135 cm the results for frequencies with length of wave below half of this dimension (below 500 Hz) are considered to invalid.

4. RESULTS

As obvious from Fig. 4 there is a significant difference between theoretical calculations and experimental results.

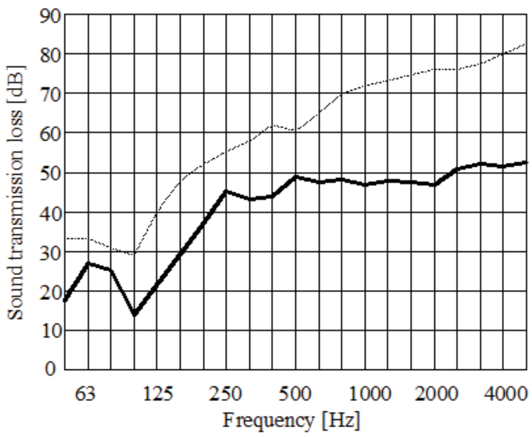

Fig. 4. Comparison of calculated and measured TL of triple panel: measured TL ▬; calculated TL —

Resonance frequency is determined well, but the sound pressure level varies in range of 5 dB for low frequencies to up to 25 dB for high frequencies. Coincidence region from is quite short compared with the measured. It can be take into account that the flanking paths determine the continuous horizontal part of transmission loss curve for measured results. It's benefit that the start of coincidence region is from 250 Hz and is well subscribed until 500 Hz after that the amplitude of bending waves is reduced.

On Fig. 5 is presented comparison of TL between triple partition with middle solid of honeycomb, triple partition with middle solid of gypsum fiber board and double partition where middle solid is removed.

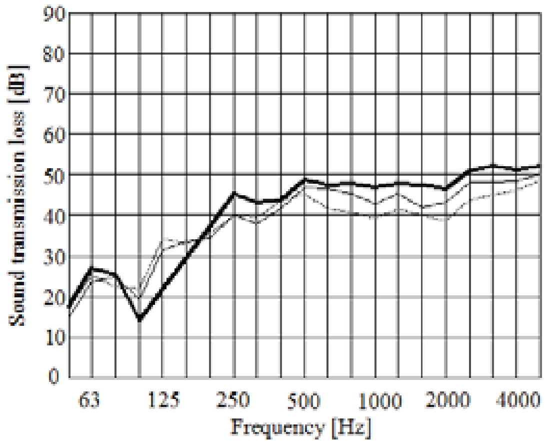

Fig. 5. Comparison of TL between: triple partition with honeycomb: ▬; triple partition with gypsum fiber board:—; double partition with removed middle solid layer: ·······

5. CONCLUSION

For triple anti symmetric partitions the usage of middle orthotropic honeycomb solid panel benefit TL behaviour. In comparison with heavy solid middle layer from gypsum fiber board TL is improved up to 7 dB and the coincidence region is with smaller amplitude of bending waves.

This phenomenon is provided by different bending stiffness in directions and highest internal loss of honeycomb structure. When partitions are used for blocking intelligible speech with frequency range of interest from 400 to 4000 Hz the application of honeycomb structure is beneficial. Theoretical model for prediction is poor presented so for future work will be useful to be developed model for predicting TL of triple anti symmetric partitions with orthotropic middle solid layer.

6. APPENDIX AND ACKNOWLEDGMENTS

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