Proceedings of 20th International Congress on Acoustics, ICA 2010

23-27 August 2010, Sydney, Australia

Effect of micro-perforation on sound insulation of double-leaf structures

Mu Rui Lin (1), TOYODA Masahiro (2) TAKAHASHI Daiji (1)

(1) Graduate School of Engineering, Kyoto University,
C1-4-392, Kyoto University Katsura,, Nishikyo-ku, Kyoto, 615-8530 Japan 1
(2) Kyoto University Pioneering Research Unit, Kyoto University,
B104, Kyoto University Katsura, Nishikyo-ku, Kyoto 615-8530, Japan 2

PACS: 43.55Rg

ABSTRACT

The double-leaf structures cause a significant peak in radiated sound power due to the mass-air-mass resonance, which leads to the deterioration of the sound transmission loss. This study attempts to improve the sound insulation performance at low-and mid-frequencies by using micro-perforated panel (MPP). In this study, a prediction method is introduced for sound transmission loss (STL) of double-leaf structures with MPP of infinite extent. And the possibility of improving the sound insulation performance by microperforating the panel of the transmitted side is discussed. Considering the practical application, the effect of double-leaf structures with acrylic MPP is studied and the efficiency is confirmed. In addition, in order to verify the sound transmission theory with MPP, the theoretical model in cylindrical coordinates is also presented and discussed in comparison with the experiment using an acoustic tube, where panels are clamped at edge.

1. INTRODUCTION

Multilayer leaf structure has been applied in many fields. However, this type of structure has a problem of sound insulation dip at low-and mid-frequencies caused by mass-air-mass resonance. Meanwhile, MPP can provide good absorption in the wide frequency range as reported by Maa [1], and it is recognized as the next-generation absorption materials. From this point of view, discussions are given to the possibility of improving the sound insulation performance of double-leaf structures by using MPP.

Several papers reported that sound insulation performance at low-and mid-frequencies of multilayered structures can be improved by using mpp. However, in these studies, MPP is set in the air layer having less effect on the improvement, and the prediction methods do not well correspond with the experiment [2] [3].

In this study, a prediction method is introduced for sound transmission loss of double-leaf structures with MPP of infinite extent. In the STL calculation process, coupled vibration of air and the panel, and directional distribution of incident energy in a reverberation chamber are considered. Two types of analytical model are studied: one is single panel with MPP and the other one is double-panel with MPP.

2. THEORETICAL CONSIDERATIONS

2.1 Calculation of sound transmission loss

A plane-wave of angle θ is considered as a source incident upon multilayer panels of infinite extent. Sound transmission loss is calculated on the basis of wave equation and equation of panel vibration. The effects of micro-perforations are considered at each boundary in the coupled analysis of wave motion and panel vibration [4]. In addition, considering directional distribution of incident energy in a reverberation chamber [5], the average sound transmission loss of multi-layer panels is calculated.

2.2 Case 1: single panel with MPP

The analytical model of single panel with MPP is shown in Figure 1. In this case, a double-leaf structure of infinite extent with a plane-wave of angle θ incidence is considered.

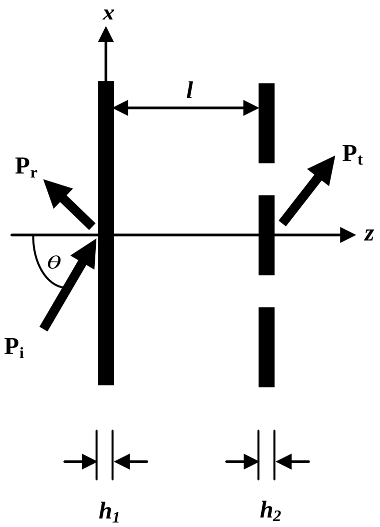

Figure 1. Analytical model 1

2.3 Case 2: double-panel with MPP

The analytical model of double panel with MPP is shown in Figure 2. In this case, a triple-leaf structure of infinite extent with a plane wave of angle θ incidence is considered.

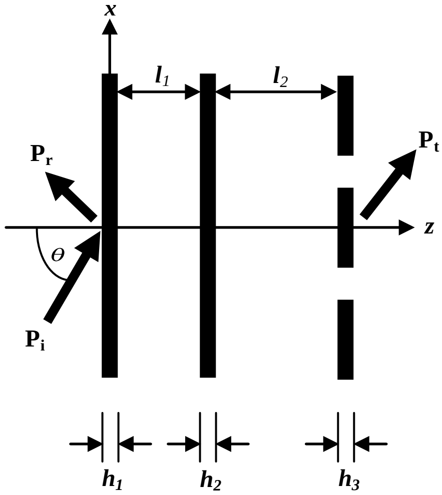

Figure 2. Analytical model 2

3. NUMERICAL RESULTS AND DISCUSSIONS

In this section, the effect of micro-perforation on sound insulation of multi-layer glass window is studied. Furthermore, the possibility of improving the sound insulation performance is discussed.

3.1 Case 1: single panel with MPP

The comparison of sound transmission loss calculated for double glass (h_1=h_2=3mm, l=6mm) and single glass with MPP (the diameter of perforation 1mm, the perforation pitch 10mm) are shown in Figure 3. By micro-perforating the glass, improvement of sound insulation performance is observed in the low-frequency range, the effect of resonance at around 400Hz is prevented. Altough there seems some deteriorated change at low frequencies can be seen, on the whole, expected effect is implemented.

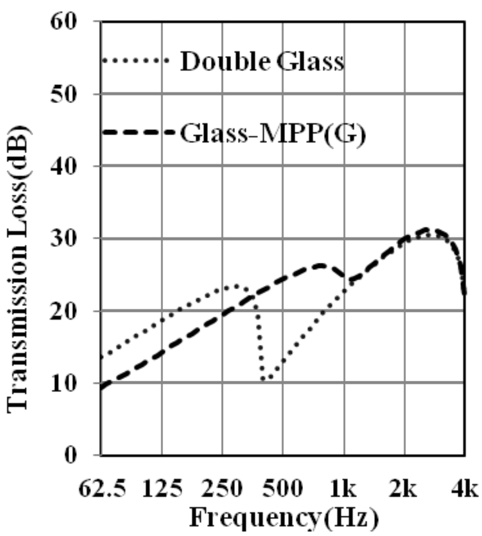

Figure 3. TL Comparison between Double Glass and Glass-MPP (Glass)

3.2 Case 2: double-panel with MPP

The results of sound transmission loss are shown in Figure 4 as a comparison between a triple glass window (h_1=h_2=h_3=3mm, l_1=6mm, l_2=100mm) and a double glass window (h_1=h_2= 3mm, l=6mm). The resonance frequency of triple glass shifts to low frequency in comparison with the double case. As a result, sound transmission loss of triple glass at mid- and high- frequencies is improved.

Figure 4 also shows the comparison of sound transmission loss of triple glass and double glass with MPP (h_1=h_2=h_3= 3mm, l_1=6mm, l_2=100mm), the diameter of perforation 0.3mm, the perforation pitch 6.2mm). Because the dip caused by mass-air-mass at low frequencies is prevented, the sound insulation performance at low frequencies is improved up to about 5dB in the range 100-400Hz. And, at other frequencies, there seems no significant change. Therefore, changing the glass of inner side into MPP can improve the sound insulation performance, and could be an effective method to remedy the deficiency of the resonance effects.

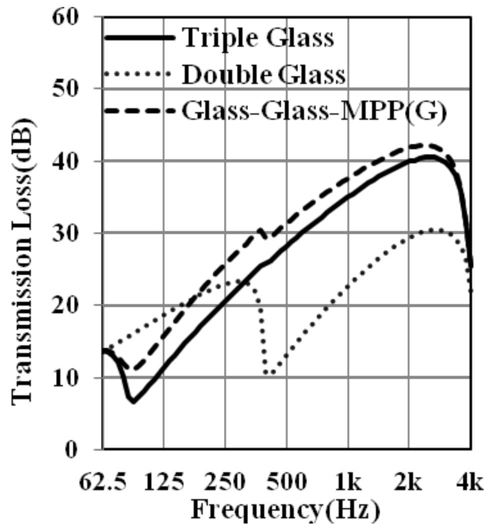

Figure 4. TL comparison of Triple Glass, Double Glass and Glass-Glass- MPP (Glass)

4. THE CASE OF USING ACRYLIC MPP

Sound insulation performance of multilayer windows with glass MPP was studied in the previous section. In this section, considering the practical application, the effect of multilayer windows with acrylic MPP is studied. It is feared that the use of acrylic panel might impair the insulation performance because of its light-weight material.

4.1 Case 1: single panel with MPP

The results of sound transmission loss calculated for single glass with acrylic MPP (the diameter of perforation 1mm, the perforation pitch 10mm), single glass with glass MPP and single glass with acrylic panel are shown in Figure 5. From the results, single glass with acrylic MPP has good agreement with single glass with glass MPP, and comparing with single glass with acrylic panel, the dip at low-frequencies caused by mass-air-mass resonance is prevented. In addition, in the range 400Hz-3700Hz sound insulation performance is improved. In this case, even changing glass MPP to acrylic MPP, this double-layer structure can obtain same sound insulation performance.

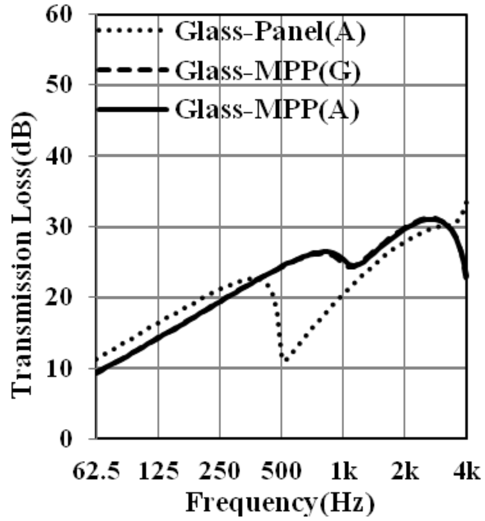

Figure 5. TL Comparison of Glass-Panel (Acrylic), Glass-MPP (Glass) and Glass-MPP (Acrylic)

4.2 Case 2: double-panel with MPP

The results of sound transmission loss are shown in Figure 6 as a comparison of double glass with acrylic MPP (the diameter of perforation 0.3mm, the perforation pitch 6.2mm) and double glass with acrylic panel. By micro-perforating the acrylic panel of the transmitted side, the dip caused by mass-air-mass resonance of double glass with acrylic panel is prevented. The improvement of sound transmission loss is about 3dB at 100Hz-400Hz.

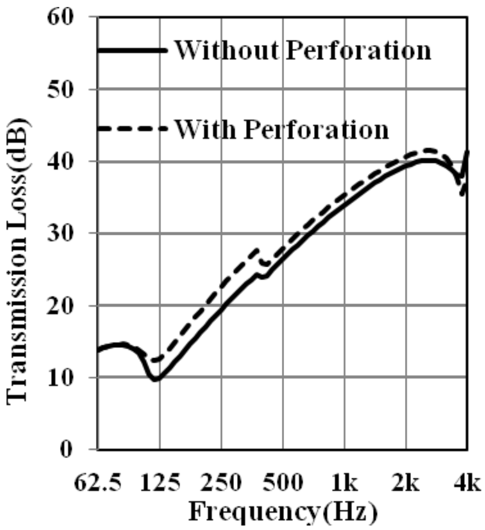

Figure 6. TL comparison of With Perforation and Without Perforation

According to the above results, by micro-perforating the acrylic panel the sound insulation dip of multi-layer glass window caused by mass-air-mass resonanace is prevented, and the sound insulation performance is improved. Thus the method of perforating the acrylic panel of the transmitted side has a possibility to be an effective sound insulation design approach.

5. COMPARISON BETWEEN CALCULATION AND MEASUREMENT

For verifying the introduced prediction method, the theoretical model with MPP in cylindrical coordinates is presented and discussed in comparison with the experiment using an acoustic tube.

The sound transmission loss of single acrylic panel with acrylic MPP is calculated by theoretical model in cylindrical coordinates. In this model, it is considered that the panels are clamped at edge with a normal incidence of plane wave.

The experiment was conducted using an acoustic tube of diameter 10cm: B&K Type4206 for the source side, and hard vinyl-chloride tube of length 4m with open end for the transmitted side. The STL was calculated from measured data obtained at 3 microphone positions based on wavefield decomposition method using impulse response at 3 positions. The transmitted signal separated from reflections are clipped and used for calculation. The specimens are sandwiched between wooden boards which have the same diameter as acoustic tube, and are clamped at the edge. The comparison between calculation and experiment of double acrylic panel is shown in Figure 7. And the comparison of singal acrylic panel with acrylic MPP is shown in Figure 8.

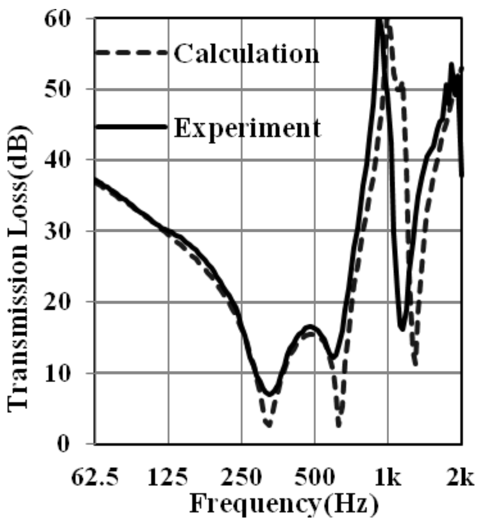

Figure 7. Comparison of calculation and experiment

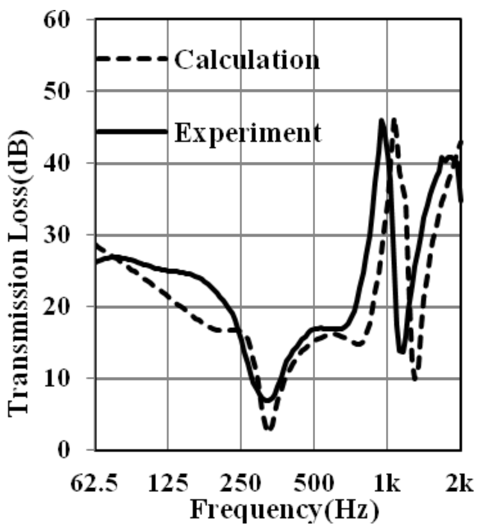

Figure 8. Comparison of calculation and experiment (MPP)

In the two types of multi-layer structure, the calculaed results are in fairly good agreement with the experimental results except the frequency range below 400Hz and above 1800Hz.

By perforating the panel, the sound transmission dip caused by mass-air-mass resonance at around 700Hz is prevented, and the total performance of the sound insulation is improved. The prediction theory for the STL of double-leaf panels with MPP shows good agreement with the experiment. Therefore, the introduced calculation theory is validated, and it was confirmed that the method could be effective to predict the sound insulation performance of multi-layer structures with MPP.
However, small gap between theory and experiment was appeared at all frequencies. This may be caused by the edge condition of experiments. In addition, the discrepancy between theory and experiment at low frequencies may be caused by the effect of truncation of the measured impulse response for the transmitted waves.

6. CONCLUSIONS

The effect of MPP on the performance of multilayer windows was studied. The approach for micro-perforating the glass window of double glass and triple glass can prevent the sound insulation dip caused by mass-air-mass resonance, and improve the sound insulation performance. Considering the practical application, the effect of multilayer windows with acrylic MPP was studied and the efficiency was confirmed. Alternatively the use of acrylic MPP has almost the same effect as the glass MPP. Finally, the introduced prediction method of finite extent was experimentally investigated and the effect of MPP was confirmed by calculation and measurement. For the good agreement with experiment, this prediction method could be effective to predict the sound insulation performance of multi-layer structures with MPP. Furthermore, the approach using MPP to improve the sound insulation performance at low- and mid-frequencies is considered to be an effective sound insulation design approach.

REFERENCES

1 D.Y.Maa, “Potential of micro-perforated panel absorber,” *J. Acoust. Soc. Am.* 104, 2861-2866(1998)
2 Christian. Thomas, Uwe. Weltin, “Sound Reduction of Double Walls Containing Inner Microperforated Panel Absorbers,” *ICA.*Ⅱ, 1403-1406(2004)
3 M. Yairi, K Sakagami, “Effect of microperforated panel inside the cavity on structure-borne sound radiation from a double-leaf structure,” *ICA.*Ⅱ, 1399-1402(2004)
4 D.Takahasi, “Flexural vibration of perforated plates and porous elastic materials under acoustic loading a),” *J. Acoust. Soc. Am.* 112, 1456-1464 (2002)
5 JuKang.H, “Prediction of sound transmission loss through multilayered panels by using Gaussian distribution of directional incident energy,” *J. Acoust. Soc. Am.* 107, 1413-1420 (2000)