IMPROVING THE LOW FREQUENCY SOUND TRANSMISSION LOSS OF DOUBLE-PANEL STRUCTURES WITH PERFORATED BALL SOUND ABSORBERS

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A perforated ball sound absorber with extended tubes (PBETs) was designed to improve the low frequency sound transmission loss of the double-panel structures. First the sound absorbing performance of the PBETs was measured in the impedance tube. Then the measurement of the transmission loss of the double-panel structures with or without PBETs was conducted in the sound insulation testing room. The experiment results indicated that the sound transmission loss of the double-panel structures was improved 5dB at the target frequency by inserting the PBETs between them. The sound pressure level in the receiving room was reduced 9dB at the target frequency.
Keywords: sound transmission loss, a perforated ball sound absorber, double-panel

1. Introduction

A perforated panel sound absorber with extended tubes (PPETs) had been designed to improve the low frequency sound absorbing performance of the perforated plates by many researchers. Lu first tried to attach flexible tube bundles to the perforated panel and micro-perforated panel for low frequency (above 250Hz) and wider bandwidth sound absorption [1]. Zhang and Lu further improved lower frequency (120Hz) sound absorption by attaching tree-like tube bundles to the perforations [2]. Iwan also presented a design from MPP to array of constrained short tubes (ASCT) to enhance the sound absorbing performance of perforated plates in low frequency range(250-700Hz)[3].He experimentally investigated the influence of the tube number, tube length(50mm) and cavity depth(100-150mm) on the sound absorption coefficient of the perforate plates. But the theoretical analysis could not be presented in the paper. The mentioned prior works on the perforated plates with extended tubes could not present optimal design for the perforation and tube parameters. So the length of the tubes and the cavity were too longer for some special circumstances in which the weight and space were strictly limited. Li and Chang discussed how to design a low frequency perforated panel sound absorber with short extended tubes (PPET) in a limited thickness[4,5]. The emphasis was focused on the low frequency range 100-300Hz and the size limit 100mm in thickness. In order to widen the sound absorption frequency bandwidth four parallel PPETs and three PPETs compound with one MPP were also investigated. They also presented a theoretical model to predict the sound absorption coefficient and the simulated annealing method to optimize the PPETs parameters.

In this paper the PBETs were introduced to improve the low frequency sound transmission loss of the double-panel structures. First the sound absorbing performance of the PBETs was measured in the impedance tube. Second the sound transmission loss of the double-panel structures with and without PBETs was experimentally investigated in the sound insulation rooms. Finally the discussions and conclusions were made in the following section.

2. Theoretical analysis

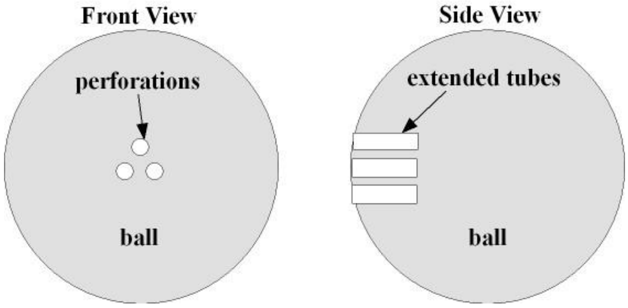

Figure 1: The sketch of the PBET.

Fig.1 shows the sketch of the PBETs of which sound absorbing performance is measured in the impedance tube. The specific acoustic impedance of the circular tubes could be expressed as [6]

$$\boldsymbol{z_{tube}} = \boldsymbol{j\omega\rho_0 t'}\left[\mathbf{1} - \frac{2}{x\sqrt{-j}}\frac{J_1(x\sqrt{-j})}{J_0(x\sqrt{-j})}\right]^{-1} + \boldsymbol{R_e}. \tag{1}$$

Where $x = (d/2)\sqrt{\omega\mu/\eta}$, $t' = t + 0.85d$, t was the length of the tubes (m), d was the diameter of the tubes of the PBET (m). The end correction due to the sound radiation at both ends was $0.85d$. ω was the angular frequency (rad/s), ρ_0 was the density of the air (kg/m^3), c_0 was the speed of the sound in the air (m/s), η was the viscous coefficient of air (kg/sm), and μ was the kinematic viscosity (m^2/s). In the Eq. (1) it was necessary to add the end corrections to the acoustic impedance according to Ingard [9], the additional resistance due to the air flow friction on the surface of the panel was $R_e = (1/2)\sqrt{2\omega\rho\eta}$. For the sound normal incidence on the perforated ball, the specific acoustic impedance of the PBET was then obtained as

$$\boldsymbol{z} = \boldsymbol{z_{tube}} + \boldsymbol{z_{cavity}}. \tag{2}$$

$$\boldsymbol{z_{cavity}} = \frac{\boldsymbol{N s_{tube}\rho_0 c_0^2}}{\boldsymbol{j\omega V}}. \tag{3}$$

Where V was the inner volume of the ball which was filled with air. s_{tube} was the cross section area of the tube. N was the number of the perforated holes.

In order to measure the sound absorption coefficient of the PBET, it was stick on the impedance tube's end, as shown in the Fig.2. The specific acoustic impedance of the PBET could be approximately written as

$$\boldsymbol{z_{PBET}} = \boldsymbol{z/\sigma_p}. \tag{4}$$

Where σ_p was the perforation ratio on the ball. The specific acoustic impedance on the Plane A z_{PT} was depended on the specific acoustic impedance of the PBET z_{PBET} and the impedance of the air outside of the ball z_{TE} which had the surface area S_1. The specific acoustic impedance z_{TE} and z_{PT} could be written as

$$\boldsymbol{z_{TE}} = -\boldsymbol{j}\,\mathbf{cot}\left(\frac{\boldsymbol{\omega D}}{\boldsymbol{c_0}}\right). \tag{5}$$

$$\boldsymbol{z_{PT}} = \left(\frac{\mathbf{1}-\boldsymbol{\sigma_b}}{\boldsymbol{z_{TE}}} + \frac{\boldsymbol{\sigma_b}}{\boldsymbol{z_{PBET}}}\right)^{-1}. \tag{6}$$

Where σ_b was the ratio of the ball cross section area to the impedance tube cross section area S_0. The sound absorption coefficient could be written as

$$\boldsymbol{\alpha} = \frac{\mathbf{4}\boldsymbol{\rho_0}\mathbf{c_0}\mathbf{Real}(\boldsymbol{z_{PT}})}{(\boldsymbol{\rho_0}\mathbf{c_0}+\mathbf{Real}(\boldsymbol{z_{PT}}))^2+(\mathbf{Imag}(\boldsymbol{z_{PT}}))^2}. \tag{7}$$

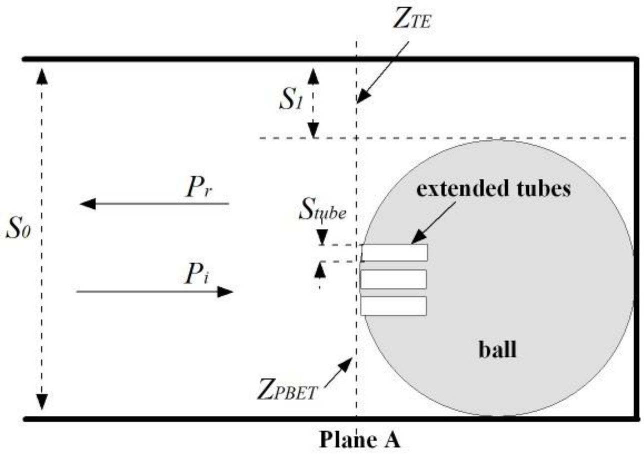

Figure 2: The sketch of the PBET in the impedance tube.

3. The sound absorbing performance of the PBET

The normal incidence sound absorbing coefficient is measured in an impedance tube (B&K4206) with a diameter of 100 mm according to ISO 10534-2. The PBETs sample is shown in Fig.1. It is installed at the end of the impedance tube, as shown in Fig. 2. The length of the tube was 10.1mm. The diameter of the tube was 4.9mm. Five holes were perforated in the ball with an inner diameter 64mm. The measured sound absorption coefficient of the PBET was shown in the Fig.3. The calculated result based on the equation (7) was also presented for comparison. The measured frequency of sound absorption peak was 387Hz which had a good agreement with the calculation result. However the measured sound absorption value off the resonant frequency was bigger than the calculation result. The discrepancy was mainly induced by the underestimated damping in the frequency range.

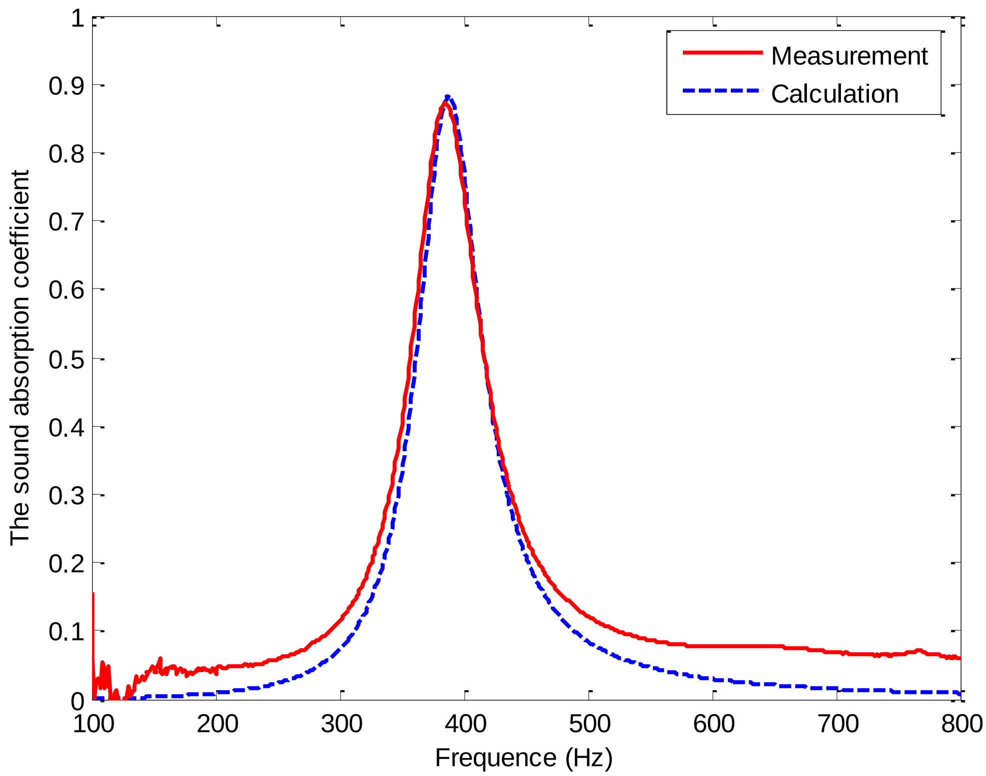

Figure 3: The measured and calculated sound absorption coefficient.

4. Measurement of the sound transmission loss

The double-panel structure is composed of a 1.5mm thick aluminium plate and a 2mm thick ABS plastic plate. The distance between the plates was 100mm. One layer of foam with a 50mm depth was inserted between the double plates and attached on the ABS plastic plate. The 64 PBETs were mounted in the foam. Each line mounted with 8 PBETs. The perforated holes faced to the aluminium plate which faced to the sound source room. The size of the double-panel structure was 1150mmx1100mm. The sound transmission loss was measured between two reverberant rooms according to ISO140-3:1995. Firstly the transmission loss of the double-panel structure with 50mm foam was measured as reference. Secondly the 64 PBETs were mounted in the foam and the sound transmission loss was measured. Finally all the holes of the 64 PBETs were closed and the sound transmission loss was also measured. The measured transmission loss was shown in the Fig.4. When the holes of the PBETs were closed the ball had very little influence on the sound transmission loss between 200 and 600Hz. The PBETs with open holes improved the transmission loss about 5 dB between 300 and 390Hz. The variation of the sound pressure in the receiving reverberant room was also presented in the Fig.5. Obviously the sound pressure level was reduced about 3-10dB between 330 and 440Hz when the holes of the PBETs were open.

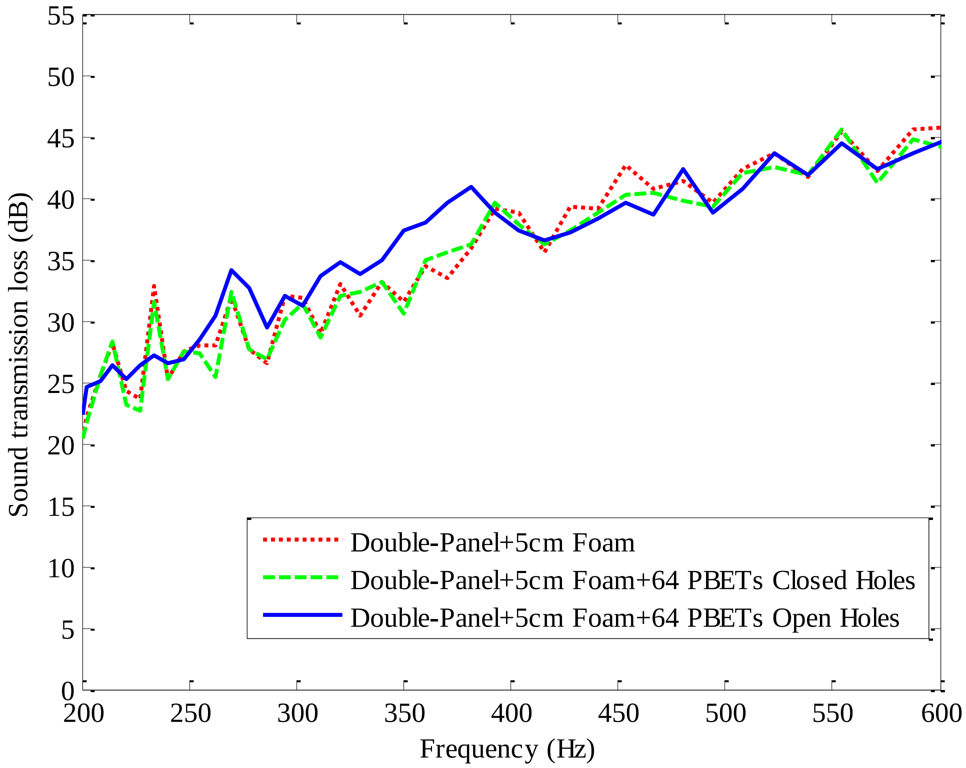

Figure 4: The influence of the PBETs on the sound transmission loss of the double-panel structure.

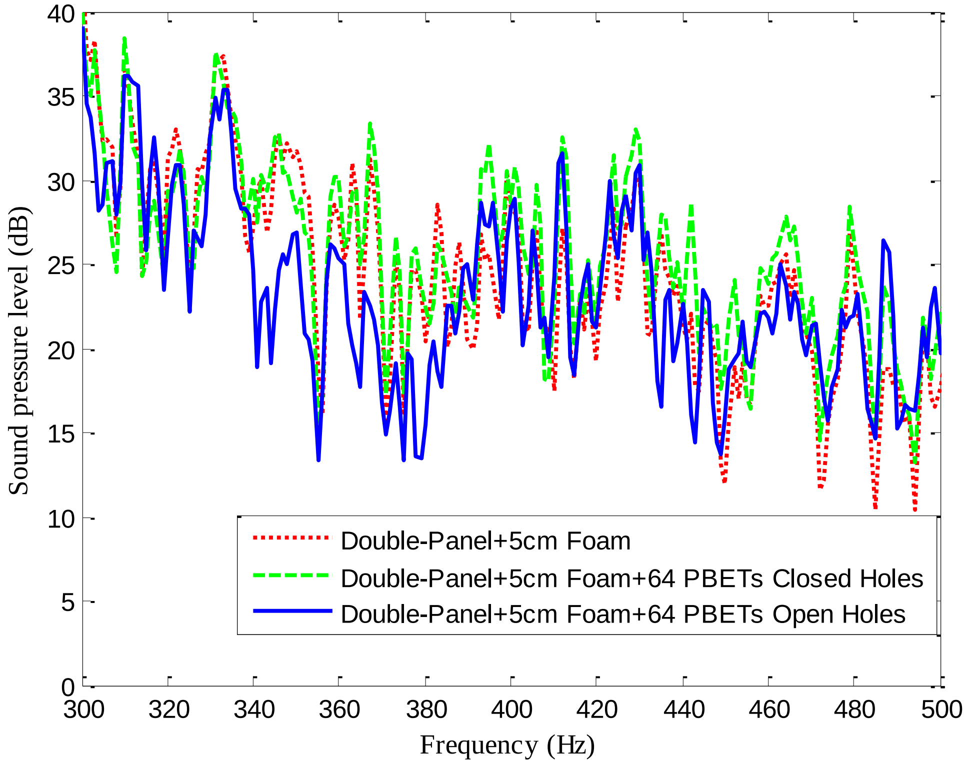

Figure 5: The variation of the sound pressure level in the receiving reverberant room.

5. Conclusions

The PBETs were designed to improve the sound transmission loss of the double-panel structure. The sound absorbing performance of the PBET in the impedance tube was measured. The value of the sound absorption peak could almost reach to unit. The sound transmission loss of the double-panel structure with and without PBETs was measured in the reverberant rooms. The sound transmission loss in the frequency range 300Hz-390Hz was improved about 5 dB when 64 PBETs were mounted in the 50mm foam between the double plates. The sound pressure level in the receiving reverberant room was reduced about 3-10dB in the frequency range 330-440Hz. The measured results illustrated that PBETs could be used to increase the sound transmission loss of the double-panel structure around its resonant frequency.

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