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STUDY THE PANEL AND HELMHOLTZ RESONANCES OF A MICRO-PERFORATED ABSORBER

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Abstract

In this study, the absorption of an absorber, which considers the three effects, micro-perforation, panel resonance and Helmholtz resonator, is investigated. The theory developed for the micro-perforated absorber is based on that the impedances of the three effects are in parallel and connected to that of the air cavity in series. In previous studies, these three effects were not considered simultaneously for acoustic absorber. It can be concluded from the theoretical and experimental results that the panel and Helmholtz resonance can enhance the absorption bandwidth of a micro-perforated absorber.

1. INTRODUCTION

Micro-perforated panels require small space to achieve high sound absorption when compared with typical foam or porous materials [1]. In the absorption test of a micro-perforated panel [2], an additional sound absorption peak was found unexpectedly around the low frequency range (50Hz to 100Hz) because of the effect of panel vibration. However, the research work did not make use of the effect of panel vibration to optimize the absorption bandwidth. The theoretical and experimental analyses of panel absorbers without perforation were presented in [3-7]. It was found that the sound absorption mechanism of a panel absorber was due to the panel/cavity resonance. These analyses, except [3], neglected the bending stiffness of the panel. In the work done by Kang and Fuchs [8], the theory for micro-perforated membrane absorber was developed and verified by the experiments. Kang and Fuchs considered the vibration effect of the membrane but neglected the bending stiffness of the absorber. The Helmholtz resonator, namely an air mass backed by an air stiffness, have been mentioned in many textbook and articles (for example [9]). In this study, the objective is to develop a sound absorption model for the combined effects of micro-perforated panel, panel absorber and Helmholtz resonator. A series of parameter studies is conducted for optimizing the performance of the acoustic treatment.

2. THEORY

In Figure 1, the acoustic impedance of the micro-perforated panel mounted with a tube and backed by an air cavity is analogous to that of the electrical circuit [8]. In the resonant system, the impedance of the panel contains the mass, stiffness, and damping elements in series. The impedance of the perforations on the panel surface and air mass in the tube contain the mass reactance and resistance elements in series. These three impedances in parallel are connected to that of the air cavity in series. The theoretical model considers the three absorption effects (i.e. micro-perforation, panel absorber, and Helmholtz resonator). According to the equivalent circuit, the normalized acoustic impedance of the whole structure Z_o can be given by

$$Z_o = Z_{com} - j\cot\left(\frac{\omega D}{c}\right) \tag{1}$$

where $Z_{com} = \dfrac{Z_p Z_a Z_t}{Z_p Z_a + Z_p Z_t + Z_t Z_a}$ = combined normalized acoustic impedance of micro-perforated panel (Z_p), panel absorber (Z_a) and Helmholtz resonator (Z_t). The derivations of the acoustics impedances can be found in [1,6,9]. c is the speed of sound. D is the cavity depth. ω is the frequency in radian/second. $j = \sqrt{-1}$

Then the absorption coefficient of the absorber α_o for normal incidence can be calculated by the well-known formula (see [9])

$$\alpha_o = \frac{4\,\mathrm{Re}(Z_o)}{\left(1+\mathrm{Re}(Z_o)\right)^2 + \left(\mathrm{Im}(Z_o)\right)^2} \tag{2}$$

3. RESULTS

Figures 2a-b show the effects of micro-perforation, panel vibration, and Helmholtz resonance on the sound absorption (where a = cross section area of the tube; l = tube length; A = panel area; D =cavity depth; p = perforation; d = hole diameter; t = panel thickness; m_p= panel surface density; ξ = damping ratio; ω_o = fundamental resonant frequency). In Figure 2a, the absorption of the absorber with the panel vibration and Helmholtz resonance effects is generally much lower than that with the additional effect of micro-perforation. The absorption peak around 100 Hz due to the micro-perforation effect and Helmholtz resonant effect is wider and higher than that without micro-perforation effect. It can be seen that the micro-perforations on the panel can enhance its sound absorption for most frequencies. In Figure 2b, the absorption peak due to the micro-perforation effect exists around 400 Hz, much higher than the Helmholtz resonant frequency (about 100 Hz). For frequencies below 500 Hz, the absorption is dominated by the micro-perforation effect, and the absorption peak at 100 Hz due to the Helmholtz resonance disappears. It is because the mass reactance of the perforations affects that of the Helmholtz resonator so the resonant property of the absorber is changed. Around 500 to 700 Hz, the absorption peak due to the panel resonance can widen the absorption bandwidth of a micro-perforated absorber. The experimental absorption results were obtained by adopting the measurements procedure according to ASTM 1050 “Standard Test Method for Impedance and Absorption of Acoustical Materials Using a Tube, Two

Microphones and A Digital frequency Analysis System”. In Figures 2c-d, the experimental absorption coefficients of the perforated absorber are shown. The general trends in Figures 2c-d reasonably agrees with those in Figures 2a-b.

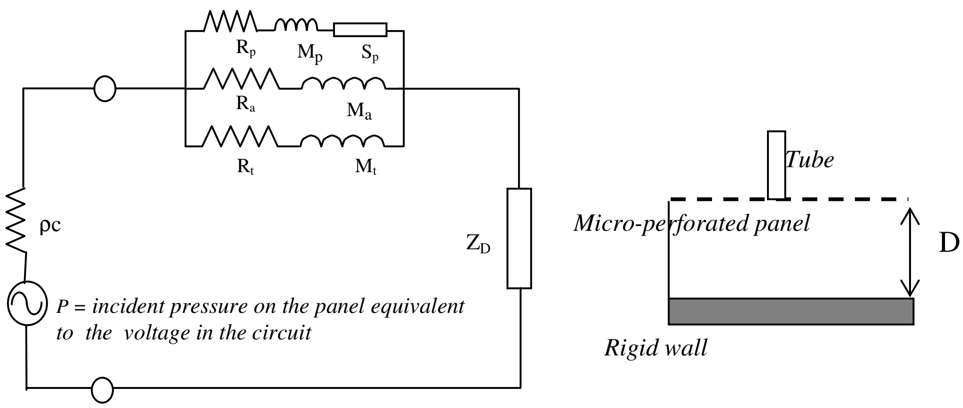

Figure 1. A micro-perforated panel mounted with a tube and the equivalent circuit

4. CONCLUSIONS

A theoretical model and experimental results have been presented for the absorption coefficient of an absorber considering the three effects micro-perforation, panel resonance, and Helmholtz resonance. It can be concluded from the theoretical and experimental results that 1) the absorption peak due to the panel resonance can widen the absorption bandwidth of a micro-perforated absorber; 2) the absorption peaks due to the micro-perforation and Helmholtz resonance are combined together to form a wider and higher one if their peak frequencies are close. The peak due to the Helmholtz resonance would disappear if the peak frequency of the micro-perforation is much higher than that of the Helmholtz resonance.

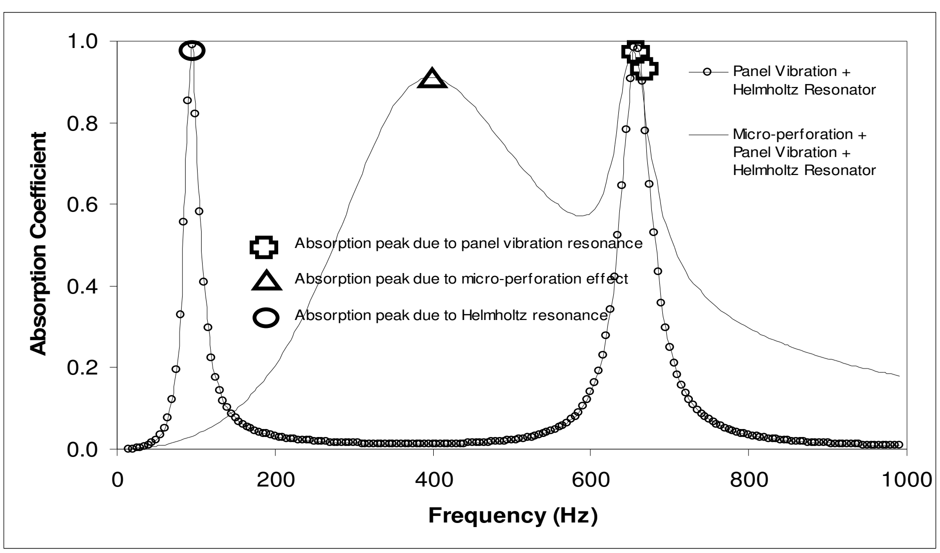

Figure 2a. The predicted absorption coefficients of the two absorbers; a = $79mm^2$, l = 10mm, A= $7854mm^2$, D =150mm, p = 0.05%, d =0.3mm, t = 0.3mm, m_p = $0.3kg/m^2$, ξ =0.04, ω_o= $2\pi 900$ radian/sec

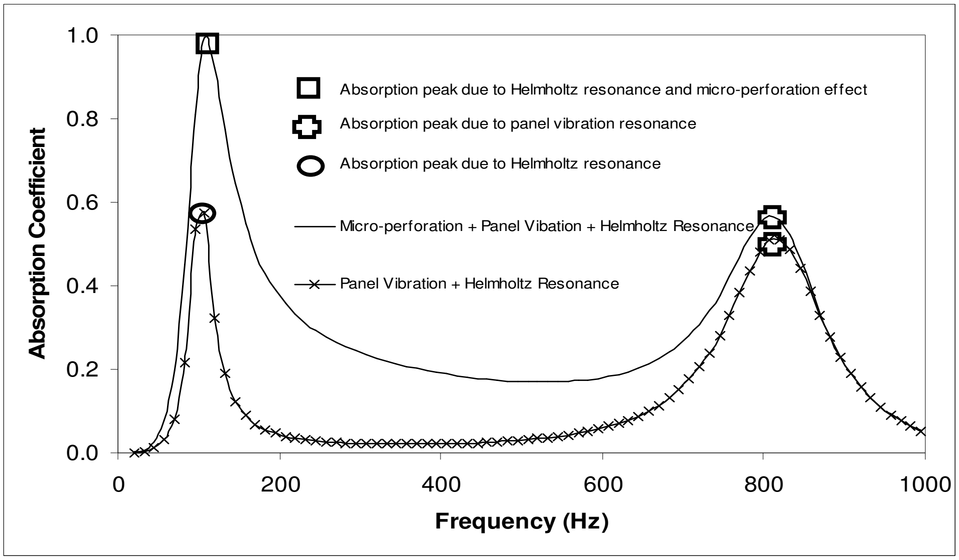

Figure 2b. The predicted absorption coefficients of the two absorbers; a = 28mm^2, l = 10mm, A= 7854mm^2, D =80mm, p =2.0%, d =0.8mm, t = 3mm, m_p = 3kg/m^2, ξ =0.04, ω_o= 2π 650 radian/sec

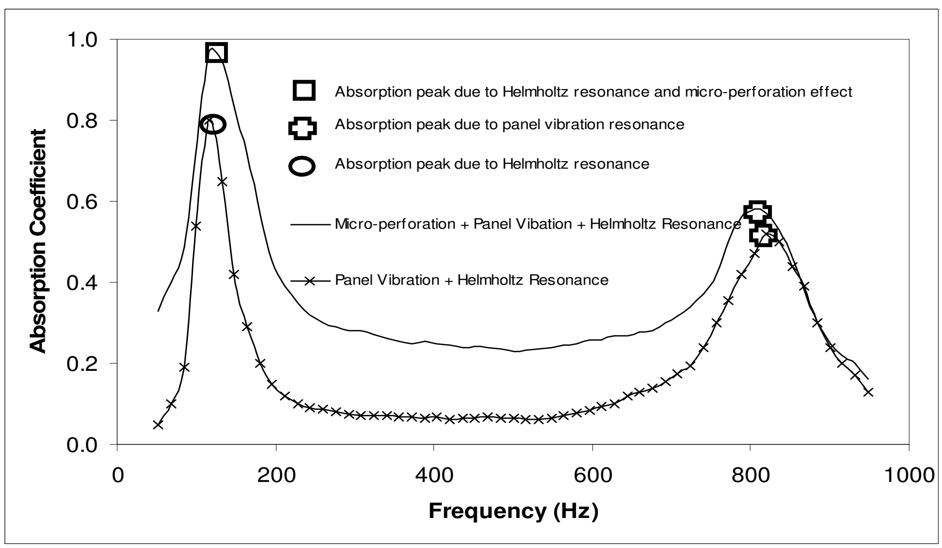

Figure 2c. The measured absorption coefficients of the two absorbers; a = 79mm^2, l = 10mm, A= 7854mm^2, D =150mm, p = 0.05%, d =0.3mm, t = 0.3mm, m_p = 0.3kg/m^2, ω_o= 2π 900 radian/sec

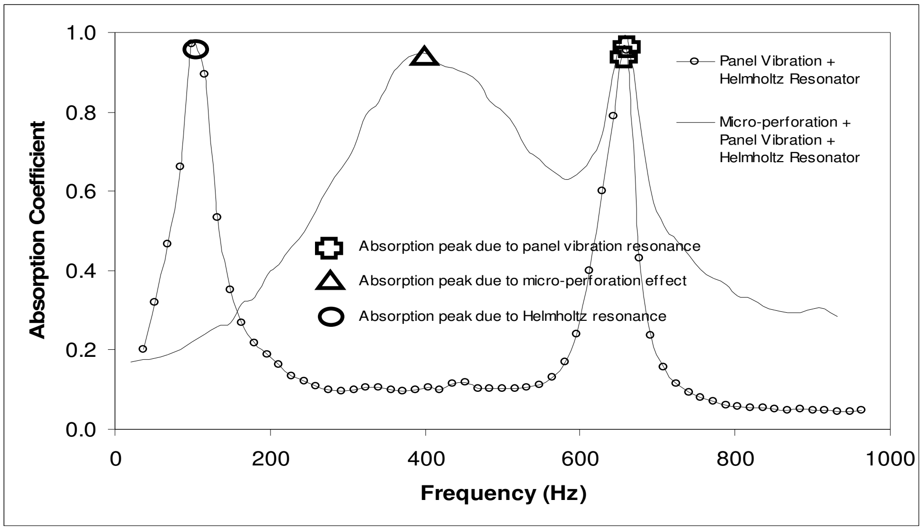

Figure 2d. The measured absorption coefficients of the two absorbers; a = $28mm^2$, l = 10mm, A= $7854mm^2$, D =80mm, p =2.0%, d =0.8mm, t = 3mm, m_p = $3kg/m^2$, ω_o= 2π 650 radian/sec

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