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Simulation and analysis for nonlinear acoustic absorption of perforated sheets at high sound pressure levels

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ABSTRACT

Comsol Multiphysics is a kind of effective simulation tool used to conduct numerical calculations for the sound propagation and absorption properties of porous materials in practical engineering. This paper mainly focuses on nonlinear acoustic absorption of perforated sheets at different high sound pressure levels inside an impedance tube in order to clearly explore the acoustic field distributions inside impedance tube at different frequencies including resonant frequency, with incident wave impinging of high sound pressure levels (great than 120dB). The changing tendency of sound absorbing capacity of perforated plates with respect to sound pressure levels of incidence wave is clearly demonstrated. It can be found out from the results of the simulation that the resonance frequency for a given plate shifts to the ascendant direction gradually as incident sound pressure level increases.

Keywords: High SPL, COMSOL, Acoustic Resistance I-INCE Classification of Subjects Number(s): 34.3

1. INTRODUCTION

The sound absorption of a perforated sheet is not only related to the frequency ,but also to the incident pressure level under high sound pressure level conditions, different from that at normal sound pressure levels. According to the works by *Dayou Ma* [1-2], the acoustic nonlinearity of a perforated sheet is mainly controlled by its acoustic resistance, whereas the effect of acoustic reactance is relatively small.

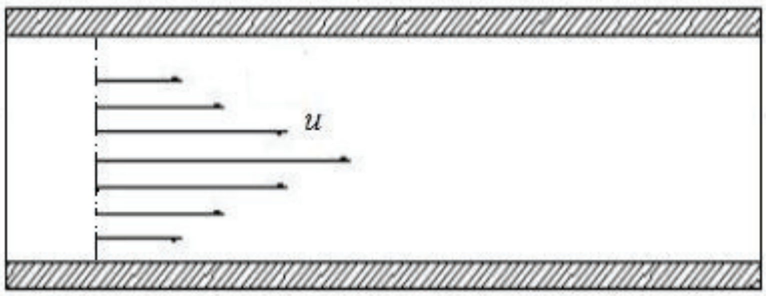

Figure1 – The air flow field in a hole of perforated sheet

Considering viscous properties of ideal air, one may get average particle velocity of air in holes of perforated sheet by the calculation of the acoustic control equation [3-4], and then obtain the relationship between incident sound pressure and particle velocity of air inside perforated sheet holes [2].

$$p_{in} = \frac{1}{2}\sigma u\left(1 + r_0 + u_0 / \sigma c_0\right)\rho_0 c_0 \tag{1}$$

In Eq.(1), r_0 is the relative linear acoustic resistance, u the average particle velocity of air in the hole, u_0 the amplitude of particle velocity of air, σ the perforation rate, and ρ_0 and c_0 the static density of air and speed of sound, respectively. According to Eq. (1), one may get the expression of u_0, incorporating incident sound pressure p_{in}. And then the simulation of the acoustic absorption of the perforated sheet at high sound pressure levels can be made by using COMSOL Multiphysics.

2. THE PROCESS OF SIMULATION

2.1 Acoustic Modeling by Comsol Multiphysics

In this subsection, the acoustic module of Comsol Multiphysics is selected for the simulation of the acoustic filed in an impedance tube with a perforated sheet placed at a position away from the end of tube. Besides, it should be noticed that the acoustic modeling is performed in 2D space in this work.

First, one must build up the geometric model of an impedance tube incorporating a perforated sheet, as shown in Fig.2. A planar wave impinges into tube from the top of tube (i.e. sound source), with the incident sound pressure levels varying from 90 to 170dB. The upper limit of frequency for this simulation is set to be 5000Hz and one just focuses on the absorbing properties at resonant frequency.

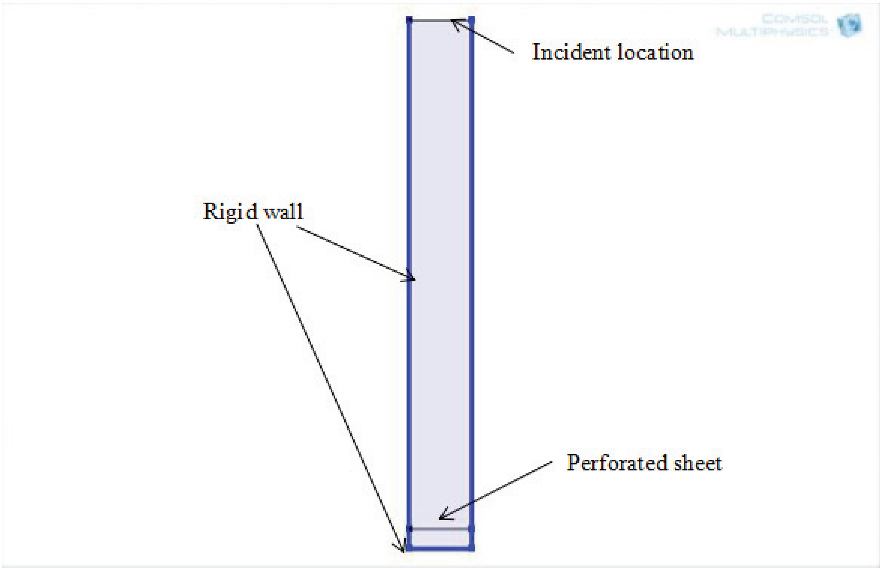

Figure 2 – Geometric model of an impedance tube in Comsol, with a perforated sheet inside it

In Fig. 2, the distance between the perforated sheet and the bottom of tube is denoted by a parameter *D*. In comparison with *Dayou Ma*'s results [1-2], *D* and the other parameters of the perforated plates under consideration are listed in Table 1.

Table 1 – Parameters of the perforated sheets [Ref.2]

	d, /mm	*h*, /mm	*σ*, / %	*D*, /mm
Plate 1	7	1	0.6	40
Plate 2	7	1	1.5	40
Plate 3	7	1	3.1	40

In Table 1, parameter *d* is the perforated hole-diameter, *h* the thickness of plate, and σ the perforation rate. After introducing the nonlinear item, which consists of u_0, σ and c_0, into the expression of acoustic impedance *z* of perforated sheet, the calculation of the sound field considering the nonlinearity caused by incident high sound pressure levels in Comsol is given as follows:

$$z=\frac{1}{\sigma}\left(1+\frac{h}{d}\right)\sqrt{\frac{8\eta k}{\rho_0 c_0}}+\frac{\sqrt{\frac{2p_{in}}{10^5\sigma^2}+\frac{(1+r_0)^2}{4}}-1}{\frac{1+r_0}{2}}+j\omega\frac{k}{\sigma}\left[h+0.85d\left(1+\frac{\sqrt{\frac{2p_{in}}{10^5\sigma^2}+\frac{(1+r_0)^2}{4}}-1}{\frac{1+r_0}{2}}\right)^{-1}\right] \tag{2}$$

In Eq. (2), η is the dynamic viscosity of air, and *k* the wave number. With this equation, one can calculate the relative acoustic impedance by means of acoustic module in Comsol. Then the sound pressure distribution and the absorption coefficient will be evaluated in 2D and 1D drawing set, respectively.

2.2 The Analysis of the Results

In this work, the simulation for the plate 1 was made first. Curves of sound absorption coefficient versus different frequencies and different incident pressure levels are plotted in Fig. 3, abscissa axis of which stands for frequency (Hz).

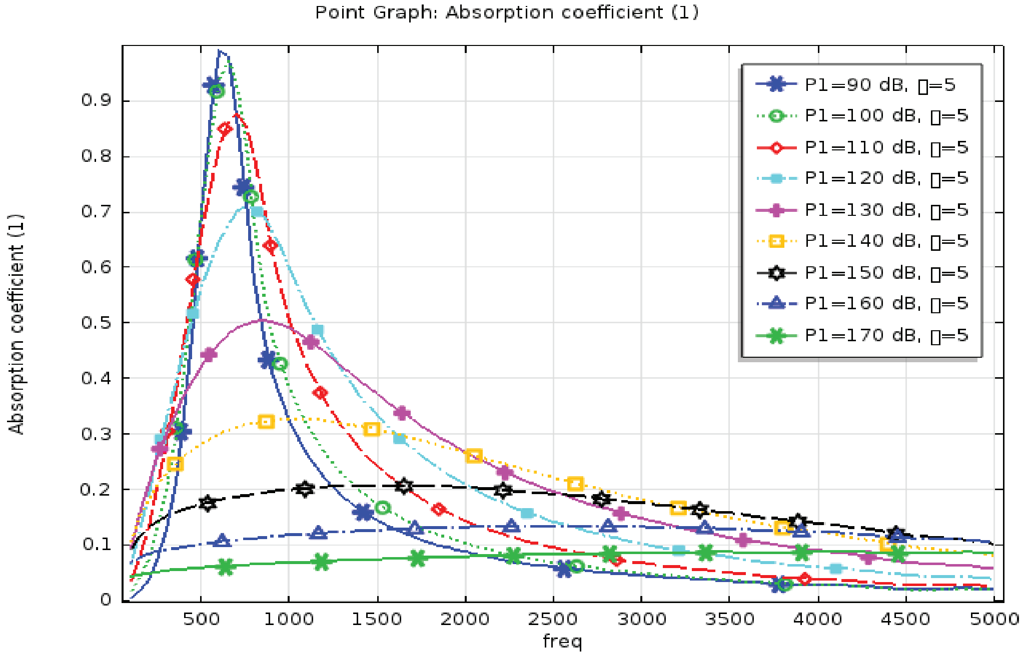

Figure 3 – Sound absorbing curves of plate 1, with respect to frequency

It can be found out from Fig.3 that the resonance frequency for plate 1 shifts to the right gradually as incident sound pressure level increases. The distributions of sound pressure for incident and reflected waves inside tube are displayed in Fig. 4, respectively.

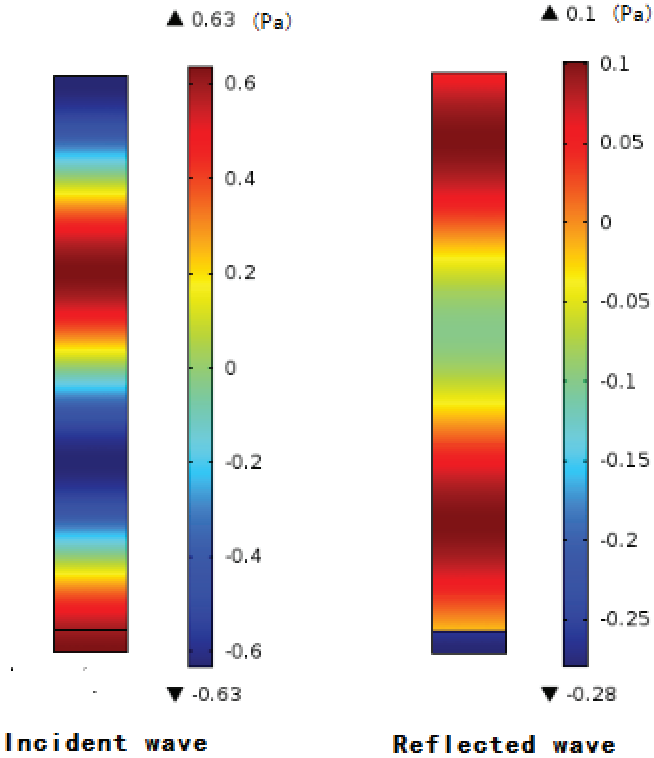

Figure 4 – The comparison of sound pressure distribution between the incident and reflected waves for plate 1

As shown in Fig.4, the magnitude of SPL for incident and reflected waves is depicted by areas of gradually varying colors. It is shown from Fig. 4 that at the resonance frequency the most of acoustic energy incident wave carried is absorbed by the perforated sheet that is located at a given position away from the bottom of impedance tube; therefore, the reflected acoustic energy is very low due to the existence of the perforated sheet. Using the similar way, one can immediately plot the sound absorption curves of other two plates. The involved sound absorbing results are given in Figs.5-6.

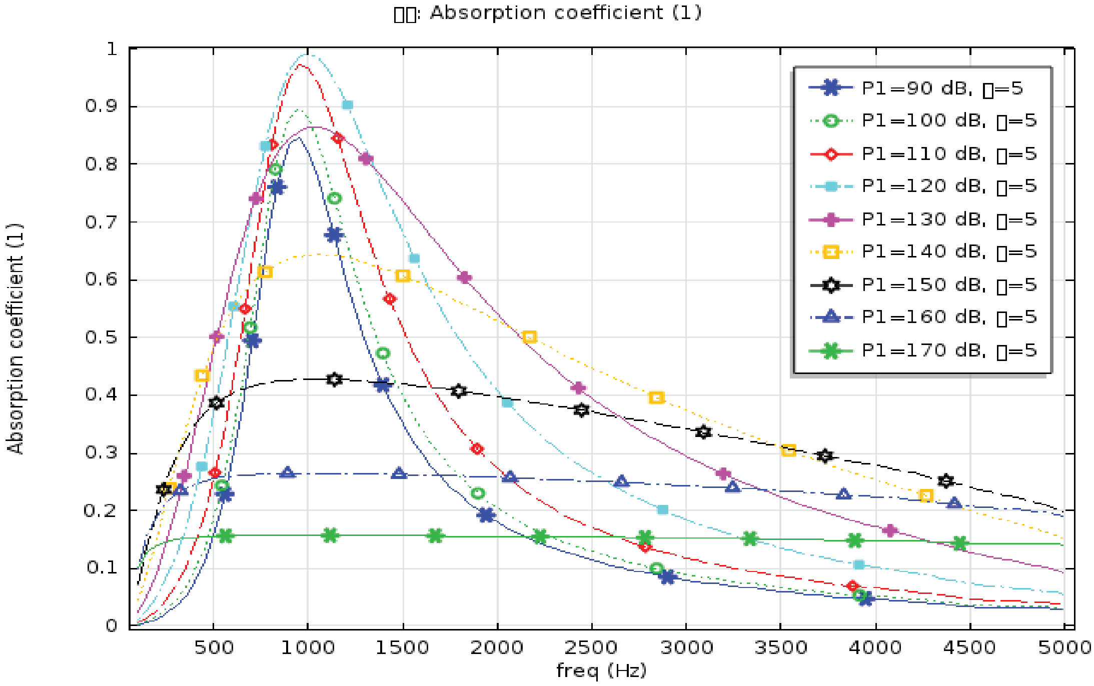

Figure 5 – Curves of sound absorption coefficient versus frequency for plate 2

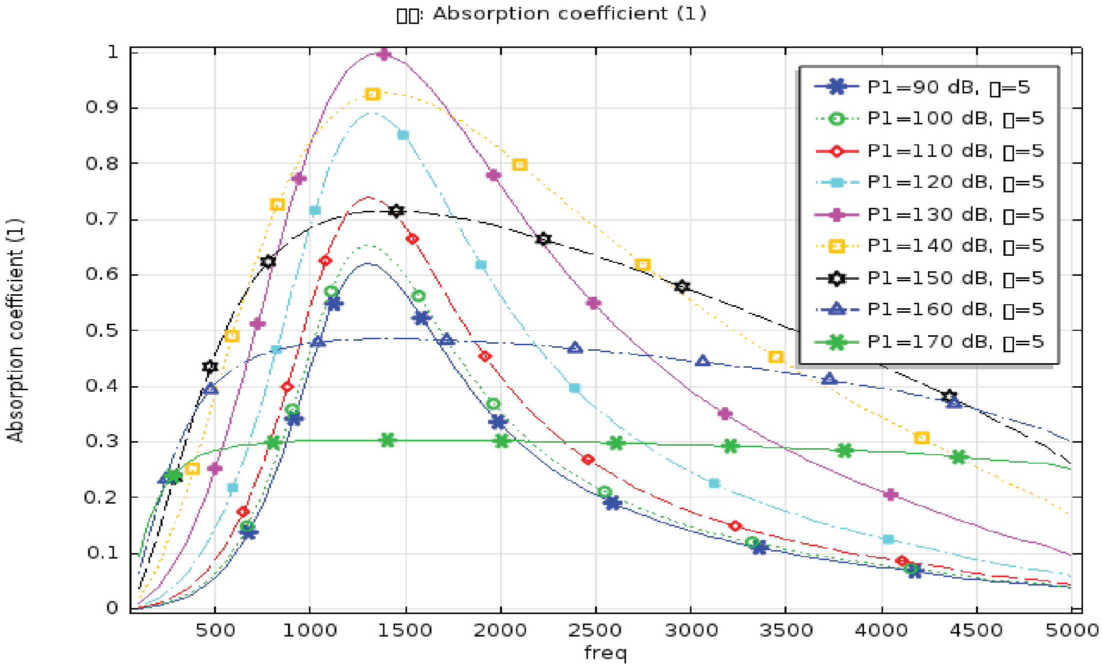

Figure 6 – Curves of sound absorption coefficient versus frequency for plate 3

Figures 5-6 showed that the sound absorption peaks for plate 2 and 3 at resonance frequency gradually arises as the incident SPLs increases from 90 to 130dB. Above SPL of 130dB, the sound absorbing amount at resonance frequency declines with further increase of incident SPL. In order to more clearly observe the variation of sound absorption coefficient with respect to incident SPLs, one may plot the relationship between sound absorption coefficient and incident SPLs (dB). As an example, the aforementioned curve of relationship for plate 1 is shown in Fig.7.

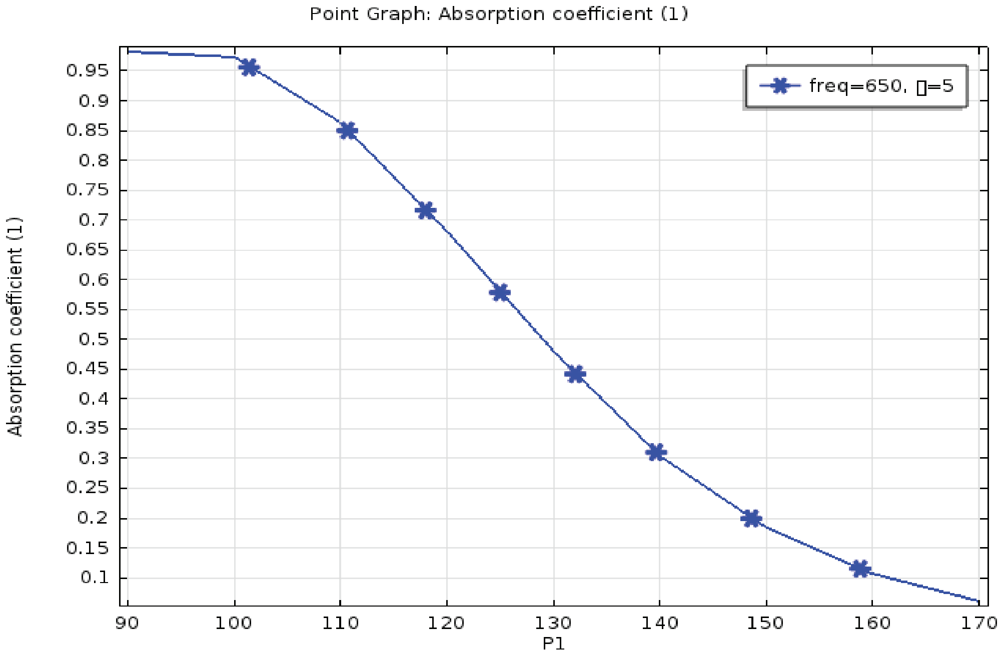

Figure 7 – Sound absorption curves for plate 1, with respect to incident SPL

As for plate 1, the perforation rate of which is 0. 6 %, the corresponding absorption coefficient tends to the maximum as incident SPL is close to 90dB. In other words, sound absorbing capacity will be weakened gradually as the increase of incident SPL. According to the work by *Dayou Ma*[1-2], one may reduce the nonlinear resistance of perforated sheet by weakening the effect of nonlinear item which is related to particle velocity of air and perforation rate at the same time. Because the air particle velocity is directly affected by incident sound pressure, one of weakening the effect of the nonlinear item is to increase the perforation rate of plate. Figure 8 shows the sound absorbing versus incident SPLs for different perforation rates.

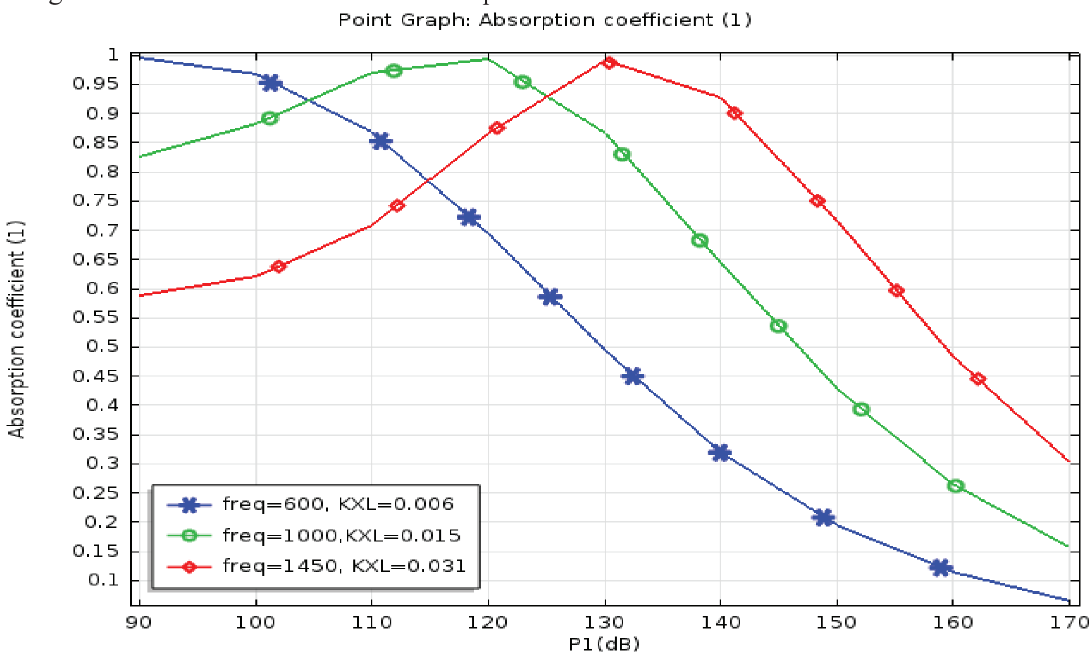

Figure 8 –Sound absorbing versus incident SPLs for different perforation rates

Figure 8 also shows that the sound absorption capacity of perforated sheet is enhanced as increasing the perforation rate. And each plate could achieve its own maximum absorbing peak in a given ranges of incident sound pressure levels. On the other hand, it can been seen from Fig.6 that although one may improve the sound absorption properties of the perforated plate at higher sound pressure levels by the increase of the perforation rate, yet the sound absorption coefficient at normal sound pressure levels will be weakened as well.

3. SUMMARY

In this paper, the simulations for three types of perforated sheets were made by using Comsol Multiphysics. The nonlinear acoustic absorption of perforated sheets at different high sound pressure levels inside an impedance tube was studied in order to clearly explore the acoustic field distributions inside impedance tube at resonant frequency, with incidence acoustic wave of high SPL (great than 120dB). The changing tendency of sound absorbing capacity of perforated plates with respect to sound pressure levels of incidence wave is clearly demonstrated. It can be found out from the results of the simulation that the resonance frequency for a given plate shifts to the ascendant direction gradually as incident sound pressure level increases.

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