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MEASURING RESONATOR PANELS’ FREQUENCY ABSORPTION AND Q FACTOR, USING FINITE ELEMENTS METHOD.

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Abstract

The analysis of the sound field generated by a Helmholtz resonators panel is described by a Finite Elements Method. The resonance frequency, absorption and Q factor of the panel was evaluated at different positions for a sound source and different geometries of the panel mainly over the frequency range from 20Hz to 100Hz. The results showed that as the source moves away from the panel, the absorbed frequency is getting lower (2-3Hz every 0.1m) but the Q factor stays constant. The attenuation 5-7 meters from the panel can be up to 20dB for the central absorption frequency. Also it was observed that the absorption frequency can be lower by reducing the panel’s perforation density.

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1. Introduction

Helmholtz resonators are probably the first acoustic element used in architectural acoustics for the acoustic quality of open space theaters improvement. According to Vitruvius Helmholtz resonators were placed under the seats in ancient Greek theaters [1]. Later in medieval ages resonators were embedded inside the walls of worship spaces for the same purpose [2, 3]. Today resonators are widely used in the form of perforated panels for sound absorption [4].

The theory of Helmholtz resonators was firstly established by Rayleigh (1896) [5]. Ingard (1953) describe analytically the function and the use of Helmholtz resonators as sound absorbers and scattering devices [6]. Computer simulation software is used today for calculation of resonators performance. Finite Elements Method (FEM) is an appropriate tool to understand and visualize the performance of such elements [7,10].

Sound control using resonators has mainly two advantages. Firstly it provides a good way to absorb low frequency signals without affecting the higher frequency ones, being possible to achieve the desired Q factor by changing the resonators' geometry. Secondly, by changing the geometry of the resonator the desired absorption frequency and Q factor can be realized.

In the present work a FEM model were used to understand the behavior of a perforated panel absorber. The models were implemented using a COMSOL Finite Element Method technique [11] and time harmonic analysis was used to determine the modal frequencies and shape of the pressure function. In this case the "radiation boundary condition" with zero pressure (p=0) was used to simulate an infinite duct.

2. Simple Helmholtz resonator

The main characteristic of Helmholtz resonators is that it performs a selective absorption or scattering at the resonance frequency of it, located into the low frequency region. The resonant frequency is depended upon the geometry of the resonator. Accurate but complicated formulas can be found in bibliography [7 - 9].

A first approximation for the resonance frequency of the resonator according to Ingard is given by:

$$f_0 = \frac{c}{2\pi}\sqrt{\frac{S}{LV}} \tag{1}$$

where c (m/s) is the speed of sound, S (m^2) the cross section area of the neck, L (m) is the effective length of the neck (including the end corrections), L=L' + 1.7a, L' (m) is the real length and V (m^3) the volume of the cavity.

The attenuation of a resonator is given by [12]:

$$a = \frac{1}{1+\left(\frac{c}{\frac{4S_b \pi f L}{S}} - \frac{c^2}{2\pi f(k) V}\right)^2} \tag{2}$$

and the Q factor [12]:

$$Q = 2\pi\sqrt{V(\frac{L}{S})^3} \tag{3}$$

The near field performance of the resonator is rather complicated since the resonator reradiates sound. Under optimum conditions the intensity of the reradiated sound at a distance r is

$$I_s = \left(\frac{c}{r\omega_0}\right)^2 I \tag{4}$$

where I is the intensity of the incident sound wave [13]. Both intensities are equal at a distance:

$$r = \frac{c}{\omega_0} \tag{5}$$

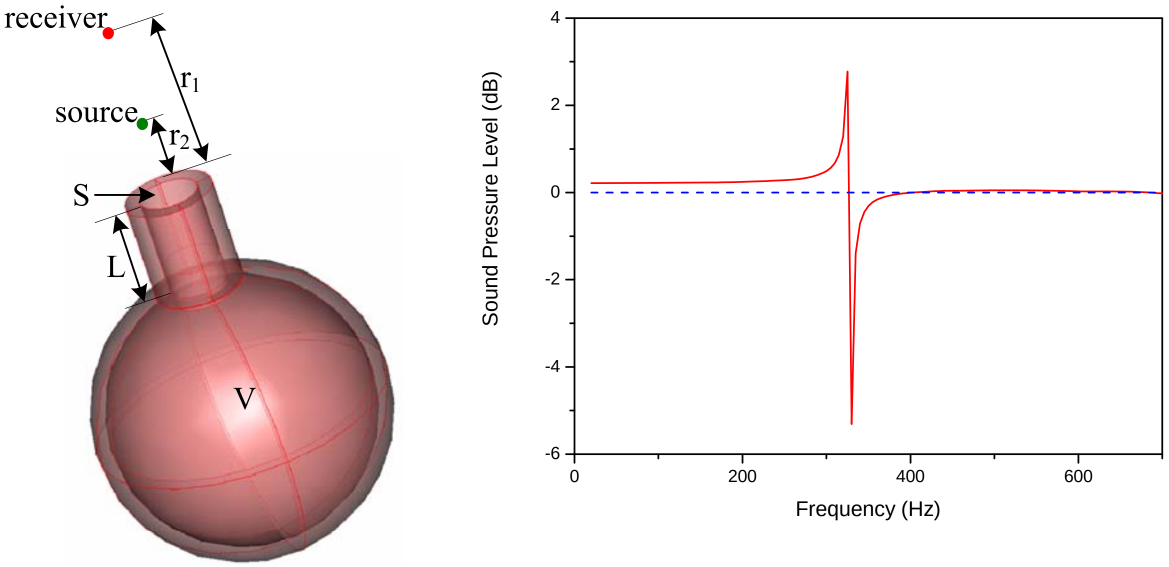

Figure 1 The model of Helmholtz resonator (left) The spectral SPL difference at the receiver position with and without the presence of resonator (right).

A simple 3D geometry resonator was established first. The 3D model as shown in figure 1 (left) developed here using COMSOL's multiphysics simulation method [11], with free field boundaries, 27°C temperature and 1.24 (kg/m^3) fluid density.

For the subsequent model, it will be initially assumed that an omni directional sound source is at distance r_2 = 2m from the top of the resonator. The sound source generates sine wave frequencies from 20 to 700Hz. By subtracting the sound field generated by the presence of the resonator from the free field condition, the typical (magnitude) Sound Pressure Level frequency response shown in figure 1(right) can be obtained. The receiver in both calculations was set at r_1 = 1m, from the resonator. The observed resonance frequency coincides with the expected resonance frequency using equation (1), i.e. is f_0 = 313Hz, for V= 0.0008 m^3, L = 0.0951 m, S = 0.0025 m^2 and c = 343 m/s.

3. Membrane Absorber

To study the effect of a perforated panel, which acts as a system of Helmholtz resonators, a 2D model of a non perforated panel absorber has been also studied. The resonance frequency of a membrane absorber might not be very accurate estimated using such a 2D model, but it is still useful to compare the absorption of the membrane with the absorption of a panel resonator. An approximate expression for the resonance frequency of a membrane panel absorber is given by [4]:

$$f = \frac{60}{\sqrt{md}} \tag{4}$$

where m is the mass per unit area and d the distance of the membrane from the wall [4].

3.1.1 The effect of membrane absorber combined with perforated panel.

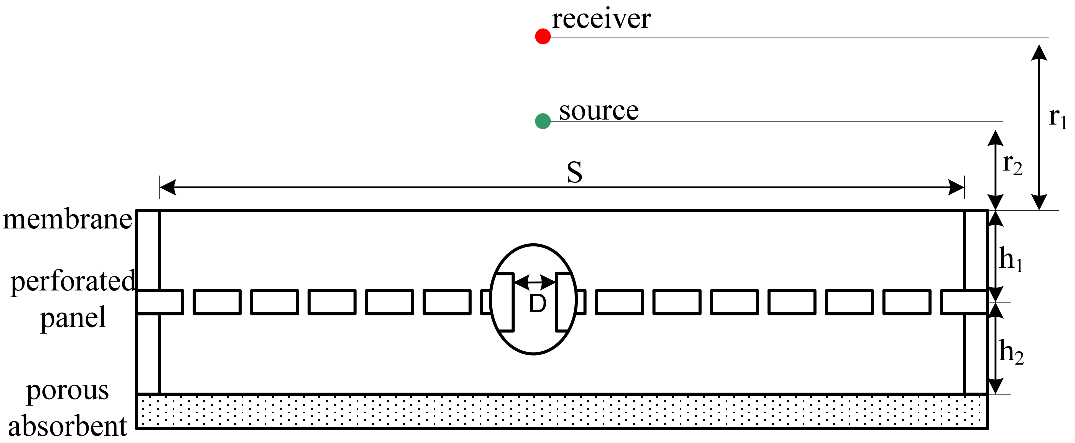

Figure 2 the basic geometry of membrane Helmholtz absorber model

The absorption ability of membrane absorbers is depending upon the absorptive material between the membrane and wall. In order to study the effect of resonators, as additional absorbers, if they are placed between the membrane and the wall on the total absorption of membranes, a model consisting by a membrane and a perforated panel between the panel and wall were established. Figure 3 shows the calculated SPL in three cases: a panel with a membrane, a panel without membrane and the source in free field. As one can see in figure 3 the use of the membrane achieves absorption at a low frequency (in this case f=50Hz), allowing the panel to behave as a notch filter. By changing the resonance geometry, this frequency and Q factor can be also adjusted. A membrane needs to be applied to the panel resonator in order to achieve absorption at such low frequency as 50Hz and also to make the panel behave as a notch filter with a higher Q factor. In such low frequencies it is normally desirable to have high Q factor because the modal resonances of the room usually have narrow bandwidths. It was expected, according to the general Helmholtz equation (1) but also to equation (4) and (5), that the absorption frequency with no membrane would be higher because the volume of the panel decreases. Then by changing the geometry of the resonator it is again possible to change the resonation frequency and the Q factor.

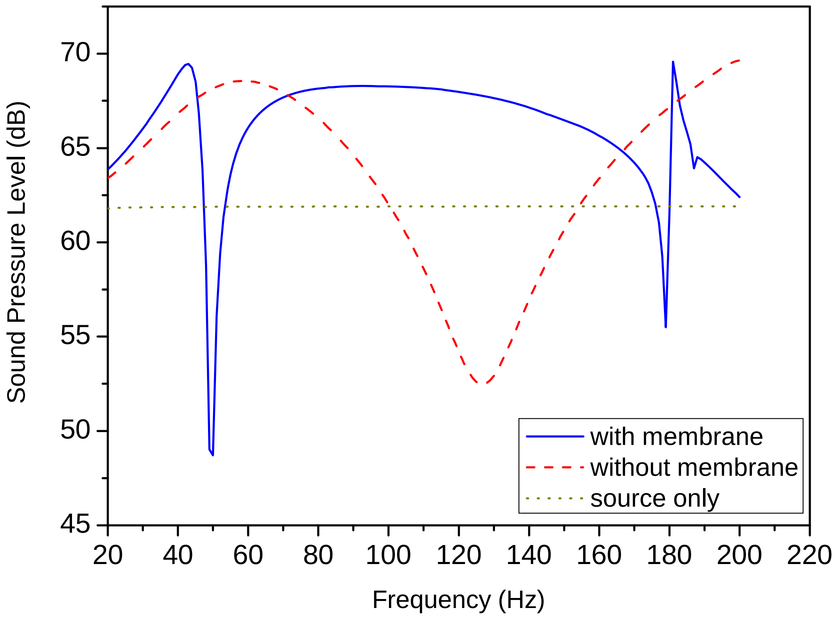

Figure 3 *Response of a perforated panel with and without membrane*

3.1.2. The effect of panel absorbers under membranes.

To study the effect of perforated panels on membrane absorbers the model describer above was modified by replacing the non perforated panel with a perforated one for different geometries and distances of the receiver, as shown in figure 3. The source was kept at a constant distance 0.33 m from the membrane. The source frequencies ranged from 20Hz to 100Hz, with a step of 1Hz. All modifications are tabulated in table 1.

Table 1 ***Geometry of the system membrane –panel absorber tested***

Model	**S (m)**	**h_1 (m)**	**h_2 (m)**	**D (m)**	**membrane**	**r_1 (m)**	**r_2 (m)**	***perforated panel***
1st	2	0.18	0.18	0.005	Yes	0.33	3.83	Yes
2nd	2	0.18	0.18	0.095	Yes	0.33	3.83	Yes
3rd	2	0.11	0.11	0.005	Yes	0.33	3.83	Yes
4th	2	-	-	-	Yes	0.33	3.83	No
5th	2	0.18	0.18	-	Yes	0.33	3.83	No
6th	2	0	0.36	0.005	Yes	0.33	3.83	Yes
7th	2	0	0.36	0.005	No	0.33	3.83	Yes

Figure 4 shows the frequency response of all models tabulated in table 1

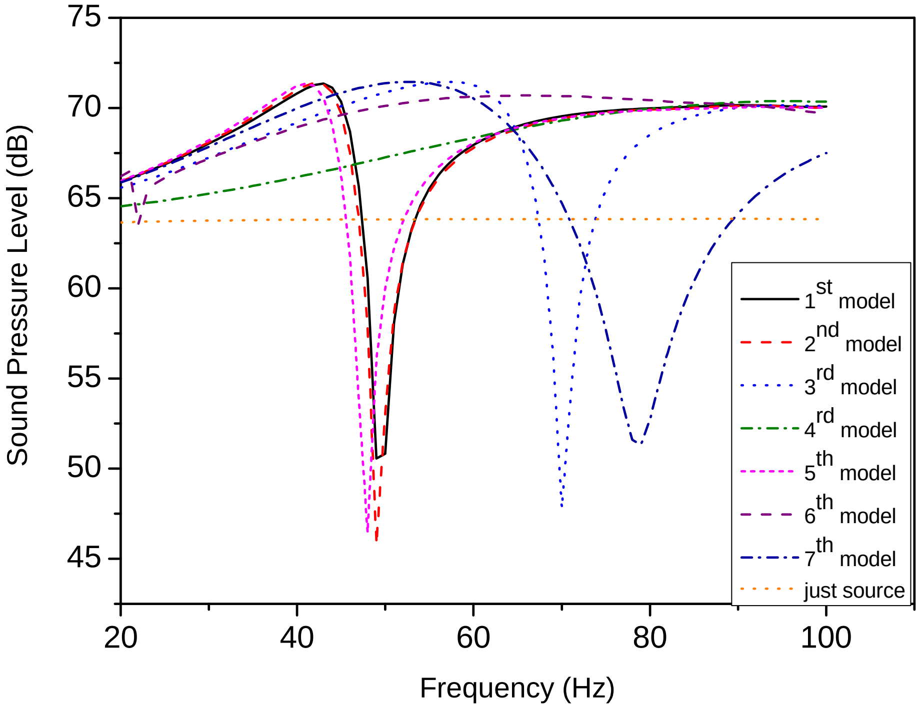

Figure 4 *Frequency response of models described in table 1*

From figure 4 one can see that the 1st models' resonance frequency is 50Hz which is close to 2nd and 5th model but with higher Q factor. As it is also observed, the size of the perforations of the perforated panel, in the presence of membrane does not affect significantly the resonance frequency, but can modify the Q factor. The 3rd model has higher resonance frequency as it was expected since it has smaller volume. The 4th model is just the membrane, there is no resonant frequency between 20 and 100Hz, it just increases the pressure level in higher frequencies, but this effect depends upon the thickness of the membrane. Since for the 6th model, the perforated panel is in contact to the membrane (i.e. h_1=0), there is no significant resonance in this frequency range. The 7th model is just like 6th but without membrane, it has a resonant frequency on this range with high Q factor.

Figure 5 shows the sound field of the 1st model in 3 different source frequencies (20Hz, 50Hz and 80Hz). As it can be easily observed, from the sound field (Figure 5), the resonance frequency is 50Hz and creates a significant attenuation of the sound field.

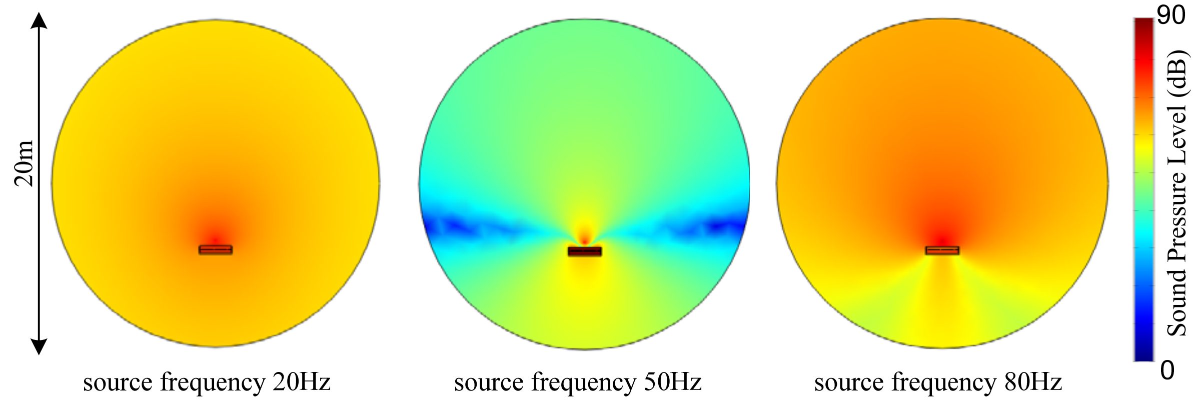

Figure 5 Sound field of the 1st model with the source generating various frequencies with 85dB Sound Pressure Level

3.1.3 *Effect of source distance.*

The source position has also an effect on the resonant frequency of the panel. For the seventh model of table 1 the source were placed at different distances from the membrane in the range of 0.1m to 0.5 in step of 0.1 m. located inside the near field of the resonator (the limiting distance described by equation (5) is 0.72m.). As it seems in figure 6 the source distance r_2 causes a small shift of the resonant frequency.

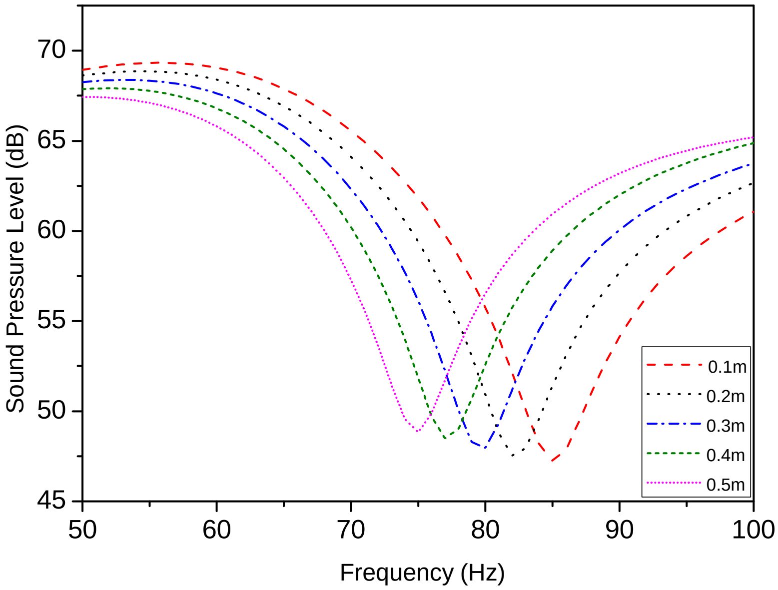

Figure 6 Resonant frequency for source moving away from r_2=0.1m to 0.5m

More precisely the frequency with the maximum absorption decreases by approximate 2Hz, for each step of 0.1m away from the panel. For the resonant frequency shift the following regression equation can be written:

$$f = f_0 - 20r \quad for \quad r > 0.1m \tag{6}$$

where f_0 is the resonant frequency of the panel, for r_2=0.1m and r = r_2 in the present work.

4. Conclusions

From the models established here it seems that the size of the perforations of a perforated panel, in the presence of membrane does not affect significantly the resonance frequency of the panel, but can modify the Q factor.

When the source is located in the near field of the resonator the resonant frequency shifts linearly with the distance of the system source-resonator.

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