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Interferences between Bandgap and Resonances in Locally Resonant Sonic Materials

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ABSTRACT

The use of Helmoltz resonators has been a classic solution for the control of acoustic wave transmission over the years. One of the most analyzed devices in the last decade is formed by arrays of these resonators, usually called Locally Resonant Sonic Materials, one of whose main applications is the development of acoustic screens with high technological value. There are two main waves control mechanisms that appear in these devices: resonances and bandgaps, due to the multiple scattering that appears because the Helmholtz resonators are ordered forming an array. But the manipulation of both phenomena is not always easy. When the resonance peaks are far enough away from the band gap (BG) in the frequency range, the coexistence of the two phenomena occurs without interferences. However, when both peaks are very close to each other, some phenomena of interference between the two mechanisms appear. In this work we present the cases in which the phenomenon of resonance-BG interference occurs, including its physical explanation and some possible solutions to control it. Although this work is developed for audible, the conclusions can be applied to any device designed for any frequency range.

Keywords: Noise, Locally Resonant Sonic Materials, Helmholtz Resonators
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1. INTRODUCTION

Acoustic screens are one of the most commonly used solutions for controlling noise in its transmission phase. Their use becomes necessary when it is not possible to reduce the levels of noise emission generated by the source or when achieving it involves large economic costs [1].

A classic acoustic screen is fundamentally made up of a continuous rigid material is interposed between the sound source and the receiver, Figure 1(a). This type of screen provides noise attenuation mainly due to the Law of Mass.

At the end of the 20th century, a new line of research arose to attenuate noise by means of sonic crystals (SC). The SCs are periodic arrays of isolated acoustic scatterers, immersed in a fluid medium that has very different properties from those of the scatterers. These materials provide a noise control mechanism called multiple scattering that allows them to be used as acoustic screens [2], [3]. The referenced studies, among others, showed that there are frequency bands in which sound propagation is attenuated, and the position of the scatterers in the crystal array determines the position of these acoustic attenuation bands in the frequency spectrum. Thus, several studies have designed sonic crystals acoustic screens with cylindrical scatterers. Early designs used rigid scatterers [4], where only the multiple scattering mechanism attenuated the noise, calling this kind of screens 1st generation screens. It was soon possible to incorporate new noise control mechanisms with the idea of constructively superimposing them on multiple dispersion [5], intrinsic to SC. This kind of screen, Figure 1(b), was called 2nd generation screens [6] and incorporated the mechanisms of absorption and resonance.

(a) *(b)*

Figure 1: (a) Classic acoustic screen; (b) 2nd generation of Sonic Crystal Acoustic Screen

The position of the acoustic attenuation band in the frequency spectrum due to multiple scattering depends on the arrangement of scatterers, e.g. square or triangular array, and at the distance at which they are located, called lattice constant. The size of the attenuation band depends on the filling factor (ff) of the array, which represents the volume occupied by the scatterers with respect to the total volume of the crystal:

$$f = \frac{c}{2\pi}\sqrt{\frac{S}{L_e V}} \qquad (1)$$

where c is the speed of sound in the air (m/s), S is the section of the resonator inlet (m^2), Le is the effective length of the resonator neck (m) and V is the volume of the resonant cavity (m^3).

In this case, as will be seen in the following section, the resonator consists of a cavity located inside the scatterer cylinder.

When several noise control mechanisms are used, it is important that they are constructively superimposed in order to achieve the widest possible acoustic attenuation band in the frequency spectrum. This work analyses the effect that produces in the spectrum, the join of the mechanism of multiple scattering with resonance. Depending on the design, the band gap (BG) may interact more or less with the introduced resonance peak.

The following section shows the scheme of simulation used to analyze the effect of the BG + resonator interaction on the attenuation spectrum. The Finite Element Method (FEM) has been used, specifically the commercial program Comsol Multiphysics. This method solves a variety of geometries with multiple acoustic phenomena in a simple way.

2. SCHEME OF SIMULATION

To solve the numerical problem, it is necessary to define the geometry which is being considered, to implement the boundary conditions and to take issue the resolution domain. The scheme of simulation is shown in Figure 2. The domain where the solution is obtained is formed by 3 cylindrical scatterers, separated between them the lattice constant (a), with an external radius (r_{ext}) and an internal radius (r_{int}), and with a nozzle at the entrance of the cavity width Lc. As part of the scatterers are considered rigid, it is considered on their surfaces the boundary condition of Neumann. These scatterers are bounded by two walls, endowed with periodic conditions, also separated from each other by the lattice constant (a), these being parallel to the propagation direction of the incident plane wave, which travels from left to right. Under these conditions, the waves scattered in the cylinders are not reflected on the walls and therefore reproduce the effect of a semi-infinite 2D crystal consisting of 3 rows of resonators arranged in a square array. This geometry allows the study of semi-infinite matrices using a reduced numerical domain volume and, therefore, lowering the computational cost. So that there is no reflected wave at the input and output of the medium, Perfectly Matched Layers (PML) have been used [6]. This simulates the Sommerfeld radiation conditions in the numerical resolution of scattering problems. The measuring point is located at the distance b from the last resonating element.

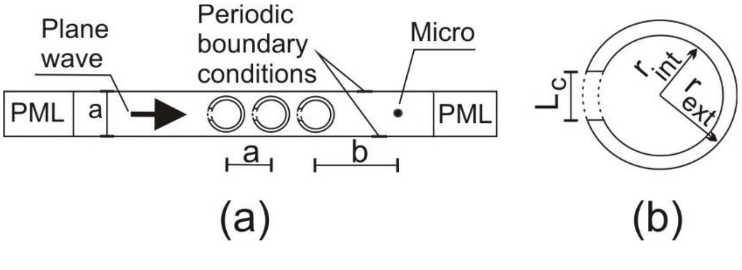

Figure 2: (a) 2D model of the acoustic screen, (b) Detail of the dispersor: it is observed that it has a cavity of width L_c and radius r_{int}

The numerical model solves the wave equation in the frequency domain,

$$\nabla\left(\frac{1}{\rho}\nabla p\right)+\frac{w^2}{c^2\rho}p=0 \qquad (2)$$

equation in partial derivatives, and the propagation of the plane wave is studied.

The values of the geometric parameters used in this work have been: r_{ext}=0.14m, r_{int}=0.1m and L_c=0.02m. The lattice constant (a), takes several values that are indicated in the results and the distance of the measurement point b=1m. To discretize the domain, a simple triangular mesh is used and the number of degrees of freedom is of the order of $4 \cdot 10^4$. The maximum size of the mesh is c / $12f_{max}$.

The results obtained from of the numerical model are shown in the noise attenuation spectrum obtained at the measurement point. For this purpose, the difference between direct noise pressure (P_d) and interfered noise pressure (P_i) is evaluated by the insertion loss parameter (Acoustic Attenuation (dB)) at that point, using the expression:

$$Acoustic\ Atenuation = 20\ log_{10}\left|\frac{P_D}{P_I}\right| \qquad (3)$$

3. RESULTS

In a first analysis, when both graphics are joined - the attenuation spectra obtained in the case of a screen formed by three rows of totally rigid scatterers with the spectrum obtained using another screen formed by three rows of scatterers with resonator cavities (Fig. 3) - it is observed that the BG is affected by the position of the resonance peak located around 200 Hz.

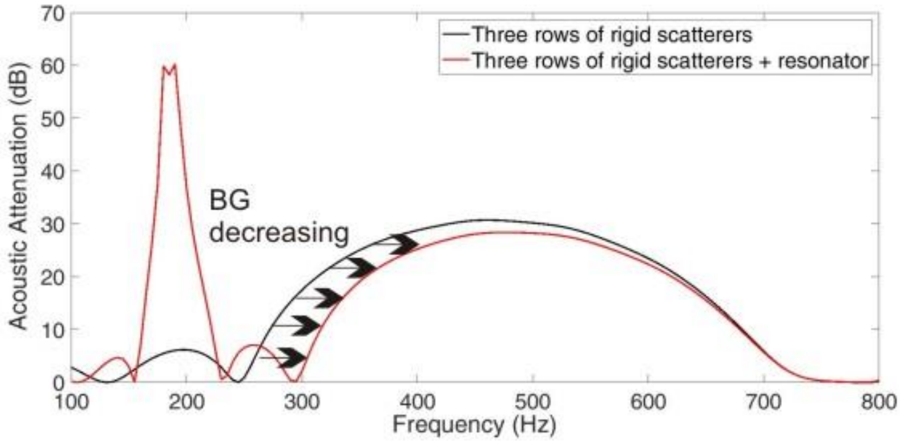

Figure 3: On the black line acoustic attenuation spectrum from 100 to 800 Hz obtained with a screen formed by three rigid scatterers, on the red line acoustic attenuation spectrum from 100 to 800 Hz obtained by a screen formed by three scatterers with resonator cavities tuned to 200 Hz. The lattice constant used is 0.33 m (f_{Bragg}= 519 Hz).

According to the result of Figure 3, the influence of resonance on the BG produced by multiple scattering implies a decrease of this BG. The lattice constant defines the position of the centre of the BG according to the expression: f_{Bragg}=c/2a. In the shown case, the BG is around 519 Hz and the resonance frequency at 200 Hz. Thus, by setting the resonance frequency fixed and changing the lattice constant, the position of the BG in the spectrum will be shifted. Some tests were performed to check whether moving the BG is still affected by the position of the fixed resonance peak. In order to verify this assumption, a parametric scan has been carried out using the numerical model. Figure 4 shows three results of the parametric scan, 0.29, 0.33 and 0.40 m.

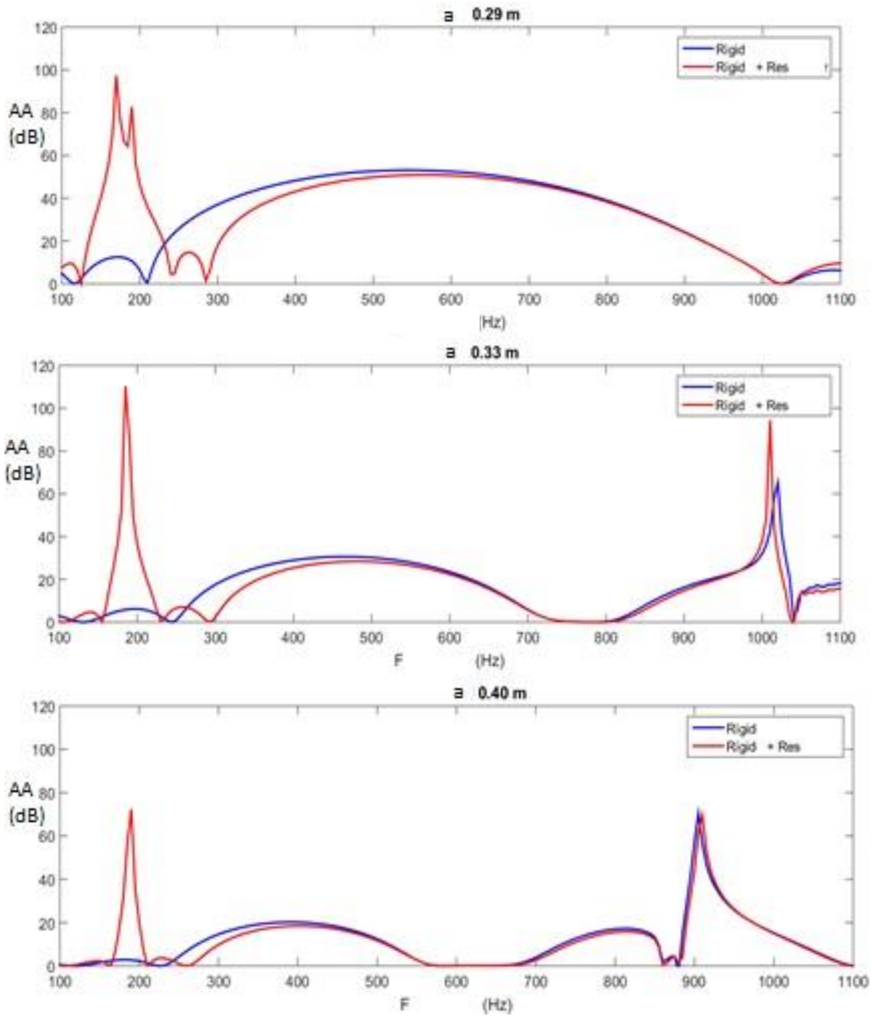

Figure 4: Acoustic attenuation spectra for the case of three lattice constant: 0.29, 0.33 and 0.40 m. In blue line screen formed by rigid cylindrical scatterers and in red line screen formed by rigid cylindrical scatterers with resonator cavities tuned to 200 Hz.

These results show that whenever the BG frequency is close to the chosen resonance frequency, the BG is affected. On the other hand, the decreasing of the lattice constant has a limit imposed by the size of the scatterer and the increasing of the lattice constant entails a reduction of the ff, making the SC more transparent and reducing its acoustic attenuation capacity.

4. CONCLUSIONS

In this work a 2nd generation SC has been analysed, and the influence of the resonance frequency, induced by the resonant cavity of the scatterers, on the BG. Two types of screens have been compared, one with a rigid scatterers and another composed by scatterers with resonant cavities; and different lattice constant have been analysed. It has been seen in all cases that if the Acoustic Attenuation parameter is calculated, there is always a loss of attenuation capacity in the BG when resonators are present. This loss could be recovered if the ff of the screen was increased. Based on this study, other tests can be carried out to ensure that these effects add up along al noise spectrum in order to achieve an attenuation band as wide as possible.

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