Noise certification of a Sonic Crystal Acoustic Screen designed using a triangular lattice according to the Standards EN 1793(-1;-2;-3): 1997

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Summary

The possibilities of Sonic Crystals (SCs) as acoustic barriers have been intensively investigated during the last decade. A SC consists of a periodic array of scatterers embedded in a host fluid medium. These periodic structures provide a new wave control mechanism based on the structuring of the considered system, not on its acoustics properties. Perhaps, the most known property is the presence of the so-called band gaps (BG), defined as ranges of frequencies where the transmission of waves is forbidden inside the periodic structure. This property is used in finite structures to produce bands of frequencies of large transmission loss. However, both its central frequency and its width mainly depend on the geometry of the array being both angular dependent. Therefore, several strategies have been developed during last years to obtain acoustic screens based on SC with better performance. Basically, the path has been twofold: (i) seeking different arrangements of scatterers or (ii) bringing additional noise control mechanisms to both achieve high attenuation bands in the low frequency regime and to enhance as well as stabilize the attenuation capability of these devices in a broad range of frequencies. Following this second strategy, we present in this work the design and manufacturing process of a prototype of SC acoustic barrier based on a triangular array of resonant absorbent scatterers. In order to compare the performance of our barrier with respect to the current ones, we have applied the European standards relative to road traffic noise reducing devices (EN 1793 (-1;-2;-3): 1997) to our prototype. Although these standards are not appropriate for our barrier, the obtained results are promising, revealing the SC acoustic barrier as a good alternative to the current devices under the acoustic perspective

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1. Introduction

One of the most common ways to reduce the effect of environmental noise during its transmission is the use of Acoustic Barriers (ABs) [1]. Generally speaking, ABs can be defined as solid systems interposed between the sound source and the receiver, and built with rigid materials with a superficial density, in accordance with the mass law, of 20 kg/m^2 at least [2]. The acoustic performance of ABs can be explained as follows: These devices interrupt the straight noise path from the source to the receiver. A portion of the acoustic energy is reflected towards the source, and another portion is absorbed by the material of the barrier, transmitted through the barrier or diffracted by the barrier's edge (Figure 1a).

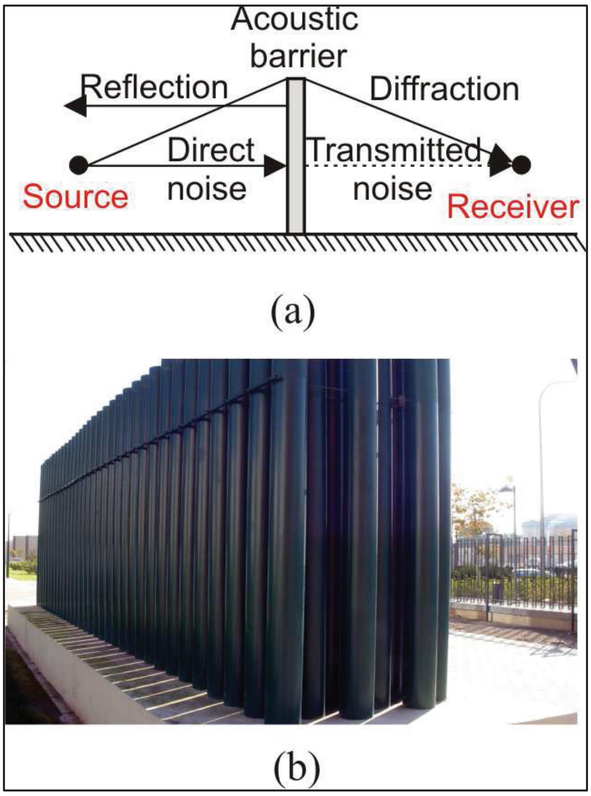

Figure 1. (a) Performance of an Acoustic Barrier; (b) An example of Sonic Crystal Acoustic Screen (SCAS).

Over the last decade, the possibility of manipulating the sound by means of Sonic Crystals (SCs) has been used to develop a new kind of ABs, usually called Sonic Crystal Acoustic Screen (SCAS), as we show in Figure 1b. SCs can be defined as heterogeneous materials consisting of a periodic array of acoustic scatterers embedded in air [3], and present an interesting property that allows its use as ABs: the existence of ranges of frequencies where the transmission of sound waves is forbidden through the system. These ranges are called band gaps (BG), and the underlying physical mechanism is the destructive Bragg interference due to a multiple scattering process related to the periodicity of the system.

However, the existence of BG is not enough to ensure a good acoustic performance of this kind of barriers, due to both the size and the position of the BG in the range of frequencies depend on several parameters as the filling fraction (defining as the percentage of scatterers existing in the SC) , the lattice constant or the direction of incidence of the wave on the SCs. In order to increase the attenuation capabilities of these systems, two research lines have been traditionally developed: (i) maximizing the BG effect by seeking novel arrangements of scatterers, as Quasi Ordered Structures (QOS) [4] and Quasi Fractal Structures (QFS) [5] or, (ii) adding new acoustic control mechanism such as absorption and resonances in the design of scatterers [6, 7]. The scatterers designed in this way are usually named multiphysical phenomena scatterers.

In this work we show the realization and acoustic characterization of a prototype of SCAS designed with multiphysical phenomena scatterers arranged in a triangular array. We have acoustically characterized this prototype for its use as traffic noise reducing device. The tests have been carried out in a laboratory approved for this purpose. European Standards UNE-EN 1793:1997 [8] relative to the intrinsic characteristics of sound absorption (Part 1) and to the intrinsic characteristics of airborne sound insulation (Part 2), have been applied.

2. SCAS design

In this section we present the design of both the SC and the multiphysical phenomena scatterers that form the SCAS, as well as the numerical results obtained in the process.

2.1 SC design

Concerning the design of the SC, we have chosen a triangular array because it presents the highest BG/filling fraction, among all the two-dimensional crystalline arrays. Moreover, we have considered three rows of scatterers to ensure a good BG performance. The lattice constant of the array has been designed to create the desired BG at relatively low frequencies.

Finally, the external dimensions of the SCAS prototype are 4.00x0.76x3.00 m^3 in order to fit it to the requirements of the approved laboratory where the tests have been carried out.

2.2 Multiphysical scatterers design

In the design of the multiphysical phenomena scatterers we have considered the following issues: (i) the external shape of the scatterers is cylindrical to simplify the theoretical simulations and for symmetry reasons in the construction; (ii) the scatterers include the following acoustic mechanisms: absorption, resonances and scattering. To include the acoustics effects named, the scatterers have designed with three parts: rigid core, porous cover and perforated sheet.

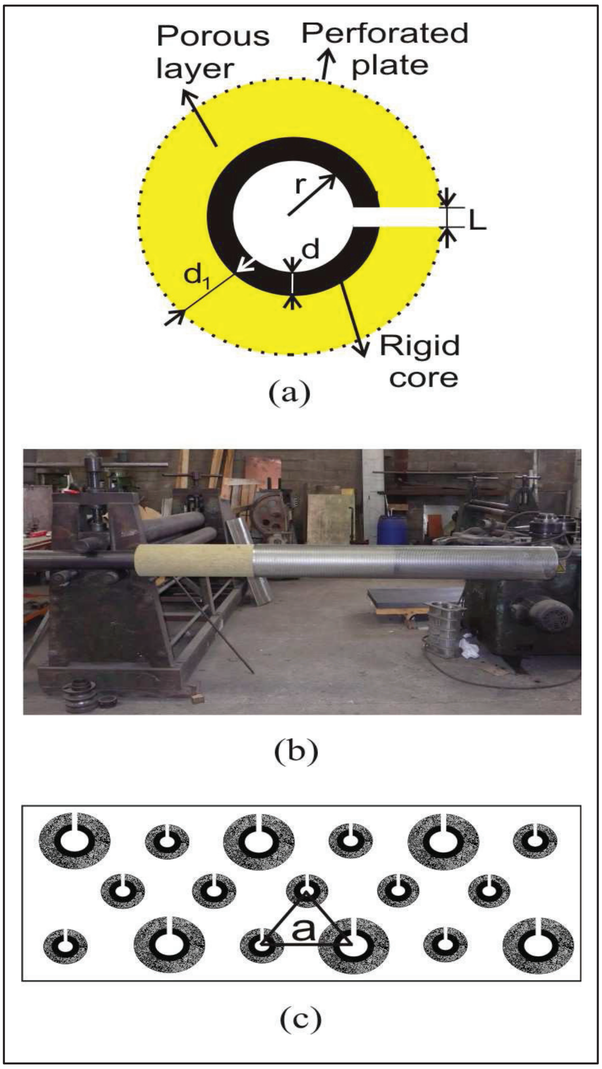

Figure 2. SCAS design and construction: (a) Cross section of the multiphysical scatterer designed; (b) Assembly of the three elements of the scatterers (rigid core, porous layer and perforated plate); c) Triangular arrangement of the Multiphysical scatterers.

In Figure 2a we show a cross section of the multiphysical phenomena scatterer designed. One can see the inner cylindrical core with radius r and formed by a rigid material with a longitudinal slot of width L. Acoustically, the rigid core enhances the scattering and, as a consequence, the Bragg interferences that creates the BG. Moreover, it forms a resonant cavity that introduces resonance peaks at low frequencies range. Structurally, the rigid core serves as a support of the scatterers. A porous (rockwool) layer (d_1 thickness) covering the rigid core can be seen in the Figure. It has a double function: acoustically increases the attenuation in a wide range of frequencies and, constructively, it protects the core of the deterioration due to the outdoor conditions. Finally, the perforated sheet is chosen so that not play a structural role but protects the rock wool of the environmental effects. It has a minimum influence in the scattering process [9].

2.3 Manufacturing parameters

The different geometrical characteristics of the SCAS have been chosen following the tunability concept [10], such that each one of the acoustic mechanisms involved acts in a predetermined range of frequencies to attenuate almost the entire range of frequencies of traffic noise (from 100 Hz to 5000 Hz). Thus, we have designed two sizes of resonant cavities (core) in order to attenuate the range of frequencies under 350 Hz (specifically, 220Hz and 310 Hz). The lattice constant of the array (0.28m) has been chosen taking into account two premises: First, several BG have to appear upper 350 Hz (first Bragg peak appears around 800Hz) in order to add its acoustic effects as close as possible of the resonance peaks and second, the width of the SCAS has to be as narrow as possible due to the limited space available at roadside. Finally, the width of the rockwool provides an extra attenuation upper 400-500Hz. A detail of the construction process of the scatterers can be seen in Figure 2b.

2.4 Theoretical tools

We have used the Finite Elements Method (FEM) as a numerical design tool due to the geometric shape of the scatterers and the different physical mechanisms involved. Using FEM and considering temporal harmonic dependence we have studied the propagation of sound in the selected domain.

The solution domain has been discretized using $3.5\text{x}10^5$ elements. A plane wave has been considered for the calculations and the acoustic attenuation has been calculated. The acoustic attenuation is presented here using the Insertion Loss parameter (IL), defined as the difference between the sound level recorded with and without the sample:

$$IL = 20\log_{10}(P_{direct} / P_{\text{int}\,erferred}) \qquad (1)$$

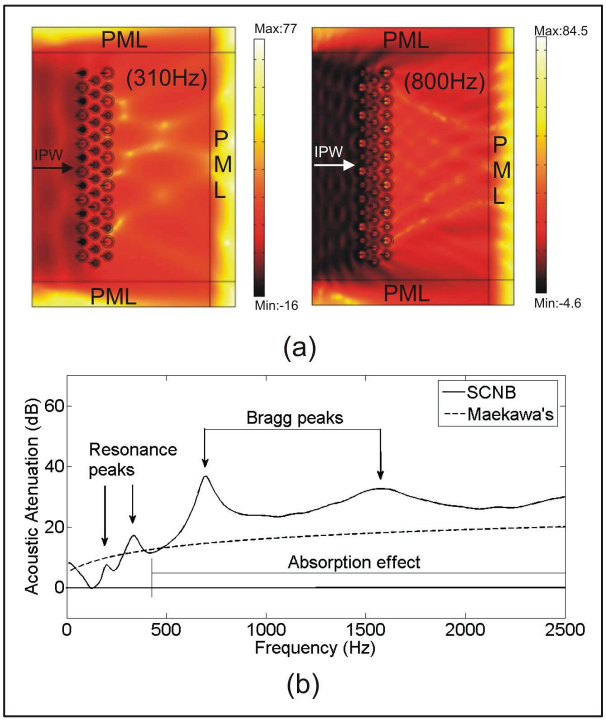

Figure 3. Theoretical simulations: a) Attenuation maps for 310Hz and 800Hz; b) Attenuation spectrum (0º incidence) measured 1m behind the end of the SCAS.

To simulate the characteristics of our problem we have considered the wave propagation performed in free space conditions (unbounded acoustic domain). This assumption is known as the Sommerfeld condition. Solving these kinds of problems using FEM is possible by applying some artificial boundaries in the numerical domain. We have used here the Perfectly Matched Layers (PML) to simulate this condition. This method was presented by Berenger [11], and is useful to emulate the Sommerfeld condition in the numerical solution of scattering and wave radiation problems.

Figure 3 shows the acoustic results obtained by means of FEM using COMSOL Multiphysics 3.5a. In Figure 3a two acoustic attenuation maps for both 310Hz (left panel) and 800Hz (right panel) can be seen. These frequencies correspond to the second resonant peak and to the first BG at 0º of incidence. One can check the high level of attenuation obtained in both cases. Figure 3b shows the attenuation spectrum at the range of frequencies from 10Hz to 2500Hz. Several attenuation peaks can be identified: two peaks at low frequencies are due to resonances; peaks at 800Hz and 1600Hz correspond to Bragg peaks at 0º of incidence; finally a baseline of attenuation is created from 500Hz due to the absorbent behaviour of the scatterers.

3. Acoustic standardization

In order to acoustically characterize the designed SCAS, we have carried out two acoustic tests in a laboratory approved for this purpose. Selected tests are used to characterize ABs for traffic noise according to the European standard. In particular, the standards EN 1793: 1997 relative to road traffic noise reducing devices: test method for determining the acoustic performance (Part 1: Intrinsic characteristics of sound absorption, CEN-1997a, Part 2: Intrinsic characteristics of airborne sound insulation, CEN-1997b, and Part 3: Normalized traffic noise spectrum, CEN-1997c), have been used to characterize our barrier. The first two standards define the tests that have been made, relative to the noise absorption and their behaviour with regard to the spread of airborne noise, while the third one defines the normalized traffic noise spectrum, which is used as a reference to obtain a ranking of barriers on the basis of their acoustic characteristics. In the following we briefly describe these standards, as well as the results obtained by our barrier in each one of the tests.

3.1 EN-1793-1:1997

According to the standard EN 1793-1:1997, we have evaluated the sound absorption coefficient (α_S) in order to calculate the evaluation index of acoustic absorption DLα. The value of this index is used to classify the barrier with regard to its acoustic absorption characteristics. In our case, DLα=8 dB, which corresponds to the A3 category that is the second category as regards the level of absorption. This result shows that a non-continuous acoustic barrier formed by multiphysics phenomena cylinders can compete, from the acoustic point of view, with traditional acoustic barriers formed by continuous systems.

3.2 EN-1793-2:1997

The test corresponding to the intrinsic characteristics of the barrier relative to the airborne sound insulation has been done following the recommendation of the Standard EN-1793-2:1997. To do that, the evaluation index of airborne sound insulation DL_R (dB) is calculated according to the standard EN-ISO 10140:2011.

The measurements take into account the sound level for each third octave band of the normalized traffic noise spectrum, given by the standard EN-1793-3 1997. The value of this index enables us to classify the capability of airborne sound insulation of the checked barrier. In this case, DL_R=20 dB, which corresponds to category B2. This category is the second level in the transmission category.

4. Conclusions

In this work, both the acoustic design and the standardization by means of the perceptive tests of a SCAS formed by an arrangement based on triangular lattice of multi-physical phenomena scatterers is reported. The goal is to create an alternative to the classical acoustic barriers made up of continuous systems. SCAS show a good acoustic response due to the constructive overlapping of several physical mechanisms, as BG, resonances and absorption. Thus, the frequency response of the system in the audible range is similar to a wideband bandstop filter that allows the use of the system as a traffic noise reduction device. In this kind of barrier the designer can select where each one of the attenuation peaks due to different acoustic mechanisms have to work, following the idea of tunability. As a conclusion, a high technological design is introduced in the field of acoustic barriers with SCAS.

Acknowledgement

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