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THE 3D PRINTED SONIC CRYSTAL NOISE BARRIER

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ABSTRACT

One of the most promising bets of last decade in noise attenuation methods in the field of environmental acoustics is the Sonic Crystal Noise Barriers, (SCNB) periodic arrays of scatterers that mitigate some target frequencies depending on the physical design of the barrier. In this work, the SCNB design has been parametrized and modelled to be carried out with the innovative 3D printing technologies and bring the construction of these acoustic devices into a more accessible and flexible process.

1. Introduction

Noise barriers (NB) are one of the most useful attenuation methods when it's not possible to mitigate the noise at the source. They act during the transmission phase of the sound and usually are made by flat walls of rigid materials, which superficial density is at least 20 Kg/m^2. However, due to this continuous construction of the classical NBs, some aesthetic inconveniences occur. On the other hand, fluids or light cannot flow between the classical NBs, also they don't discriminate between different noise types with different frequency ranges. To improve the noise control performance of the NBs, new properties have been applied using metamaterials as Sonic Crystals (SCs) to form the barrier. SC can be defined as heterogeneous materials based in periodic arrays of acoustic scatterers embedded in fluids, generally air. [1]

1.1 General design parameters for SCNB target frequencies

Sonic Crystal Noise Barriers (SCNB) are always syntonized to reduce some target frequencies. Depending on its physical parameters, the noise control mechanisms as multiple scattering and Helmholtz resonances define which frequency band gaps will be attenuated. The first equation that define the target frequency of Helmholtz resonances is modelled in 2D cylindrical scatterers as follow:

$$f_H = \frac{c_0}{2\pi}\sqrt{\frac{\Lambda}{\left(L+\Delta\frac{\Lambda}{2}\right)S}} \quad \text{[Hz]} \tag{1}$$

where:
c_0 is the sound velocity propagation in the fluid [m/s];
Λ is the width of the mouth of the resonator [m];
L is the length of the neck of the resonator [m];
Δ is the correction factor of the neck length (usually 1.6 or 1.8)
S is the internal surface of the resonator cavity [m^2].

Multiple scattering produces the second target frequencies band gaps following Braggs law [2]:

$$f_{Bragg} = \frac{nc_0}{2a} \quad \text{[Hz]} \tag{2}$$

where:
c_0 is the sound velocity propagation in the fluid [m/s];
n is the index of Band gaps, this work is focus on n =1;
a is the lattice constant of the Sonic Crystal, the separation between the periodic arrays of scatterers [m].

1.2 The flexibility and adaptability of 3D printing and parametric modelling (technology and materials)

In the past years, the flexibility and adaptability of a product has improved with the advent of the additive manufacturing (3D printing). This technology allows the production of three-dimensional objects through the deposition of successive layers of material (from plastics to cements or metals). In particular, as it is showed in recent research, 3D printing can operate in synergy with parametric modelling in order to obtain a design easily adaptable in all of its physical parameters [3].

1.3 The proposal

The current research proposes a new parametric design of SCNB to be made with 3D printing technology. The parametric modelling is combined with Finite Elements Method (FEM) simulations to identify the best configuration of the physical parameters of the barriers. In particular, the FEM analysis allows to design barriers to reduce specific target frequencies. Moreover, the parametric modelling ensures the quick adaptability and realization of the model.

2. Methodology

2.1 Concept and parametric modelling of sonic crystal noise barrier

The design parametrization of the SCNB allows to easily adjust the physical dimensions according to which target frequencies should be mitigated. Typically, the annoying noise of the train brakes is in the frequency range of 2.0 - 4.5 KHz. Consequently, in this work, noise control mechanisms are also working in this range. The lattice constant *(a)* is set to 55.32·10^{-3} m to set the first Band Gap (BG) at 3.1 KHz and the Helmholtz resonator is syntonised to 4.3 KHz as **Figure. 1** parameters illustrates.

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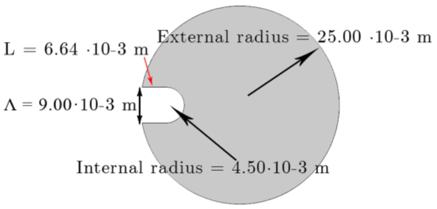

Figure 1 -2D Design of a cylindrical single scatter with a Helmholtz resonator embebbed with $f_H = 4.3$ KHz

2.2 Finite Elements Method Simulation with COMSOL

In this study, the acoustic simulations of the SCNB have been made with the Finite Elements Method (FEM), using COMSOL Multiphysics software and following a 2D periodic model.

This model is configurated to analyse square symmetry networks, using periodic conditions in the horizontal contours, reducing the computational cost, and approaching to a semi-infinite length noise barrier built in a very long wide area.

Figure. 2 shows the 4-rows network, where the scatterers with inserted Helmholtz resonators are placed in a way that normal incident plane wave (IPW) arrives from left to right. Perfectly Matched Layers (PMLs) are inserted at the side ends to prevent unwanted reflections (free field condition) [4]. The measurement point is defined at 1 m away from the surface of the last scatter.

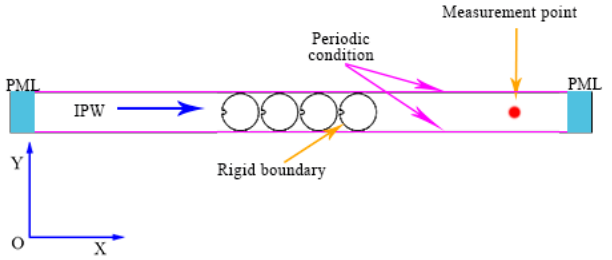

Figure 2 - 4-row SCNB simulation model with incident plane wave (IPW)

3. Results

Figure 3 shows some scaled prototypes of 3D printed Sonic Crystal Noise Barriers. In addition, the proposed figures show how with 3D printing is possible to achieve different configurations by quickly change physical parameters (e.g. width, length or external radius) and different materials.

Figure 3 - Scaled prototypes of 3D printed Sonic Crystal Noise Barriers

3.1 FEM analysis

In order to define how effective is the SCNB, the noise attenuation parameter used is the Insertion Loss (IL) that can be defined as the reduction of the sound pressure level in the measurement point related with the previous level before placing the barrier. The expression is:

$$(3)\quad IL = 20 \cdot log_{10} \left|\frac{P_d}{P_i}\right| \text{[dB]}$$

Where:

P_d is the value of the effective pressure without the barrier;

P_i is the value of the effective pressure placing the barrier.

Figure 4 shows the train brake noise spectrum, the Insertion Loss of the SCNB simulation and the result of subtract the attenuation of the barrier to the noise spectrum, which represent the annoyance reduction for brake noise. It is very interesting to observe how the interference between the first BG and the Helmholtz resonance modifies the expected range of attenuation of a SCNB without resonators. [5]

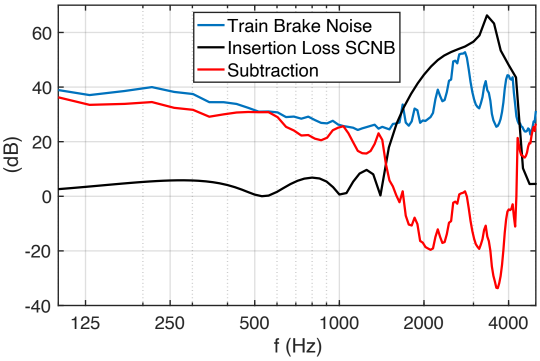

Figure 4 - Train Brake noise spectrum, Insertion Loss of the Sonic Crystal Noise Barrier and subtraction of both

4. Conclusion

To summarize, the global value of the sound insulation of a noise barrier is calculated in an analogous manner to EN 16272-6 European Standard [6], but weighting with the train brake noise spectrum instead of the railway noise spectrum. In doing so, this parameter represents the annoyance reduction for train brake noise with a value of 24.16 dB(A).

The proposed research opens up new strategies to design and carry out SCNB by exploiting novel 3D printing technologies by showing the potential of the synergic combination among parametric design, simulation and 3D printing.

5. References

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