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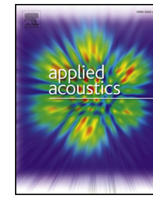

Numerical simulation and laboratory measurements on an open tunable acoustic barrier

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A B S T R A C T

A new open, thin and low frequency acoustic barrier is presented. These barriers, based on arrays of isolated pickets produce high acoustic attenuation in a selective range of frequencies related to their geometry and distribution. These open barriers are acoustically competitive with traditional ones, which are based on continuous and rigid materials. To show its versatility ~~to~~ in attenuating different selected ranges of frequencies, a compact numerical model is presented.

Different cases are analysed and compared with experimental results. The accuracy of the experimental results compared to the simulated ones allow us to use the compact model to design these barriers in order to reduce both industrial and traffic noise on demand and to introduce them into the noise control market.

1. Introduction

To reduce or eliminate the discomfort originated by noise, modifications can be carried out on the sound source, on the medium of propagation or on the receiver. When an object is interposed in the path of sound propagation between the source and the receiver, that object can act as an acoustic barrier, causing a decrease in the sound level at the position of the receiver. It is in this action framework in noise control where this paper is found.

Although research on acoustic barriers has been developing since 1950, the scientific community remains active in this area. The potential for noise attenuation of acoustic barriers with absorbent surfaces has also been evaluated. The research has mainly focused on applications with parallel displays on both sides of a road, since reflected noise between barriers is believed to increase noise levels [1–3]. The intrinsic acoustic characteristics of installed noise barriers, such as sound reflection, have also been checked to verify their compliance to design specifications or their quality after some years of life [4]. However, these traditional acoustic barriers are continuous vertical walls that must be weighed and be very tall in order to attenuate low frequency noise. In addition, these types of continuous barriers block the flow of air and water, which may limit their applications [5].

In the last two decades, there has been a growing interest in the research of periodic acoustic barriers. The major benefit of these barriers is that they produce high attenuation in selective ranges of frequencies depending on their geometry, that is, they can be frequency tuneable. Open acoustic barriers have other benefits such as they are permeable to wind and water. Moreover, they have an aesthetically pleasing appearance. These facts make them ideal both for use in roads, industrial facilities and naturally ventilated buildings. One of these types of open barriers is sonic crystal barriers, that are composite structures with their dispersing elements arranged periodically. In fact, the presence of acoustic dispersers in the medium with different acoustics characteristics, leads to the appearance of frequency intervals, dictated by Bragg's law, in which the acoustic waves do not propagate, being on the contrary totally reflected. The efficiency of the use of sonic crystal in the design of acoustic barriers with cylindrical dispersers has been demonstrated in different works [6,7] and an example of these sonic crystal acoustic barriers can be seen in the A2 ring road of Eindhoven where Van Campen industries installed 22,000 m^2 of them [8]. Other types of open acoustic barriers have also been developed, different from those based on sonic crystals, that are periodic and frequency tuneable [9]. These barriers are based on a periodic arrangement of subwavelength slits created by rectangular pickets distributed periodically.

In this paper, a solution for low frequency noise mitigation based on a periodic structure and acoustic resonators is proposed. The idea of combining the effects of periodicity and resonators aims to achieve noise attenuation at the low frequency range. This new acoustic barrier design is frequency tuneable and versatile, providing a simple design that could represent a good option for managing low frequency noise in buildings. It could also be used both for the protection of buildings

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against traffic noise and for the protection of buildings against industrial or for equipment noise. In fact, this Open and Tunable Acoustic Barrier (OTAB) is integrated by pickets that can be designed to choose the ranges of frequencies in which the barrier must act. This action framework makes these barriers technologically advanced. Moreover, the pickets include~~s~~ different noise control mechanism such as absorption or resonances so that the designer could select which of these mechanisms should appear and at which frequency it should work (following the concept of tuneability) [10].

The great advantage of the OTAB in contrast to previously existing open acoustic barriers, is its thickness. To the best of our knowledge the acoustic barriers based on sonic crystals have to be at least 0.60 m thick, which limits and precludes its use in certain applications. The acoustic behaviour of this barrier has been analysed through both numerical modelling and experimental testing under laboratory conditions where it could be verified that this OTAB, with a thickness of 0.30 m, has a great attenuation capacity at low frequencies.

2. Subwavelength slit acoustic barrier

The basic structure of a subwavelength slit acoustic barrier consists of one or two rows of rectangular pickets distributed periodically with a lattice period l_p and with a slit width s_w. The rows are separated by an air gap d_{ag} as shown in Fig. 1. The slit width is s_w and is much less than the wavelength, λ.

Several mechanism and physical phenomena contribute to the acoustic attenuation of this type of barrier. In the first place, and due to the configuration and distribution of the pickets, the acoustic barrier can be considered to be formed by a series of acoustic filters. The slits act as inlet/outlet apertures and the air gap between the picket rows acts as an expansion chamber. Moreover, the geometric parameters of the acoustic barrier play an important role in acoustic attenuation. Since the pickets are distributed periodically with a lattice period l_p, some acoustic attenuation peaks appear in the attenuation spectrum, at certain frequencies, which are the manifestation of Wood's anomalies [11]. For normal incidence, Wood's anomaly appears when the wavelength of the incident wave coincides with the lattice period, $\lambda = l_p$. On the other hand, attenuation peaks also appear in midrange frequencies that are due to the interferences between propagating and evanescent waves [12]. A complete analysis of this type of acoustic barrier can be found in [9].

3. Numerical approach: Finite element method

The geometry shown in Fig. 2a has been defined to solve the problem numerically. We have designed an acoustic barrier with 2 rows following the guidelines proposed by [9] in order to obtain a high level of attenuation. The commercial software COMSOL Multiphysics has been used to design the barriers, to develop the model and to obtain the numerical predictions. The domain where the solution is obtained is formed by 2 pickets with the following dimensions: width 0.3 m (w_p) (X direction) and depth 0.1 m (d_p) (Y direction), separated along Y direction by an air gap (d_{ag}) of 0.1 m, and confined between two completely reflected walls separated by 0.35 m (picket width plus subwavelenght slit, S_w = 0.05 m) as shown in Fig. 2b, the Y axis being the propagation direction of the incident plane wave (IPW) travelling from left to right. With these conditions, the scattered waves from the pickets are reflected by the walls reproducing the effect of a semi-infinite barrier, formed by 2 rows of pickets with a distance between them of 0.35 m along the X direction (l_p), and whose centres are separately by 0.2 m (air gap plus two half lengths of the pickets along Y direction, $d_{ag} + 2\ d_p/2$). Moreover, the walls do not reflect the IPW. This geometry allows us to understand the physical phenomena of semi-infinite arrays using a reduced volume of the numerical domain thus diminishing the burden of the Finite Element Method (FEM). Two boundaries of the domain are selected as a periodic condition which is a good alternative to simulate an infinite long barrier in X direction, whilst the other two are considered a radiation boundary condition in order to implement the Sommerfeld radiation conditions in the numerical resolution of scattering problems and therefore to simulate free space. The last domain is implemented with Perfectly Matched Layers (PML) [13], to avoid the return of the waves to the main domain.

Firstly, the pickets in question include several physics mechanism such as acoustic filter and resonances whose section is shown in Fig. 2a. When all the surfaces of each of the pickets are acoustically rigid, the Neumann boundary condition (zero sound velocity) is applied to them and they act as an acoustic filter due to the fact that a change in section occurs between the two rows. If one of their surfaces is enabled and the others remain rigid, a cavity is obtained and they act as a quarter-wavelength resonator (λ/4 resonator).

From these pickets and with a view to improving the attenuation of the barrier, a numerical design is presented that is more sophisticated than the previous one and at the same time is simpler to modify. These new pickets are based on the activation and deactivation of the different layers depending on the desired effect. We call this model a compact model.

These new designs that introduce more acoustic mechanisms to the picket can be considered as multiphenomenon pickets (MP). Thus, a layer of absorbing material is introduced around the picket keeping a thin layer of material that provides the rigidity of the picket, forcing it to keep its original size. The interior of the cavity can be completely filled with air or ~~to~~ tuned to another resonance frequency, by reducing the size of the cavity with the activation of a rigid block, see Fig. 2b. In order to achieve it, the pickets were implemented as shown in Fig. 2b. The MP are a rigid rectangle covered by a porous material. Neumman boundary condition is applied to the rigid surfaces as mentioned above, whereas the Delany-Bazley [14] model is considered to emulate the porous material. The cavity is considered filled with air, thus the length of the resonator defines the fundamental resonant frequency and its harmonics, given by the expression [15]:

$$f = \frac{c}{L\left(\frac{2n+1}{4}\right)} \quad n = 0, 1, 2....$$

where c is sound velocity (c = 340 m/s) and L is the length of the resonator cavity. When n = 0 L is equal to. λ/4 With these conditions by enabling or disabling the surfaces, it is easier and more suitable to select

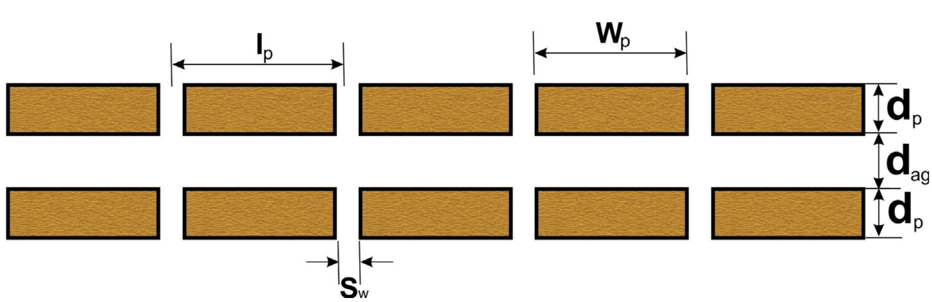

Fig. 1. Schematic diagram of a basic subwavelength slit acoustic barrier.