Euronoise 2018
Crete

Sonic Crystals acoustic screens with diffusion properties

María del Pilar Peiró-Torres
BECSA, Spain.

Manuel Parrilla Navarro
Universitat Politècnica de València, Spain.

Jose María Bravo
Universitat Politècnica de València, Spain.

Marcelino Ferri
Universitat Politècnica de València, Spain.

Juan Vicente Sánchez-Pérez
Universitat Politècnica de València, Spain.

Javier Redondo
Universitat Politècnica de València, Spain.

Summary

Sonic Crystals are defined as heterogeneous materials formed by arrays of scatterers embedded in a host material with different physical properties. Their particular properties in the control of acoustic waves have leaded the development of different Noise Reducing Devices technologically advanced, as Sonic Crystals Acoustics Screens (SCAS) to control environmental noise Sonic or Crystals Acoustic Diffusers (SCAD) to spread sound in room acoustics. In this paper we present the design process of a family of new devices developed with the help of both optimization algorithms and Finite Difference Time Domain simulations, which are able to act as acoustic barriers but with high levels of noise diffusion in the face orientated to the noise source. These new devices partially avoid the specular reflected noise produced in classical acoustic barriers, because this is an important factor that reduces their effectiveness. The diffusion capabilities of these new devices support the existence of a new generation of acoustic barriers with added characteristics of high technological value.

PACS no. 43.50.Gf, 43.50.Ki; 43.20.Fn

1. Introduction

Transport is one of the main factors and a fundamental and necessary human activity for the growth of the economy and the development of a country. The connection between people and cities, the exchange of goods, communication between people from other cities for business development… these factors are necessary for the development of a country's economy. In order to make this transport possible, the construction of a large channels of communications is essential. However, the existence of these infrastructures, also entails the generation of some problems. One of these problems is the environmental contamination and environmental noise. Environmental noise is one of the main environmental problems of the industrialized countries [1]. Where transport infrastructures run through urban areas, the conflict between development and life quality arises. The acoustic comfort of these urban areas is reduced by the noise generated by transport. More than 55 dBA in night hours and 65 dBA in day hours should not be excessed according to UE normative, however a large number of European citizens are suffering higher noise levels. In fact, the 20% of EU citizens during the day, and the 30% of citizens during the night are suffering higher noise levels. These environmental problems are linked with some health problems such as stress, fatigue, sleep disturbance, cardiovascular disorders or hearing loss [2], [3].

To control this unwanted noise, one can act at each of the three phases of noise propagation, i.e. actions at the source, actions at the transmission phase or actions at the receiver, to try to minimize the annoyance caused by the noise. If we focus on the actions taken to control sound in its transmission phase, the most commonly used is the installation of acoustic screens between the noise source (transport infrastructure) and the receiver (the near urban areas). These classical Acoustic Barriers (ABs) are made of continuous flat walls whose main noise control mechanism is reflection. At these ABs, an important quantity of the noise energy is reflected specularly to the source side. However, some unwanted problems may arise due to this reflected noise energy and even cause a noise increasing at protected areas, reducing the effectiveness of the installed ABs [4].

To minimize these specular reflections, some solutions have been developed, such as the use of absorbent materials, the installation of inclined barriers, or scatter the reflected noise [5]. However, the application of absorbent materials can be very expensive, and the use of inclined barriers could be technically complicated and impossible in some sites.

Focusing on the solution of scatter the reflected noise, some proposals have been presented recently. One of the most widely accepted is the use of new noise control devices based on technologically advanced materials. Sonic Crystals (SC) is one of these materials. SC are generally defined as heterogeneous materials formed by arrangements of acoustic scatterers embedded in air [6, 7]. Two of the many applications of these materials are their use as Acoustic Barriers (ABs) usually called Sonic Acoustic Screens (SCAS) [8, 9], and their use as sound diffusers in acoustic rooms to increase sound diffuseness [10].

Regarding the first application, SCAS are new noise reducing devices that provide a new noise control mechanism based on the existence of bandgaps, defined as ranges of frequency where the propagation of the waves is forbidden [11]. These bandgaps are the result of the interference of waves due to a Bragg scattering within the SC. These new open barriers present some technological advantages respect classical ones, however also present the specularly noise reflection problem.

Regarding the second application, SC have presented good results as diffusers in the range of lowest frequencies without the need of extremely deep structures [12]. These devices are called usually Sonic Crystals Acoustic Diffusers (SCAD).

Following this research line and in order to increase the acoustic performance of both SCAS and SCAD, an elitist Multiobjective Evolutionary Algorithm (MOEA) has been used in recent years successfully [13, 14].

In this work we propose the use of MOEA to design devices based on SC that work simultaneously as SCAS and SCAD. Thus, we will obtain devices with double function, which works as acoustic barriers but avoiding specularly reflected noise. To obtain this goal we have used a new designing tool. We have applied this optimization process to a starting modulus of SC. We will refer to these new devices designed which present double function as SCASAD (Sonic Crystals Acoustics Screens and Diffusers).

2. Optimization process

Because the goal is to design devices that maximize two acoustic properties (insulation and diffusion) through an optimization process, a multiobjective evolutionary algorithm was chosen. This kind of algorithms obtains solutions that satisfy several conflicting objectives simultaneously. In some optimization processes that involve two properties to be satisfied simultaneously, such as the one studied here, improvements in one of them usually produce degradations in the other. That means there is no unique solution in the optimization process, and the general way to solve the proposed problem is to localize a set of infinite optimal solutions, which is mapped as the Pareto front. This Pareto front shows the candidates who are the best in some sense according with the values of the objectives sought. Due to the difficulties to reach the exact Pareto front, we have used here an elitist multi-objective evolutionary algorithm based on the concept of e-dominance [15] named ev-MOGA [13].

The starting point of the optimization process carried out in this work is a SC module formed by 28 cylindrical rigid scatterers arranged in a square array in 4 rows with a lattice constant p=0.17m. This module presents the first band gap at 1000Hz, the most important frequency of the normalized noise spectrum according to the standard EN 1793-3:1998. However, this starting module has not a high performance as a diffuser and its isolation properties can be largely improved in the optimization process carried out. To characterize each candidate it is necessary to establish a gene codification. The candidates have been encoded by a set of genes that represents a set of 28 normalized cylinders radii. Thus, in the optimization process, the radii of the cylinders can take any value from 0 to 0.9. If the value is 0, the cylinder does not exist and, if the value is 0.9, the cylinder almost has the maximum possible radius (half lattice constant, p/2). In this way, any candidate ϴ of the optimization process can be represented by a genotype given by a vector of length 28, varying each element from 0 to 0.9.

Once the codification is determined, two are the steps to start an optimization process. First, the definition of the objectives to be optimized, usually called cost functions. Second, a simulation model that performs the necessary calculations to obtain the values of the cost functions for all the candidates involved in the optimization process. The simulation model used will be explained in the next section.

It has been considered here two cost functions, the first one referred to the isolation capabilities of the candidates, given by the Insertion Loss (IL) index, defined as the difference of acoustic pressure in a point or area without and with the sample.

$$J_{IL}(\theta) = 10log\left|\frac{P_d}{P_{inter}}\right| \quad (dB), \qquad (1)$$

where P_d is the direct acoustic pressure (without device), and P_{inter} is the acoustic pressure interfered (with device), both calculated at the same point.

The second cost function is referred to the diffusion properties of the candidates. Here, we have defined a new index called Specular Reflection Sound (SRS). This index determines which part of the total sound pressure reflected by the device does so specularly, and is defined as:

$$J_{SRS}(\theta) = 10log(1-\alpha) + 10log(1-d) \ (dB), \qquad (2)$$

where α is the absorption coefficient and d is the diffusion coefficient of each candidate.

Both cost functions, defined in this way, will determine the performance of the potential candidates both as SCAS and as SCAD in a predetermined range of frequencies stablished by us. In this work we have selected a range of frequencies formed by the octaves bands whose central frequencies are 500Hz, 1000Hz and 2000Hz, i.e. a range of frequencies from 355Hz to 2840Hz. We have selected this range taking into account the normalized traffic noise spectrum defined in the EN 1793-3:1998 norm.

Finally, taking into account the characteristics of the ev-MOGA algorithm, which works minimizing cost functions, the final form of the selected ones will be –IL and SRS. That means that the insulation and diffusion are maximized

3. Simulation model

To determinate the acoustic performance of the different candidates obtained in the optimization process, a simulation model has been developed based on the numerical technique called Finite

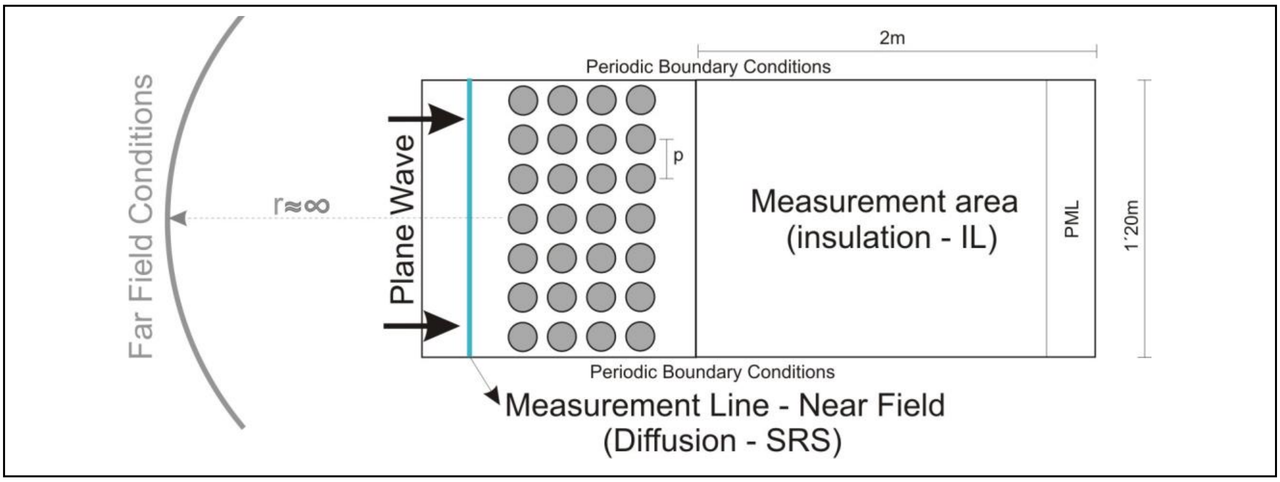

Figure 1. Numerical domain used for SCASAD simulations.

Difference Time Domain (FDTD). This technique has been used successfully to quantify the performance of SC, working together with the ev-MOGA optimization algorithm [14]. The model developed specifically for this work is shown in Figure 1.

A plane wave travelling from left to right impinges on the SC sample (candidate). Part of this wave is transmitted through the device, and another part is reflected to the left. The insulation performance of each SCASAD candidate, given by the -IL cost function, is measured on the right area of the model ("measurement area"). The acoustic pressure of insulation has been calculated every 0.02m, with and without the sample.

4. Results and discussion

The optimization process works using together ev-MOGA and the FDTD model developed. The first one leads the process (i) generating new SCASAD candidates by mixing, following the genetical rules, the genotypes of the candidates of an initial population generated by us; (ii) ordering the solutions in the objectives space according to the values of each one of the cost functions and (iii) stablishing the Pareto Front in the objectives space. On the other hand, FDTD evaluates the acoustic performance of each candidate generated by ev-MOGA, calculating the values of its acoustic indexes defined in the previous section (-IL and SRS).

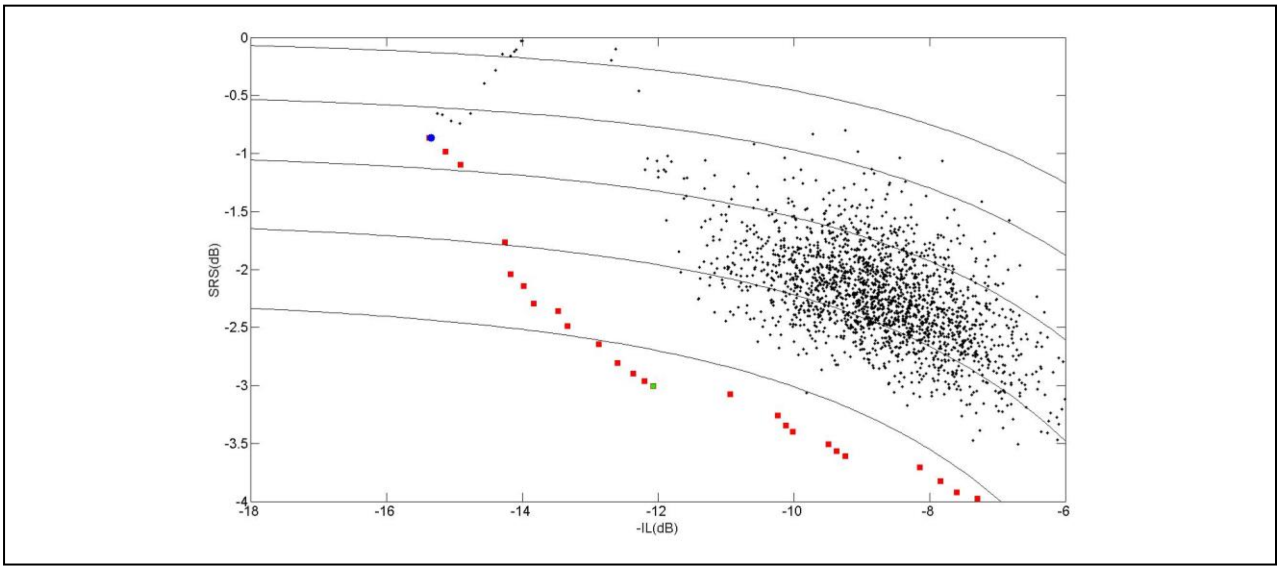

Figure 2. Objectives Space of the optimization done. The initial population (black dots), the Pareto Front (red dots), the most balanced individual selected (green point) and the reference individual (blue dot) are represented according their values of IL and SRS indexes.

Then the acoustic pressure average with and without the sample has been calculated in all the points included in the "measurement area" before applying equation (1) to estimate IL. On the other hand, to calculate the SRS index the reflected pressure has been estimated along the entire vertical blue line shown on the left in Figure 1 ("measurement line"). With these results, a near field to far field transformation has been carried out in order to estimate the value of the diffusion coefficient, d, in free field conditions according to the standard EN 17497-2:2012. Finally, α has been calculated directly from the model.

The results of the optimization process can be seen in Figure 2. This figure shows the objectives space of the optimization carried out. Black dots means the individuals (candidates) of the initial population represented as a function of their values of the acoustic indexes considered, -IL and SRS (Abscissa and ordinate axes respectively). The best candidates obtained in the complete optimization process are represented in red color. These individuals form the Pareto Front, and are the best candidates, in some sense, according to their values of the -IL and SRS indexes.

Thus, red dots on the right of the figure represent some candidates who are the best in terms of their SRS (diffusion) values although their -IL (insulation) values are poor. On the other hand, red dots on the left of the Figure represent candidates whose -IL values are excellent but their SRS values are poor.

The decision maker selects the best candidate obtained in the optimization process according to his preferences. The green dot represented in the figure is the candidate whose -IL and SRS indexes take more balanced values. That is, its acoustic performance is quite good according to both indexes.

The blue dot in the figure 2 represents a Reference Sonic Crystal, formed by cylinders of equal radius with 80% filling fraction. This Reference Sonic Crystal represents a non-optimized SC. Note the high insulation performance of this candidate but its low performance in terms of its diffusing properties. The position of this candidate in the objectives space serves as a reference of the improvement achieved in the optimization process. In our case, comparing the positions of both the green dot -considered the most balanced candidate of the optimization process-, and the blue one -the Reference Sonic Crystal- in the objective space in Figure 2, we can conclude that a relevant improvement of both -IL and SRS indexes has been obtained. Therefore, a candidate has been achieved (represented by the green dot) that could work as SCASAD with insulation and reflection properties improved.

Finally, in Figure 3 is showed the design of SCASAD selected (green dot in Figure 2) and the design of the Reference Sonic Crystal (blue dot in Figure 2). Note the variability of the radii of the cylinders that form the selected SCASAD obtained in the optimization process. In Figure 4 and 5 is showed their IL and -SRS spectra in the range of frequencies selected.

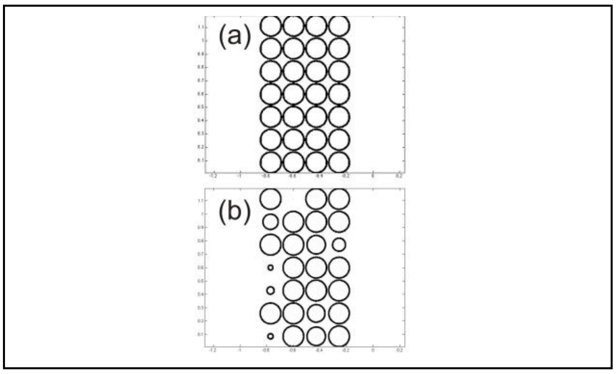

Figure 3. Scheme of the design of both (a) reference Sonic Crystal and (b) selected SCASAD (blue and green points in Figure 2, respectively).

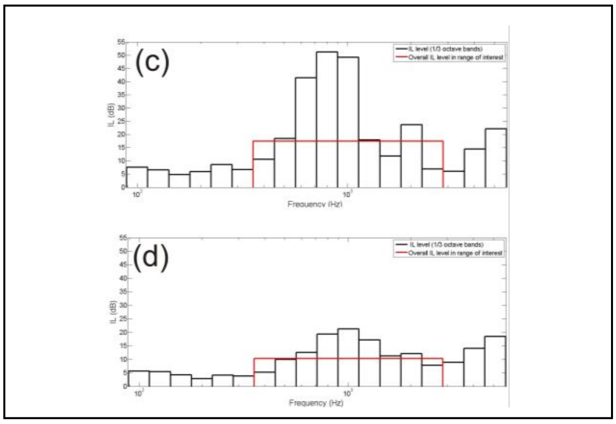

Figure 4. (c) Insulation properties of candidate a. (d) Insulation properties of candidate b.

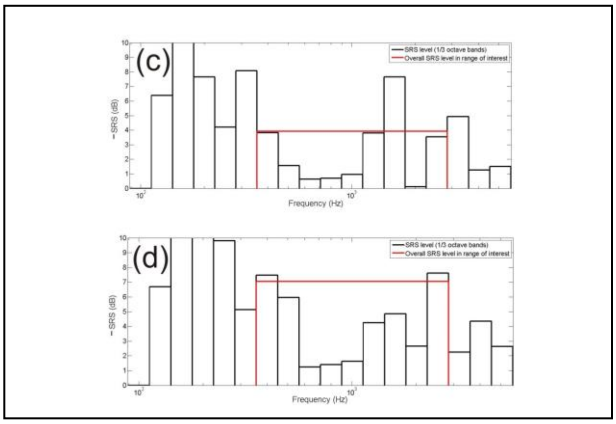

Figure 5. (c) Diffusion propierties of candidate a. (d) Diffusion properties of candidate b.

5. Conclusions

In this work a Multiobjective evolutionary algorithm has been used together with a simulation acoustic model based on the numerical technique called Finite Difference Time Domain (FDTD) in an optimization process. The optimization algorithm used, called ev-MOGA, allows the obtaining of devices with high performance in some sense, according with the cost functions selected. In this case, we have optimized the insulation properties, given by –IL, and the diffusion, given by the SRS index. The main goal has been to obtain the design of a device based on Sonic Crystals that works as an acoustic barrier and as sound diffuser. The result has been called Sonic Crystal Acoustic Screen and Diffuser (SCASAD).

References

[1] EC Directive, Directive 2002/49/EC of European Parliament and of the Council of 25 June 2002 relating to the assessment and management of environmental Noise, Official J. Eur. Communities L 189 (2002) 0012e0026(18.7.2002), Brussels.

[2] Kotzen B., English C., (1999). Environmental Noise Barriers, E&FN SPON, London.

[3] Platon, S.N., Hionis, C.A. (2014). Preventing risk of noise exposure in working environment using noise mapping. Environ. Eng. Manag. J. 13(6), 1349-1354.

[4] Kotzen, B., & English, C. (2009). Environmental noise barriers: a guide to their acoustic and visual design. CRC Press.

[5] Pigasse, G., & Kragh, J. (2011). Optimised Noise barriers-a State-of-the-art report. Danish Road Directorate.

[6] M.S. Kushwaha, P. Halevi, L. Dobrzynski, B. Djafari-Rouhani, Acoustic band structure of periodic elastic composites, Phys. Rev. Lett. 71(13) (1993), 2022–2025.

[7] R. Martínez-Sala, J. Sancho, J.V. Sánchez-Pérez, V. Gómez, J. Llinares, F. Meseguer, Sound attenuation by sculpture, Nature 378(6554) (1995) 241.

[8] F. Morandi, M. Miniaci, A. Marzani, L. Barbaresi, M. Garai. Standardised acoustic characterization of sonic crystals noise barriers: sound insulation and reflection properties. Appl. Acoust. 114 (2016) 294-306 http://dx.doi.org/10.1016/j.apacoust.2016.07.028

[9] S. Castiñeira-Ibañez, C. Rubio, J.V. Sánchez-Pérez. Environmental noise control during its transmission phase to protect buildings. Design model for acoustic barriers based on arrays of isolated scatterers. Build. Environ. 93 (2015). 179-185. http://dx.doi.org/10.1016/j.buildenv.2015.07.002

[10] M. R. Schröeder, Diffuse sound reflection by maximum length sequences, J. Acoust. Soc. Am. 57(1), (1975) 149–150. https://doi.org/10.1121/1.380425

[11] M.M. Sigalas, E.N. Economou, Elastic and acoustic wave band structure, J. Sound Vib, 158(2) (1992) 377-382. https://doi.org/10.1016/0022-460X(92)90059-7

[12] Redondo, J., Picó, R., Sánchez-Morcillo, V. J., & Woszczyk, W. (2013). Sound diffusers based on sonic crystals. J. Acoust. Soc. Am. 134(6), 4412-4417.

[13] Herrero, J. M., García-Nieto, S., Blasco, X., Romero-García, V., Sánchez-Pérez, J.V., García-Raffi, L.M. (2009). Optimization of sonic crystals attenuation properties by ev-MOGA multiobjective evolutionary algorithm. Struct. Multidisc. Optim. 39, 203-215.

[14] Redondo, J., Sánchez-Pérez, J. V., Blasco, X., Herrero, J. M., & Vorländer, M. (2016). Optimized sound diffusers based on sonic crystals using a multiobjective evolutionary algorithm. J. Acoust. Soc. Am. 139(5), 2807-2814.

[15] Laumanns, M., Thiele, L., Deb, K., Zitzler, E. (2002). Combining convergence and diversity in evolutionary multiobjective optimization". Evol. Comput. 10, 263–282.