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SONIC CRYSTAL NOISE BARRIER DESIGN TO REDUCE RAILWAY NOISE EMISSIONS

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ABSTRACT

In the heart of a tense competitive context, railway transport has a major advantage through its low environmental impacts. Among these, particular attention is paid to acoustic emissions. For people living near railway infrastructures, noise emissions are a major concern. Noise barriers are an effective and traditionally implemented solution to reduce the acoustic impact of railway traffic. Nevertheless, these barriers are generally not well accepted by the population for aesthetic reasons. Sonic crystals are structures that provide significant acoustic attenuation, particularly around certain frequencies (so-called “band gaps”). Using this new type of noise mitigation solution has advantages in terms of integration into the landscape and cost but remains a challenge given the plurality of railway acoustic sources, both in terms of their location, directivity and spectral content. This study presents results obtained by 2D Finite Element Method (FEM). This paper has two objectives. The first one is to study the sensitivity of acoustic performance to geometric parameters such as the filling factor or the shape of the elementary structure of the crystal. The second seeks to design a sonic crystal adapted to each type of railway source (rolling, equipment, aeroacoustics) - which differ from each other in their sound emission spectrum. A comparison with a full classic screen is also presented.

1. INTRODUCTION

Sonic crystals (SCs) are structures made of sound scatterers periodically arranged in a lattice. SCs forbid sound propagation for some frequency bands, named bandgaps. The physical mechanism behind the formation of bandgaps is the destructive interference between waves reflected by the two consecutive planes of sound scatterers [1].

The centre frequency of the band gap f_{BG} is determined by the diffuser network constant “a” which represents the distance between two adjacent diffusers (see Fig. 1).

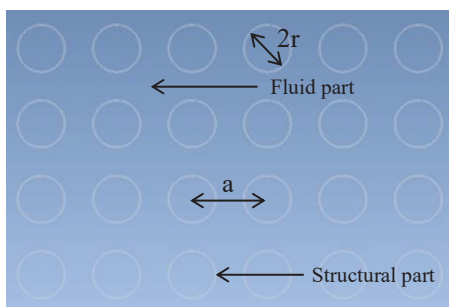


Figure 1. square lattice of cylinder scatterers

For a square lattice:

$$f_{BG} = \frac{c}{2a} \quad (1)$$

where c is the speed of sound in the air.

For a triangular network:

$$f_{BG} = \frac{c}{a\sqrt{3}} \quad (2)$$

We define also the fill factor as (for a square lattice of cylinder diffusers):

$$ff = \frac{\pi r^2}{a^2} \quad (3)$$

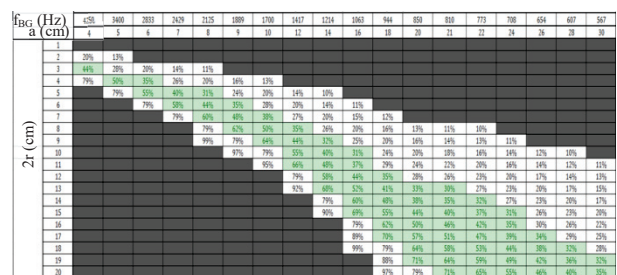


Figure 2. f_{BG} according to the parameter “a” and the ff according to “a” and “r” (square lattice of cylinder scatterers)

2. REDUCTION OF RAILWAY NOISE

Noise is a historical component of railways, in both freight and passenger transport. Reducing it means making the train more socially and environmentally acceptable [2].

These noise emissions are subject to a national (France) and international legislative framework:

- At rolling stock level, by the Technical Specifications for Interoperability (TSI) [3]. They set emission limits for indicators such as pass-by or stationary noise.
- At the level of local residents, through the national legislation in force and the European Directive (2002/49/EC) [4]

If the limit values are exceeded, there are three possibilities:

- Noise reduction at the source (rails, wheels, equipment ...)
- Reduction of traffic
- Installation of protection along the tracks (noise barriers) or directly in the neighbours (double windows)

Most of the screens used on railway tracks and roadsides are "straight" reflective barriers, which offer a reduction of about 8dB(A) in global. This is the cheapest solution, and these barriers are often large concrete panels. However, there are other types of

barriers, such as absorbent barriers (reduction of about 10dB(A)), or low or multi-diffractor barriers.

Here, the possibility of using a different type of trackside sound barrier is being considered to replace the existing ones, which are often not accepted by the neighbourhood. Indeed, we wish to accompany the reduction of noise pollution with a decrease in visual pollution.

We are going to study the potential of sonic crystals as a mitigation measure, despite the evidence of their lower performance over the whole frequency range. This work follows a previous study [5].

3. RAILWAY NOISE SOURCES

3.1 General Information

Environmental noise includes railway noise, which encompasses different kind of noise sources. Railway noise is generally classified in three categories: auxiliary, rolling, and aerodynamic noises [6].

Auxiliary noise arises from the different technical equipments, like diesel engine, power transformer, converter, etc. These equipments are located in the upper or lower parts of locomotives and coaches, either on the roof or at the wheel height. This noise is predominant during parking periods and at very low train speeds (<50km/h).

Rolling noise is radiated by the rolling stock and the track, due to the vibration originated at the wheel-track contact, mostly because of rail roughness and corrugation. The global noise radiation is therefore the sum of different contributions arising from the train wheels, the rail and the sleepers of the track. This second type of noise is predominant for train speeds between 80 and 300km/h.

Finally, the aerodynamic noise appears for higher train speeds, up to 300km/h (bogies area, pantograph, etc.).

3.2 Source Typologies

The European Noise Directive 2002/49/CE request a harmonized prediction method to be used in order to update the strategic noise map across Europe for transport and industrial activities (so-called CNOSSOS) [7].

In its initial version, CNOSSOS proposes default sound power templates by source type, by setting two associated heights A ($h = 0.5\text{m}$) and B ($h = 4\text{m}$), see Fig. 3. We used these data to create typical power spectra and to match sonic crystals with a design adapted to the sound emission frequencies.

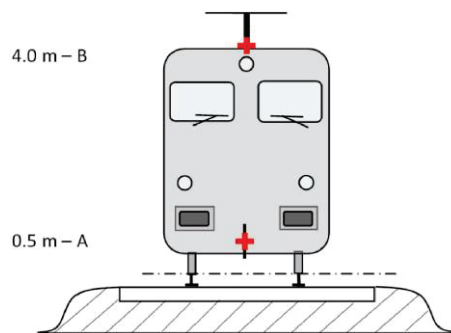


Figure 3. Two positions of sources according to CNOSSOS

3.2.1 Rolling Noise

Concerning rolling noise, CNOSSOS proposes tabulations of values in order to calculate it. Here is what has been considered here:

- Mixed brakes
- One bogie with two axles
- Normally maintained network, rather smooth rails
- Wheel diameter 920mm, axle load 50kN
- Monobloc sleeper on medium stiffness pads
- Speed: 50km/h and 150km/h
- Position A

Two families of acoustic emission spectra can be distinguished:

- Spectrum with many frequency emergence zones (see Fig. 4)
- Rather wide band spectrum (see Fig. 5)

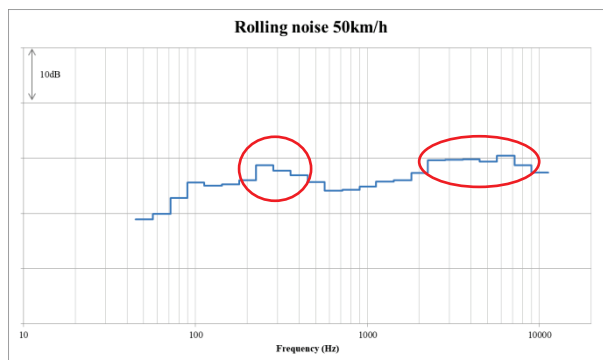


Figure 4. Acoustic power spectrum L_w (dB) calculated for 50km/h

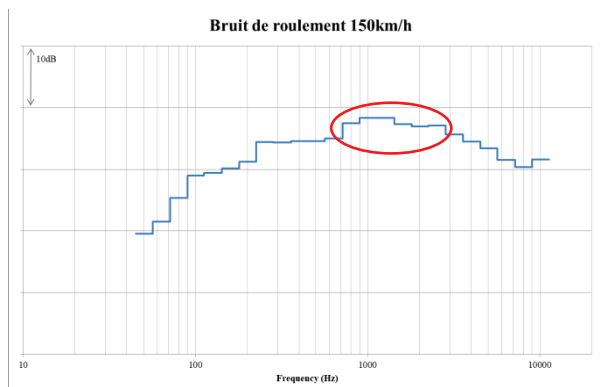


Figure 5. Acoustic power spectrum L_w (dB) calculated for 150km/h

3.2.2 Aeroacoustics

Concerning aerodynamic noise, CNOSSOS proposes a formulation according to position (A or B) and speed.

In the end, two types of acoustic spectra can be observed:

- Rather wide band spectrum (see Fig. 6)
- Spectrum with one specific frequency emergence, like the pabtopgraph radiation (see Fig 7)

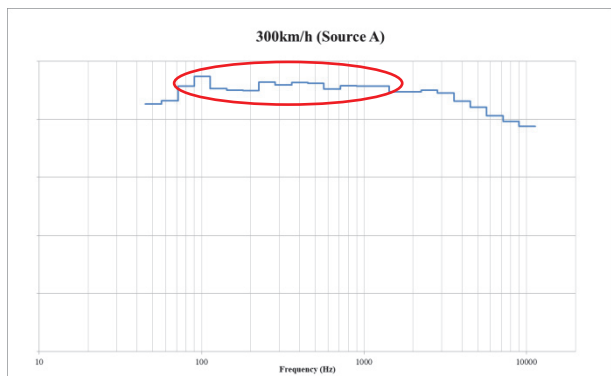


Figure 6. Acoustic power spectrum L_w (dB) calculated for 300 km/h – source A

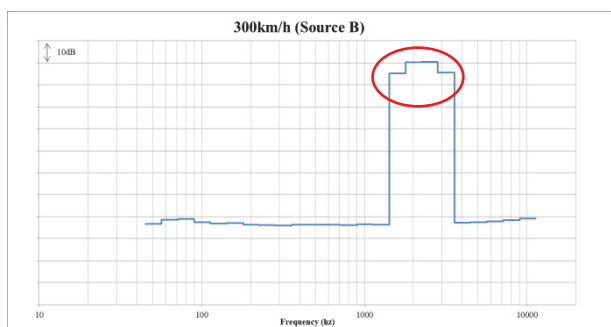


Figure 7. Acoustic power spectrum L_w (dB) calculated for 300 km/h – source B

4. MODELISATION

The objective of this study is to investigate the potential application of sonic crystals as acoustic barrier in the railway case, using ACTRAN FEM software.

4.1 FEM Model

As in existing work on the subject of sonic crystals [8], we have chosen to use the Insertion Loss (IL) as a numerical indicator. It is expressed as follows:

$$IL(f) = 20 \text{Log} \left(\frac{p_{ref}(f)}{p_{crystal}(f)} \right) \quad (4)$$

for each point, with $p_{ref}(f)$ the value of the pressure in the absence of the sonic crystal and $p_{crystal}(f)$ the same value in the presence of the crystal. All are depending of frequency f .

Here, the description of the generic model (see Fig. 8-9):

- 2D model in plane (X,Y)
- Location and type of excitation: we chose to place a plane wave radiating at 60dB (white noise). The position of the source is $Y = -5\text{m}$ and it radiates an infinite wavefront in X, propagating in Y direction.

- Location of the calculation points: we place a first point at a distance $2a$ from the crystal along the Y axis, and 4 other points on either side of the first one on the X axis (symmetrically with respect to the central point; 20° and 45°).
- To observe only the phenomenon of interference within the crystal, the diffusers are considered infinitely rigid.
- **Structure meshing:** we decided to carry out the study over the frequency range 10Hz-5000Hz. To respect the criterion of a mesh size of 8 elements per wavelength, elements have been defined according to size $l \leq \frac{c}{8f}$, where c is the speed of sound in the air 340m/s, i.e. $l \leq 0,0085\text{m}$.
- **Acoustic meshing:** we used the "Exterior Acoustics" feature of the ACTRAN software. This function is used in wideband study cases. It divides the total frequency band of the study into thinner bands. For each band, this function allows to define around the targeted elements (here the crystal) first an acoustic finite element mesh adapted to the smallest wavelength, and then an APM (Adaptive Perfectly Matched Layers) mesh around it with a non-reflection condition to obtain a far-field condition.

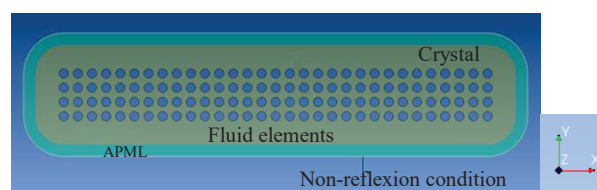


Figure 8. FEM generic model of crystal

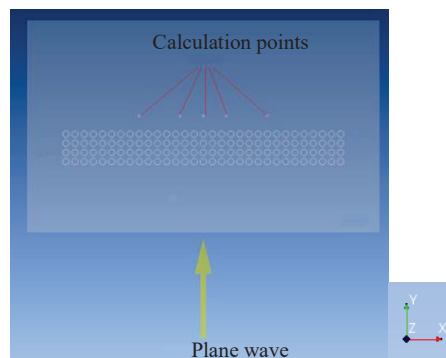


Figure 9. FEM generic model

4.2 Results

4.2.1 Sensitivity to Selected Parameters

The idea is to see the influence of the fill factor on the acoustic performance around the forbidden center frequencies.

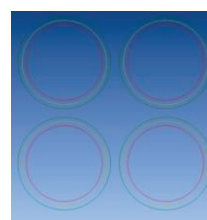


Figure 10. Square lattice with different values of r

Below is an example of the impact of the evolution of the fill factor in case $a=0,12\text{m}$ ($f_{BG} = 1416\text{ Hz}$). We can observe an increasing of the band around f_{BG} :

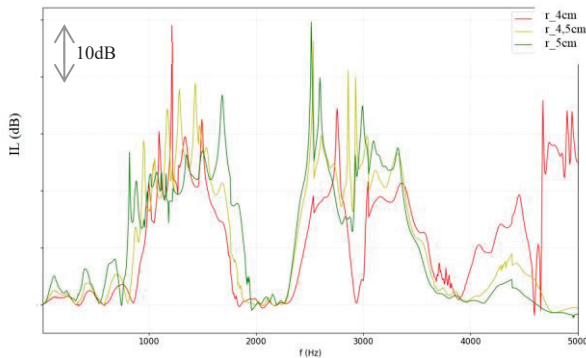


Figure 11. Effect of the fill factor on the width of the band gap

4.2.2 A design Adapted to the Source

In order to optimize performance, designs adapted to source typologies were researched (wideband vs. narrowband emergent character, low frequencies vs. high frequencies, etc.). In the long term, we will also be able to imagine different sound barrier heights depending on whether the problematic source is in position A or B (not discussed in this article).

Example of rolling noise at speed 150 km/h:

Proposal of a square lattice crystal, with $a=0,08\text{m}$ ($f_{BG} = 2125\text{ Hz}$) and whose diffusers are cylinder with diameter of $0,07\text{m}$ ($ff=60\%$):

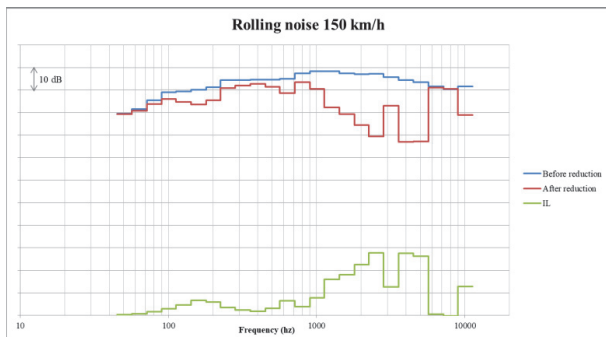


Figure 12. Mitigation effect of a sonic crystal barrier on an acoustic source representing the rolling noise at 150 km/h

Example of upper aeroacoustic source at speed 300 km/h:

Proposal of a square lattice crystal, with $a=0,06\text{m}$ ($f_{BG} = 2833\text{ Hz}$) and whose diffusers are cylinder with diameter of $0,05\text{m}$ ($ff=54\%$).

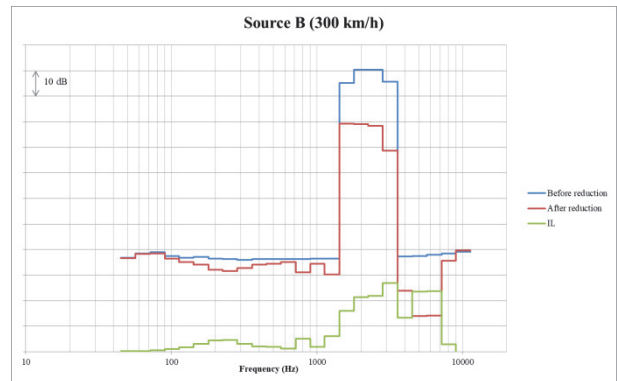


Figure 13. Mitigation effect of a sonic crystal barrier on an acoustic source representing the upper aeroacoustic source at 300 km/h

For more complex acoustic sources, with emergences in different frequency ranges, different crystal design strategies are possible in order to optimize its performance:

- Addition of a Helmholtz resonator to increase performance at lower frequencies, in addition to the Bragg phenomenon.



Figure 14. Lattice integrating Helmholtz resonator in each scatterer

- Creation of a double crystal in order to cumulate the band gap effect in two different ranges



Figure 15. Double sonic crystal

4.2.3 Comparison with Classical Noise Barrier

Necessarily the question of the comparison with a classic screen is asked. This is why, via the numerical model set up, a comparison between the two devices has been carried out.

Concerning the crystal, we consider:

- 4 rows of cylinder diffusers
- Distance between axes: $a=0,05\text{m}$
- Bragg frequency: $f_{BG}=2833\text{ Hz}$
- $r=0,025\text{m}$, i.e. $ff=55\%$

For the screen, we used a wall with a thickness and length equal to the total width of the crystal (i.e. $0,2\text{m}$) and the total length of the crystal (i.e. $1,55\text{m}$). Concerning the material composing the wall:

- Density: $\rho=1710 \text{ kg/m}^3$
- Young's modulus: $E=35 \text{ GPa}$
- Poisson's ratio: $\nu=0,2$

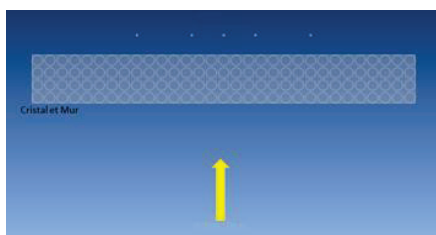


Figure 16. Numerical model: standard barrier vs. sonic crystal

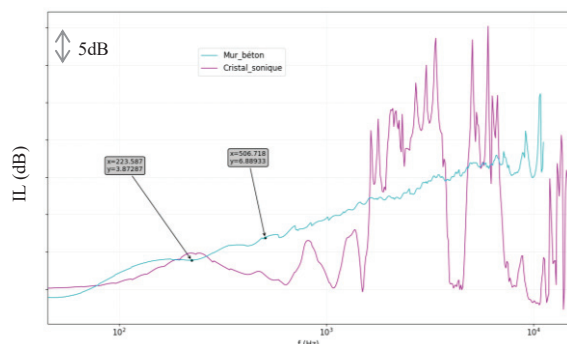


Figure 17. IL results for both technical solutions

We find the slope of 3dB/octave for the full screen. Nevertheless around f_{BG} the acoustic performance calculated for the crystal exceeds the acoustic performance of the standard barrier (see Fig. 17).

5. CONCLUSIONS

The use of sonic crystals to reduce the acoustic impact of rail traffic is very attractive, particularly in terms of design and cost (lighter foundations compared to standard screens). Nevertheless, and this is the very principle of sonic crystals, the attenuation is more targeted in frequency. It is up to us to invent this type of technology according to the use and the technical noise issue. The numerical pre-dimensioning of this type of solution is interesting and will allow us to optimize the design before installation. This work must continue in order to estimate the impact of source directivity and 3D effects (distance to the source, height of protections, multitude of source points, etc.) on acoustic performance. Discussions on the choice of appropriate numerical tools for the large dimensions of the railway (structure and propagation) must also be carried out.

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