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THEORETICAL CONTRIBUTIONS TO PHONOABSORBANT STRUCTURE WITH FUNCTIONALITY IN THE LOWER FREQUENCIES FIELD

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Abstract: *This work proposes theoretical quantification of an aqueous solution of the noise attenuation encountered in road traffic. Theory of operation of these acoustic absorbers is based on the principle of Helmholtz resonator which in this case consists of a perforated panel mounted over four types of cavities with the profile sections identical but with different lengths, arranged in parallel. Due to the arrangement on the same plan, Helmholtz resonators, forms an overall operational with four frequencies (resonance) influenced by the lengths of the four types of cavities behind kink perforated panel with uniform over its entire surface area.*
Keywords: *acoustic absorbers, structure, lower frequencies field*

1. INTRODUCTION

This work proposes theoretical quantification of an aqueous solution of the noise attenuation encountered in road traffic. Theory of operation of these acoustic absorptions is based on the principle of Helmholtz resonator which in this case consists of a perforated panel mounted over four types of cavities with the profile sections identical but with different lengths, arranged in parallel. Due to the arrangement on the same plan, Helmholtz resonators, forms an overall operational with four frequencies (resonance) influenced by the lengths of the four types of cavities behind kink perforated panel with uniform over its entire surface area. By composing specific impedances to each of the four resonators, is aimed at an acoustic resonance over a range of frequencies as high as possible. But, taking into account the ability of each acoustic to diminish, the resonator in part decreases significantly to change the working of the resonance frequency, air cavities lengths mounted behind perforated panel have been selected in such a way that:

- Oscillations of the absorption coefficient in relation to frequency that it does not have significant differences between the four frequencies of resonance and should not depend on interval between them.
- Diminishing need to be the smallest value of absorption coefficient about the maximum capacity of each resonator in part running at the resonance frequency. This phenomenon is due to the acoustic energy ratio of the incident wave front velocity, what resonate with structure composed of the four resonators in hand, at the same time.

Another important factor that must be taken into account, it is the size and the perforation profile, as well as thickness of the panel. In view of the fact that this structure will be located in areas with heavy road traffic, is not clogged capability perforations is obvious. So as to reduce clogging phenomenon of perforations it is necessary that the diameter of them need as high as possible and thickness of the panel as low.

Taking into account the elements described, his neck Helmholtz resonator, (profile and diameter perforation) have been carried out in four variants are operated: - Cylinder; - Cone surmounted; - Cone surmounted with hollow profile; - Cone surmounted with convex profile.

Dimensions are: -Cylinder's radius 4 mm; - For perforated sections in the form of cone surmounted small base radius is 3 mm and the bottom than 5 mm; -The thickness of the panel from 1 to 10 mm for all types of panel; -The length of the hollow section 30mm, 45mm, 80mm, 150mm for all types of panel; -The ratio of the perforation is approximately 0.0044.

2. THEORETICAL BASIS

A hole in a perforated panel may be treated as a cylindrical tube in which its size compared with the wavelength of sound that interfaces with these structure, have small value. Specific acoustic impedance of a cylinder given by [*Maa* 87] and [*All*93] is:

$$Z = \frac{\Delta P}{\langle u \rangle} = j\omega\rho_0 h\left[1 - \frac{2}{x\sqrt{-j}}\frac{J_1(x\sqrt{-j})}{J_0(x\sqrt{-j})}\right]^{-1} \qquad (1)$$

The notations are: $j = \sqrt{-1}$; h - Thickness of the panel micro-perforated; u - Is the average speed of the particle cross-section of the cylinder; ΔP- acoustic pressure variation; ρ_0 - Air density; and x – The constant perforation can be expressed by the following relation:

$$x = r\sqrt{\frac{\rho\omega}{\mu}} \qquad (2)$$

having: r – Cylinder radius; μ- Air viscosity.

Determination of acoustic impedance of a perforation is not limited only to the phenomenon of the propagation of sound through a cylindrical hole causing noise inside its reaction, but it is necessary to add some additional acoustic mass right Δm on both sides of the panel, and a coefficient of acoustic resistance RS.

$$\Delta m = \frac{8a}{3\pi} \quad \text{[RFB01]} \qquad (3)$$

$$Z_m = j\omega\rho_0\left(\frac{8r}{3\pi} + \frac{8r}{3\pi}\right) \approx j1{,}7\omega\rho_0 r \qquad (4)$$

$$R_S = \frac{1}{2}\left(\sqrt{2\omega\rho_0\mu}\right) \quad \text{[RTP 00]} \qquad (5)$$

RS-"Ingard and Labate defines an additional factor for the resistive part of the tube [UIS 50]" [RTP 00].

Thus, taking into account the corrections mentioned above, summed up the relationship (1), acoustic impedance of a perforated panel can be obtained by dividing the total value penetration ratio (total area perforated/panel surface resulting from relations (7)).

$$Z_{perf} = \frac{j\omega\rho_0 h}{rp}\left[1 - \frac{2}{x\sqrt{-j}}\frac{J_1(x\sqrt{-j})}{J_0(x\sqrt{-j})}\right]^{-1} + \frac{\sqrt{2\omega\rho\mu}}{2\,rp} + \frac{j1{,}7\omega\rho_0 r}{rp}$$

[OOM 10] (6)

$$rp = \frac{\pi r^2}{b^2} \qquad (7)$$

In these relations, the notations are: rp – perforated ratio, n – number of perforations, b – distance between two perforations, d – perforation diameter, Sp – panel surface.

In the case of determining acoustic impedance by a panel perforated with perforation profile in the form of cone surmounted required an adaptation of the procedure described above. On the basis of the relationship (1) which defines the impedance of a small cylinder, the impedance defined for a perforation with profile in the form of cone surmounted, which may be achieved by its discreetizating heights as seen in Figure 1.

So the relation (8) (possession and [RTR00]) is obtained acoustic impedance of this type of perforation noted as Z_h.

$$Z_h = \sum_{m=1}^{M} j\omega\rho_0\,\Delta h\left[1 - \frac{2}{x_m\sqrt{-j}}\frac{J_1(x_m\sqrt{-j})}{J_0(x_m\sqrt{-j})}\right]^{-1} \qquad (8)$$

Spice radius m relationship resulting from $\bar{r}_m = \frac{1}{2}(r_{m-1} - r_m)$,and $r_m = r(m\Delta z)$, where the perforated constant is $x_m = r_m\sqrt{\frac{\rho\omega}{\mu}}$ given by relation (2) (possession and [RTR00]).

To achieve the correct calculation it is necessary that at both ends of the perforation profile in the shape of a slightly cone surmounted to be included corrections, of relation (6) representing soundproofing and acoustic resistance.

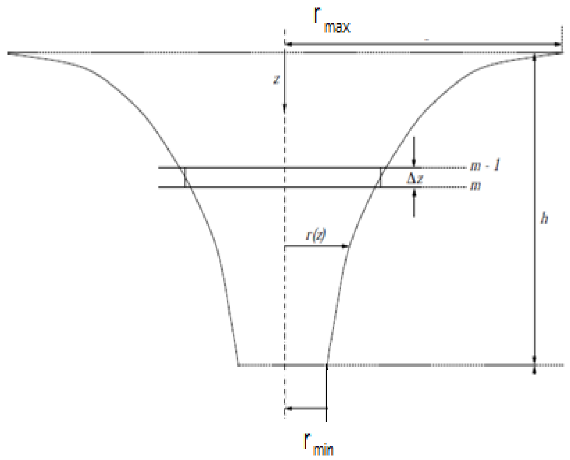

Fig.1 Sketch of discreetizating for conic perforation profile ([RTR00] modified)

But, in this case, the perforated report on both surfaces is different. The resistance acoustic coefficient, R, need to consider the relation (5) being the sum of the two resistances in parallel linked, and can be write the expression:

$$R = \frac{1}{\frac{1}{\frac{1}{rp_{max}}\sqrt{2\omega\rho\mu}}+\frac{1}{\frac{1}{rp_{min}}\sqrt{2\omega\rho\mu}}} \qquad (9)$$

The perforated ration of the great base is: $rp_{max} = \pi r_{max}{}^2/b^2$, and for the smoler base is: $rp_{min} = \pi r_{min}{}^2/b^2$.

Taking into account the relation (4), the additional acountic mas, Z_{Mh} ,can be write as:

$$Z_{Mh} = j\omega\rho_0\left(\frac{8r_{max}}{3\pi}+\frac{8r_{min}}{3\pi}\right) \qquad (10)$$

Similar relationship (6), taking into account the relations (9) and (10) the impedance of the perforated panel with conic perforation is as follows:

$$Z_{h,perf} = \frac{1}{rp_{med}}\left(\sum_{m=1}^{M} j\varpi\rho_0\Delta h\left[1-\frac{2}{x_m\sqrt{-j}}\frac{J_1\left(x_m\sqrt{-j}\right)}{J_2\left(x_m\sqrt{-j}\right)}\right]^{-1}\right)+$$
$$j\varpi\rho_0\left(\frac{1}{rp_{max}}\cdot\frac{8r_{max}}{3\pi}+\frac{1}{rp_{min}}\cdot\frac{8r_{min}}{3\pi}\right)+\frac{1}{\frac{1}{\frac{1}{rp_{max}}\sqrt{2\varpi\rho\mu}}+\frac{1}{\frac{1}{rp_{max}}\sqrt{2\varpi\rho\mu}}} \qquad (11)$$

Where: rp_{med} is the average radius taken in the distance h in there number.

Determine the impedance of Helmholtz resonator (relation (13)), shall be carried out by adding acoustic impedance provided by the panel perforated with specific acoustic impedance measured by cavity air located to the back of panel (12) [ZEK 49].

$$Z_D = -j\,\rho c \cot(kD) \qquad (12)$$

The relation contains: Z_D - Specific acoustic impedance of the hollow section air located behind perforated panel; D – is the cavity length; k - is the wave number; c - is the sound speed.

The relation (12) determines the specific acoustic impedance of all cavities of air taken into account in this case, and the total value of impedance for each resonator can be found in the relation (13) [ZEK 49].

$$Z_{tot} = Z_p + Z_D \qquad (13)$$

Z_{tot} – Specific total acoustic impedance of the resonator (for each resonator);

Z_p – Specific impedance perforated panel (for each type of perforation).

Sound absorption coefficient $Alfa$ an entire structure is inversely proportional to the coefficient of reflection (14), and, in the case incident wave propagated perpendicular to its plane is determined reflection on the plan of separation between two environments depending on their impedance and thus relationship (14) becomes relationship (15) [RFB01] [RTP 00].

$$Alfa = 1 - r^2 \qquad (14)$$

r- reflection coefficient

$$r = \frac{Z_{tot}-Z_0}{Z_{tot}+Z_0} \qquad (15)$$

Z_0 – the air specific impedance.

For the determination of the absorption coefficient achieved by the four acoustic absorbents fit in parallel, it is necessary to determine total impedance acoustic by stitching impedances carried out by each party in accordance with the resonator relationship (16) [NET 01]. After obtaining the total impedance values and using specific relationship (15) is obtained the absorption coefficient of the assembly.

$$Z_{tot} = 1\Big/\left(\frac{1}{Z_p+Z_{D1}}+\frac{1}{Z_p+Z_{D2}}+\frac{1}{Z_p+Z_{D3}}+\frac{1}{Z_p+Z_{D4}}\right) \qquad (16)$$

Z_{tot} – Specific impedance realized impedances by acoustic composition of the four resonators mounted in parallel; $Z_{D1,\ 2\ 3,\ 4}$ – Specific impedance produced by air cavity behind the panel perforated with the lengths: 30. 45, 80 and 150mm; Z_p – Specific impedance perforated panel (for each type of perforation).

3. THE RESULTS OF THE ABSORPTION COEFFICIENT

For the determining, from a theoretical point of view of the absorption coefficient for perforated panels with cylindrical perforation profile and in the form of cone surmounted with air cavity behind them or taken into account dimensional characteristics, as follows: - cylindrical radius 8 mm; - for perforated sections in the form of con small base radius is 6 mm and large base is 10 mm; - thickness of the panel from 1 to 10 mm; - hollow section length of 30mm, 45mm, 80mm, 150mm for all types of panel; perforation ratio is 0.0044.

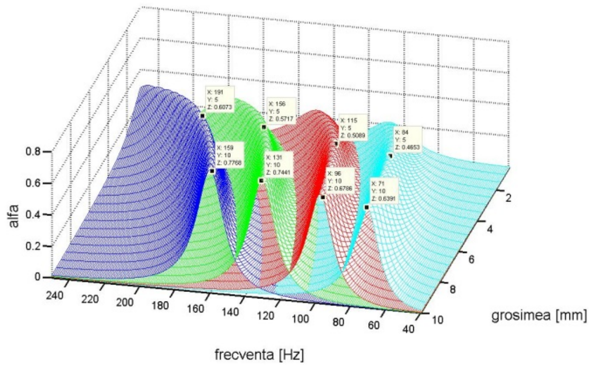

Fig.2 Compare of absorption coefficient made throw cylindrical perforation behind the perforated panel with the length cavities having 30, 45, 80 and 150mm

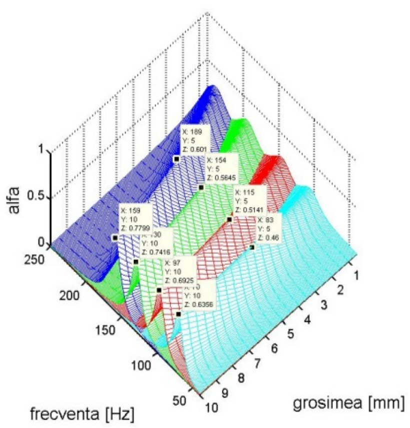

Fig.3 Comparison of the absorption coefficient of perforations on cone surmounted, with the following hollow sections are located behind perforated panel with a length of 30, 45, 80 and 150 mm

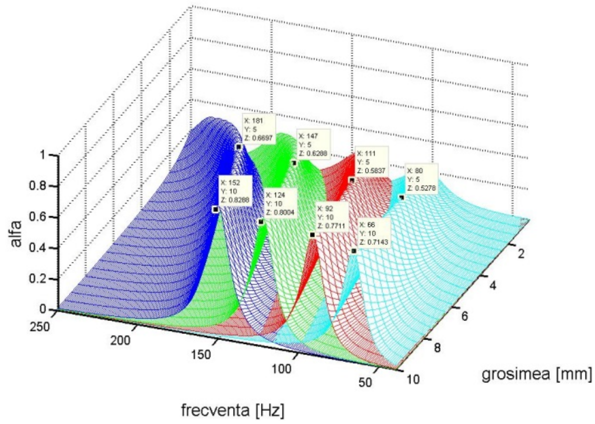

Fig.4 Comparison of the absorption coefficient of perforations on concave cone surmounted, with the following hollow sections are located behind perforated panel with a length of 30, 45, 80 şi 150 mm

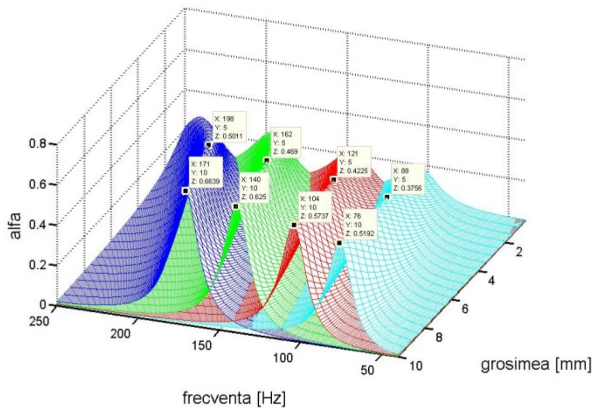

Fig.5 Comparison of the absorption coefficient of perforations on convex cone surmounted, with the following hollow sections are located behind perforated panel with a length of 30, 45, 80 and 150 mm

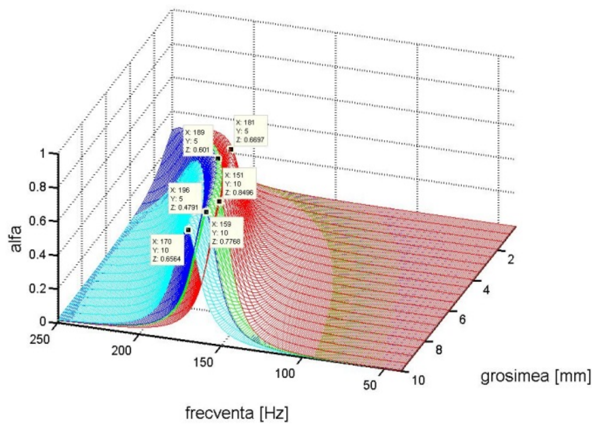

Fig.6 Comparison of the absorption coefficient with perforations on the profile: cylinder, linear, concave, convex, and cavity is situated of 30 mm

The graphs showed in Figures 2, 3, 4 and 5 shows the variation of the absorption coefficient of perforated panels fitting on the four types of hollow sections in relation to thickness of the panel and the frequency. The graphs illustrated in figures 6, 7, 8 and 9 highlights the difference between the four profiles of perforates carried out on the same cavity.

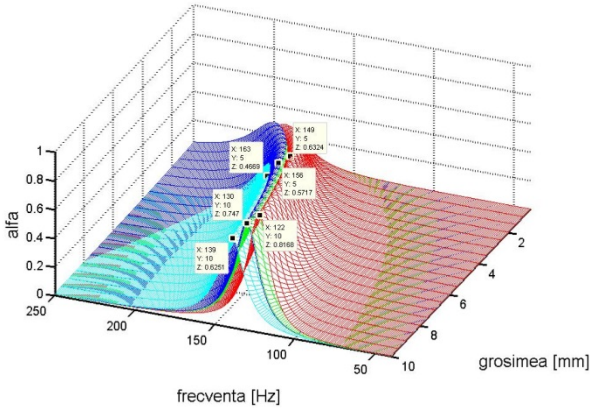

Fig.7 Comparison of the absorption coefficient with perforations on the profile: cylinder, linear, concave, convex, and cavity is situated of 45 mm

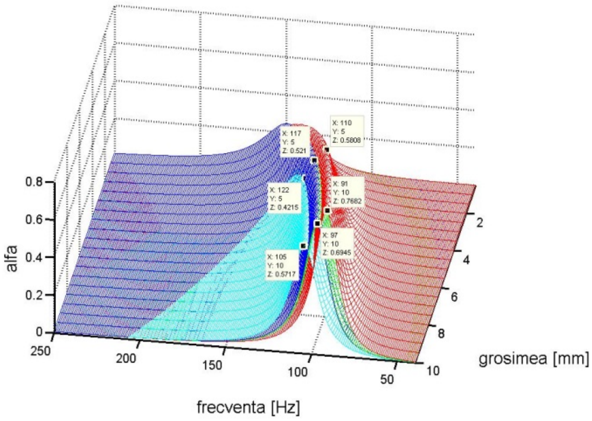

Fig.8 Comparison of the absorption coefficient with perforations on the profile: cylinder, linear, concave, convex, and cavity is situated of 80 mm

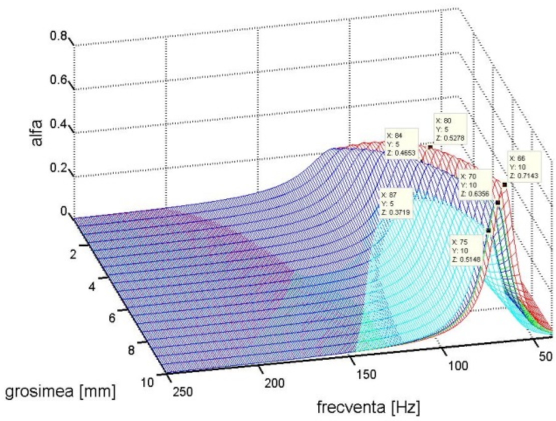

Fig.9 Comparison of the absorption coefficient with perforations on the profile: cylinder, linear, concave, convex, and cavity is situated of 150 mm

4. COMPARISON OF THE ACOUSTICS ABSORPTION COEFFICIENT CARRIED OUT BY COMPOSITION OF THE FOUR STRUCTURE

The results obtained for acoustic absorption shoot with perforated panels with its profile to form a cylinder, cone surmounted linear, concave and convex, mounted on the four types of cavities has been observed in this case an increase of the absorption coefficient with the increase in the thickness of the panel, as well as a decrease in the resonance frequency with the increase in the thickness of the panel. For a sample as clear have been carried out the graphs 10 and 11 illustrating the amplitude of the absorption coefficient of acoustic to impact absorbing pad mountings on bumper shoot with perforated panels have the thickness of 5 and 10 mm.

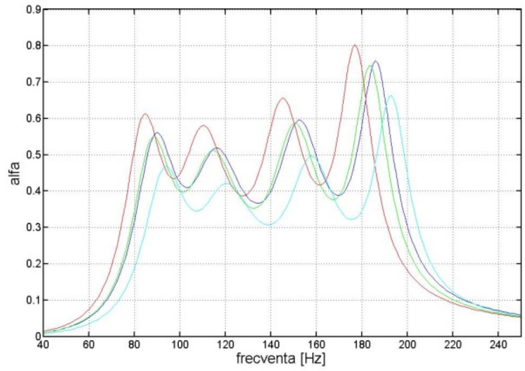

Fig.10 The absorption coefficient achieved by stitching resonator Helmholtz with four types of hollow sections for perforations on cylinder, linear, concave, convex and the panel thickness of the 5 mm

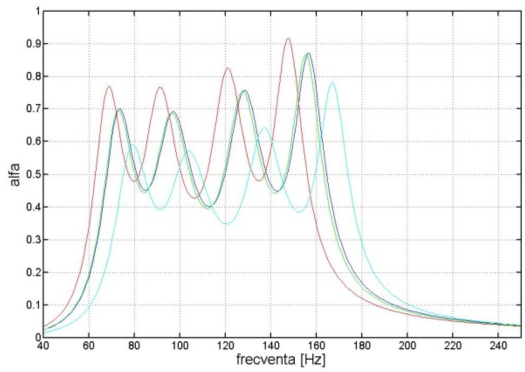

Fig.11 The absorption coefficient achieved by stitching resonator Helmholtz with four types of hollow sections for perforations on cylinder, linear, concave, convex, and the panel thickness of the 10 mm

5. CONCLUSIONS

Taking into account the results obtained by acoustic absorptions (representations in figures 2, 3, 4, 5, 6, 7, 8 and 9), you can make with perforated panels with its profile to form a cylinder, linear, concave and convex respectively, mounted on the four types of cavities to observed in this case an increase of the absorption coefficient as well as a decrease in the resonance frequency with the increase in the thickness of the panel.

From the graphs represented in figures 6, 7, 8 and 9, it is observed that influence perforation models which have been taken into account does not affect significantly the amplitude of the absorption coefficient.

In figures 9 and 10 you can see an average amplitude of the absorption coefficient located at value of 0.5 as well as a slight delay of the range of frequency in which these structures have a high efficiency.

Due to the frequency range in which these structure provides a significant attenuation of the noise, make these elements can be considered to be particularly useful for their location on surface acoustic barriers.

ACKNOWLEDGMENT:

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6. REFERENCES

[MAA87] MAA D Y. Micro-perforated wideband absorbers. Noise Control Engineering Journal, 29(3), 77–84 (1987)

[All 93] ALLARD J F. Propagation of Sound in Porous Media; Modeling Sound Absorbing Materials. Elsevier (1993)

[RFB01] Industrial Noise Control and Acoustics **Randall F. Barron** Louisiana Tech University Ruston, Louisiana, U.S.A. ISBN: 0-8247-0701-X ,2001

[RTR00] Rolf Tore Randeberg; Perforated Panel Absorbers with Viscous Energy Dissipation Enhanced by Orifice Design; DOCTORAL THESIS; Norwegian University of Science and Technology, in partial fulfillment of the requirements for the degree of doktor ingeniør Trondheim, June 2000; 117 pag

[NET 01]http://whirlwindusa.com/support/tech-articles/high-and-low-impedance-signals/

[ZEK 49] ZWIKKER C and KOSTEN C W. *Sound Absorbing Materials*. Elsevier (1949)

[RTP 00] Rostand Tayong, Thomas Dupont, and Philippe Leclaire, On the variations of acoustic absorption peak with flow velocity in Micro-Perforated Panels at high level of excitation, Laboratoire de Recherche en Mécanique et Acoustique (LRMA), ISAT Université de Bourgogne, Nevers France, pag 14

[UIS 50]U. Ingard, S. Labate, "Acoustic Circulation Effects and the Nonlinear Impedance of Orifices", J. Acoust. Soc. Am. 22, 211-218 (1950).

[OOM 10]Onursal Onen , Mehmet Caliskan, Design of a single layer micro-perforated sound absorber by finite element analysis, Applied Acoustics 71 (2010) 79–85, 2010, pag 7

CONTRIBUȚII TEORETICE PRIVIND REALIZAREA UNOR STRUCTURII FONOABSORBANTE CU FUNCȚIONALITATE ÎN DOMENIUL FRECVENȚELOR JOASE

Rezumat: *Această lucrare îşi propune cuantificarea teoretică a unei soluții de atenuarea a zgomotului, întâlnit în traficul rutier. Principiul de funcționarea a acestor absorbitorii acustici se bazează pe principiul rezonatorului Helmholtz care în acest caz este format dintr-un panou perforat montat peste patru tipuri de cavități cu profilul secțiuni identic dar cu lungimi diferite, aşezate în paralel. Datorită poziționării pe acelaşi plan, rezonatoarele Helmholtz, formează un ansamblu funcțional cu patru frecvențe de rezonanță influențate de lungimile celor patru tipuri de cavități aflate în spatele panoului perforat cu perforație uniformă pe toata suprafața sa.*

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