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DETERMINATION OF SOUND ABSORPTION OF DOUBLE MICRO-PERFORATED ABSORBERS BY TWO ANALYTICAL METHODS

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Abstract: *Micro-perforated panels (MPP) present an increasing use in terms of acoustic energy absorption capacity, efficient design and simulation. A double micro-perforated absorber (DMPA) is formed by two micro-perforated panels placed in parallel backed by a rigid wall, and it is based on the principle of Helmholtz resonator which presents a small opening connected to a closed volume of air. The air space can be filled partially or completely with different sound-absorbing materials. The analytical models used to calculate sound absorption coefficient are based on the electrical equivalent circuit of the structure and the transfer matrix method. The compatibility of these two methods is observed and analyzed in order to improve them. Both methods imply the models predicted by Maa for the acoustical resistance and reactance of the MPPs.*
Keywords: *absorption coefficient, double micro-perforated absorber, sound wave, electric equivalent circuit, transfer matrix method.*

1. INTRODUCTION

For a good absorption of sound waves, micro-perforated panels (MPP) are increasingly used due to their advantages. They are made of different materials like metal or acrylic with micro-perforations of less than 1 mm diameter and placed at a certain distance from a rigid wall giving high sound absorption at mid- to high-frequencies [8], [12].

A double micro-perforated absorber panel (DMPA) is composed of two micro-perforated panels (MPPs) placed in parallel having an air-cavity in-between, followed by a rigid wall as can be seen in Figure 1.

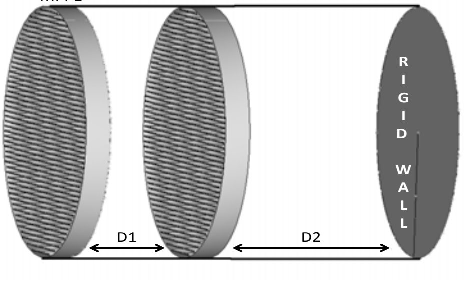

Fig. 1. Schematic representation of a double micro-perforated absorber

This kind of acoustical structures can be used for a sound absorbing screen or panel. It is known that conventional MPP absorbers are effective only around theirs resonant frequency and a DMPA can give good absorption also at low frequencies [7].

Different studies regarding analytical and experimental models of double micro-perforated panel were carried out lately. Starting from the model developed by Maa, another researchers have proposed a series of acoustical structures that includes micro-perforated panels aranged in different ways, even developing them as noise barriers [2]. Sakagami et all (2009) proposed a model of double micro-perforated panels without rigid backing underlining the advantage of using them as noise absorptive panels.

In this paper, some theoretical considerations regarding double micro-perforated panels are studied and presented. Two analytical methods are used for determination of sound absorption coefficient α. The results are analyzed and compared to serve further for experimental approach.

2. THEORETICAL CONSIDERATIONS

The first model of a DMPA was proposed by Maa [6], [8]. A good method to represent double micro-perforated sound absorbers is using a simplified electro-acoustical equivalent circuit (Fig. 2), which is a simplified model [5].

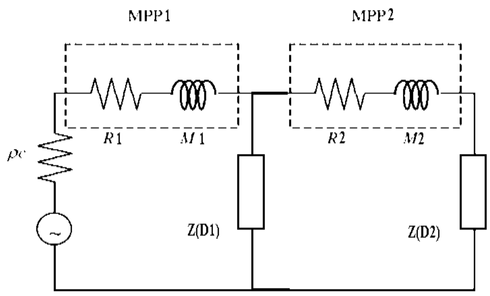

Fig. 2. Electrical equivalent circuit of double MPA (R1,2 – resistance of each MPP, M1,2 – acoustical mass of each MPP; Z(D1,D2) – impedance of air cavities)

According to electrical equivalent circuit of a DMPA, the impedance of the second micro-perforated panel Z_{MPP2} is in series with the impedance of backed air volume Z_{D2} which are in parallel with the cavity impedance Z_{D1}. Further, the impedance of first micro-perforated panel Z_{MPP1} is in series with the rest of the electrical circuit.

2.1 Helmholtz resonator effect

Figure 3 shows the model for an acoustical structure formed by two MPPs with their adjacent air cavities and a rigid backing. The sound source radiates plane sound waves that are assumed to be normally incident upon MPP1.

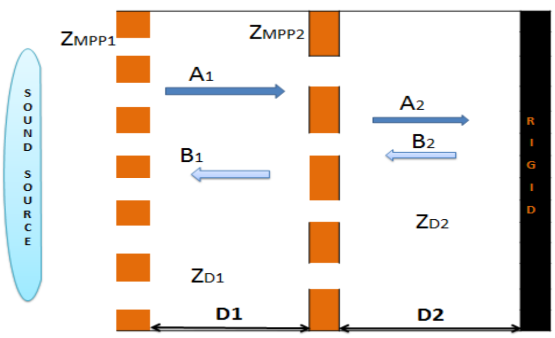

Fig. 3. Double micro-perforated panel absorber excited by sound waves radiated from an acoustic source

The geometrical characteristics of the MPP1 and MPP2 are: thickness t_p, distance b between micro-perforations, holes diameter d_p. The thickness of the air cavities are given by D1, respectively D2.

Incident sound waves arriving on the MPP1 surface are exciting the air from the micro-perforations which will act like a mass over the elastic air volume from the cavity D1[10], [12]. Thereby, the Helmholtz effect can be observed which will further manifest for the second MPP, observing the different amplitudes of incident and reflected sound waves in both air cavities (Fig. 3).

Knowing that impedance has a real part, namely resistance (r_{MPP}) and an imaginary one called reactance (ωm_{MPP}) as can be seen from Eq. (1) [2], [5], [6], Eq. (2) and (3) were developed by Maa for a single MPP.

$$Z_{MPP} = r_{MPP} + j\omega m_{MPP} \tag{1}$$

$$r_{MPP} = \frac{32\eta t_p}{c p_p \rho_0 d_p^2}\left(\sqrt{1+\frac{k_p^2}{32}} + \frac{\sqrt{2}k_p d_p}{32 t_p}\right) \tag{2}$$

$$\omega m_{MPP} = \frac{\omega t_p}{c p_p}\left[1+\left(\sqrt{1+\frac{k_p^2}{2}}\right)^{-1} + \frac{0.85 d_p}{t_p}\right] \tag{3}$$

with: $k_p = d_p\sqrt{\omega\rho_0/\eta}$

where:
c – sound speed in air (m/s)
ρ_0 – air density (kg/m^3)
k_p – perforation constant
η - air viscosity coefficient

Using equations above and considering the equivalent electrical circuit from Fig. (2), the acoustical impedance of the entire structure can be calculated by Eq.(4) [3], which will lead to the prediction of sound absorption coefficient.

$$Z_{DMPA} = Z_{MPP1} + \frac{(Z_{MPP2}+Z_{D2})Z_{D1}}{Z_{MPP2}+Z_{D2}+Z_{D1}} \tag{4}$$

Absorption of sound takes place due to the viscous friction of the air in the holes and its coefficient is given by [2], [6]:

$$\alpha = \frac{4\,\mathrm{Re}(Z_{DMPA})}{[1+\mathrm{Re}(Z_{DMPA})]^2 + \mathrm{Im}(Z_{DMPA})^2} \quad (5)$$

2.2 Transfer matrix method

Acoustic field of a fluid medium is defined at each point by its pressure-velocity vector. Transfer matrix method is applied to each layer or component of the acoustical structure and "takes place" between the existing surfaces of each layer, as can be seen from Fig.4 [1].

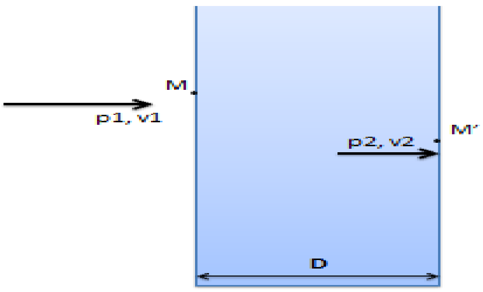

Fig. 4. Double micro-perforated panel absorber excited by sound waves radiated from an acoustic source

An acoustic element can be modeled by the four parameters of a transfer matrix that connects the sound pressure and particle velocity on both sides of the medium of thickness D [11].

For an acoustic system consisting of a single layer (Fig. 4) the transfer matrix method is characterized by Eq. (6) with the four poles T_1, T_2, T_3 and T_4.

$$\begin{bmatrix} p_1 \\ v_1 \end{bmatrix} = \begin{bmatrix} T_1 & T_2 \\ T_3 & T_4 \end{bmatrix} \begin{bmatrix} p_2 \\ v_2 \end{bmatrix} \quad (6)$$

The presence of a new environment in a structure involves determining the transfer matrix of that medium. Thereby, the pressure-velocity vector will be equal to the product of the transfer matrix of the new layer and pressure-velocity vector that records the output of the system [13].

In order to find the total impedance of the acoustic structure consisting of four components (two MPPs and two air cavities) it is necessary to find out the transfer matrix of the entire system given by Eq.(7).

$$T_{DMPA} = T_{MPP1} \cdot T_{D1} \cdot T_{MPP2} \cdot T_{D2} \quad (7)$$

where:

T_{MPP1}, T_{MPP2} - transfer matrix of MPP1, MPP2 respectively

T_{D1}, T_{D2} - transfer matrix of air cavity D1, D2 respectively

Considering the air density ρ_0 in the cavity and the wave number k, pressure and particle velocity expressions are given by the equations (8) and (9) to the sound wave propagation in the x direction [1], [3].

$$p(x) = P_i \exp(-jkD) + P_r \exp(jkD) \quad (8)$$

$$v(x) = \frac{k}{\rho\omega}[P_i \exp(-jkD) - P_r \exp(jkD)] \quad (9)$$

Where:

P_i - incident wave amplitude;

P_r - reflected wave amplitude.

Thus, observing Figure 4 and choosing the origin of the coordinate axes at the point M', the equations (8) and (9) can be expressed in a matrix form Eq.(10) [4], [11].

$$\begin{bmatrix} T_1 & T_2 \\ T_3 & T_4 \end{bmatrix} = \begin{bmatrix} \cos(kD) & j\rho_0 c \sin(kD) \\ j\dfrac{\sin(kD)}{\rho_0 c} & \cos(kD) \end{bmatrix} \quad (10)$$

This expression represents the transfer matrix of an air cavity of thickness D. In DMPA case there are two air volumes: one between MPP1 and MPP2 as in Fig.1 or 3 with distance D1, and the second one between MPP2 and the rigid backing with distance D2.

If we consider the layer from Fig.3 as being a micro-perforated panel, Eq. (11) gives the harmonic form of the equation of motion based on the MPP's impedance [1].

$$Z_{MPP} v(M') = p(M') - p(M) \quad (11)$$

The velocity at points M and M' is considered to be the same. Thereby, we reach to the form of the transfer matrix for a micro-perforated panel given by the expression (12). The form of the transfer matrix from Eq.(12) is applicable to a panel that is not connected to another structure [4].

$$\begin{bmatrix} T_1 & T_2 \\ T_3 & T_4 \end{bmatrix} = \begin{bmatrix} 1 & Z_{MPP} \\ 0 & 1 \end{bmatrix} \quad (12)$$

Using Eq.(10) and (12) the transfer matrix of a DMPA can be calculated by Eq.(13) which will lead to the total impedance of the acoustical structure given by Eq.(14) [4], [13].

$$T_{DMPA} = \begin{bmatrix} 1 & Z_{MPP1} \\ 0 & 1 \end{bmatrix} \begin{bmatrix} \cos(kD1) & j\rho_0 c \sin(kD1) \\ j\dfrac{\sin(kD1)}{\rho_0 c} & \cos(kD1) \end{bmatrix} \cdot \begin{bmatrix} 1 & Z_{MPP2} \\ 0 & 1 \end{bmatrix} \begin{bmatrix} \cos(kD2) & j\rho_0 c \sin(kD2) \\ j\dfrac{\sin(kD2)}{\rho_0 c} & \cos(kD2) \end{bmatrix} \quad (13)$$

$$Z_{DMPA} = \frac{T_{DMPA}(1,1)}{T_{DMPA}(2,1)} \quad (14)$$

3. ANALYTICAL RESULTS

For numerical calculations two existing micro-perforated panels have been chosen. The micro-perforations diameter and the thickness of the samples are 0.0007 m. The only difference for the MPPs is the distance between holes which, for the MPP named Plexi2 is equal to 0.002 m and the other one for the Plexi4 sample is equal to 0.004 m. Each sample is placed at a specific distance from the rigid wall which is assumed to be perfectly reflecting.

For the first arrangement, two identical MPPs are placed in parallel at a distance of 0.02 m one from another and from the rigid end. A single peak of absorption appears, for both methods (TMtx – transfer matrix method and ElEq – equivalent electrical circuit).
In Fig.5 a good agreement between transfer matrix method (TMtx) and electrical equivalent circuit (ElEq) can be observed. The maximum value of α is around 3400 Hz and exceeds 0.9.

Another type of a DMPA composed by different MPPs and separation distances of 0.02 m is represented in Figure 6.

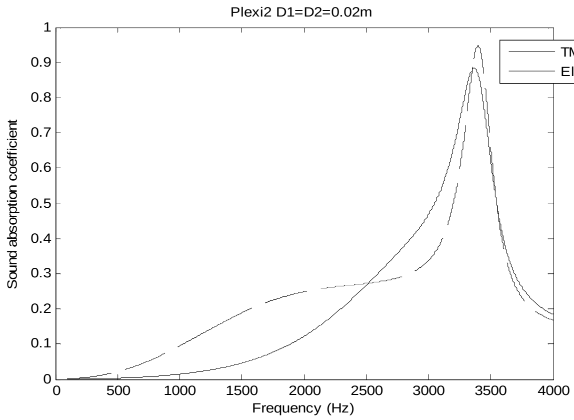

Fig. 5. Sound absorption coefficient of identical MPPs and equal distances

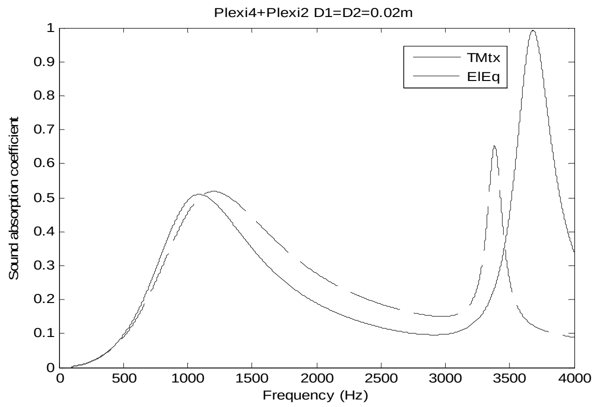

Fig. 6. Sound absorption coefficient of different MPPs placed at equal distances one from another and the rigid end

Compared to the first type of DMPA, two peaks of absorption can be observed. Both method give good suitability for the low and middle frequencies. The second peak resulted from the equivalent circuit is much lower than the one obtained from the transfer matrix. The frequency range is also different, the highest absorption being over 3500 Hz.

If the two MPP's are reversed, such that Plexi2 is in front of Plexi4 at a distance of 0.02, sound absorption coefficient can be also observed (Fig.7).

The analytical approaches presented in this paper provide a mismatch regarding the values of sound absorption coefficient from Fig.7. The transfer matrix model gives two flattened peaks, while the electrical model gives maximum values that exceed 0.6.

A double micro-perforated absorber with different thickness values of the existing air volumes is considered (Fig.8).

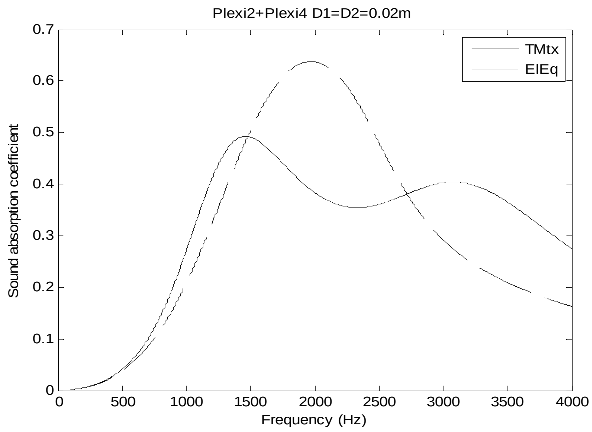

Fig. 7. Double micro-perforated panel absorber with equals air volume thicknesses and different MPPs

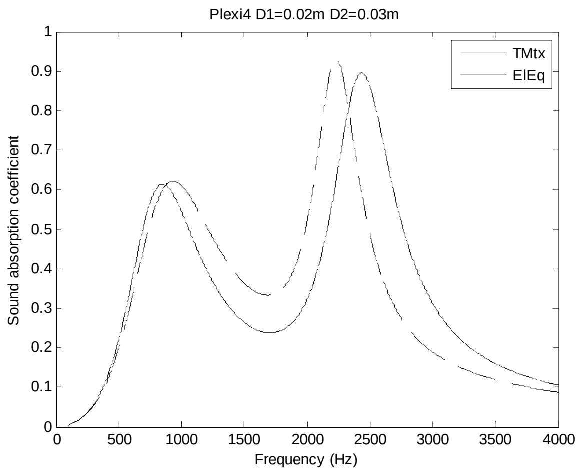

Fig. 8. Acoustical structure formed by identical MPPs placed at different distances one from another and the rigid end

For this kind of arrangement of the MPPs, sound absorption coefficient presents maximum values over 0.6 for both analytical models. A difference about 250 Hz for the second peak between both approaches can be observed.

4. CONCLUSIONS

In this article, the electrical equivalent circuit and the transfer matrix method have been applied to predict the sound absorption coefficient of double micro-perforated absorbers. Analytical approaches for determination of the total impedance (Z_{DAMP}) are presented.

Both methods use the geometrical parameters of the acoustic structure formed by MPPS and air volumes.

For some type of double micro-perforated absorbers there is a good agreement between the two methods studied. Some discrepancies can be observed for two kinds of arrangements (Fig.6 and Fig.7).

The electrical circuit model is presented in many studies regarding sound absorption of micro-perforated panels. The transfer matrix method is also general and convenient to be used. Acoustical structures composed by MPPs placed in parallel are being measured and further conclusion will be presented.

5. AKNOWLEDGEMENTS

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Determinarea absorbției acustice a absorbitorilor micro-perforati dubli utilizând două modele analitice

Rezumat: Panourile micro-perforate (MPP) prezintă o utilizare tot mai mare din punct de vedere al capacității de absorbție a energiei acustice, al proiectarii și simularii eficiente. Un absorbitor micro-perforat dublu (AMPD) este format din doua MPP-uri amplasate în paralel și mărginite în partea din spate de un perete rigid, bazându-se pe principiul rezonatorului Helmholtz care prezintă o mică deschidere conectată la un volum de aer închis. Spațiul de aer poate fi umplut, parțial sau complet, cu diferite materiale fonoabsorbante. Modelele analitice utilizate pentru a calcula coeficientul de absorbție acustică se bazează pe circuitul electric echivalent al structurii analizate și metoda matricei de transfer. Compatibilitatea acestor două metode este observata si analizată. Ambele metode au la baza modele prezise de Maa privind rezistența acustica și reactanța MPP-urilor.

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