International Journal of Applied Engineering Research ISSN 0973-4562 Volume 15, Number 12 (2020) pp. 1135-1141
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Designing Of Micro Perforated Panels for Low Frequency Passive Acoustic Absorption

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Abstract

Passive and Active Methods of noise controlling and their acoustic frequency response cum efficiency need serious investigation as unwanted noise and vibrations accompanied with fast industrial and technological developments adversely affect the living and nonliving world simultaneously. Active noise controlling is proven as efficient in controlling low frequency sound below 500Hz where the conventional porous passive ones are inefficient even though they are efficient in controlling the high frequency sound. In this article the micro perforated panel absorber (MPP) is modeled based on Maa's theory in order to establish the potential of this energy efficient passive acoustic absorber in controlling low frequency as well as high frequency noise. The crucial role of the geometrical parameters of the MPP such as peroration diameter, air cavity length, separation between the perforations and the thickness of the Micro Perforated Panel in determining and controlling the frequency response of the acoustic absorption coefficient is being established. For the optimized values of the above mentioned geometrical parameters of the MPP an acoustic absorption coefficient close to 0.99 is achieved even at the very low frequency region close to 375Hz where only the Active Noise Controllers are proven as efficient ones and the conventional porous passive ones are inefficient. This modeling study clearly reveals that the active noise controllers and the conventional porous acoustic absorbers can be successfully replaced with this one. Thus the challenging issue of passive low frequency noise controlling can be addressed and solved with the help of this passive MPP absorber.

Keywords: Mpp, Passive Noise Controlling, Acoustic Absorption Coefficient, Active Noise Controlling

Introduction

The methods of Noise Controlling attained much importance and relevance in this modern world of industrialization and technological development. The noise pollution arising as result of industrialization and development is harmful to the environment and to the ecosystem as such. It has adverse effects on the physical and psychological health state of human beings. Noise pollution introduces hearing loss and other physical cum psychological adverse effects in mankind. Wild animals and aquatic organisms suffer many issues related to health, reproduction, breeding cycles, communication, behavioral changes etc. as a result of this noise pollution. Even the technological world itself suffers from the problems introduced by the unnecessary vibrations of the machinery parts which affects their performance and efficiency [1-2].

Most of the commonly used passive absorbers like the granular, fibrous and the tubular ones with their own peculiar microstructures are proven as efficient in absorbing sound in the high frequency region above 500Hz [3]. The active noise controllers show better response in noise controlling compared to the passive ones in the low frequency region below 500Hz even though they use external power for their functioning and are less energy efficient compared to the passive ones [4]. Physical and psychological impacts of low frequency noise on human health such as changes in the heartbeat rate, reduced respiration, aural pain, hearing impairment etc. are now a days reported with much anxiety. Long term noise exposure cause increased blood pressure, cardiovascular functioning irregularities, hormone imbalance cum immunomodulation; sleep disturbance etc. [5-9]. In the present scenario low frequency noise controlling is inevitable because of the serious concern about the health, environment and ecosystem. Low frequency noise controlling-especially that below the sound of frequency 500Hz- is more challenging as this one with high wavelength penetrates much without attenuation and is less sensitive to passive noise reduction mechanisms [10]. The Active Noise Controllers (ANC) are proven to be efficient in controlling noise above 500Hz. Steve Wise et.al developed ANC for controlling the low frequency noise generated by the HVAC systems (Heating-Ventilation- Air Conditioning systems) installed at schools and the Air Handling Unit (AHU) at hospitals [10]. It is difficult to develop an ANC producing coherent signals exactly out of phase with the noise required to be controlled. ANC will be efficient when the different modes are accurately and separately detected which is very difficult in practical situations [11-12]. So it is promising if it is possible to engineer and develop a passive absorber which is efficient in controlling the low frequency noise. In this particular article low frequency passive Micro Perforated Panel (MPP) acoustic absorber is modeled based on Maa's theory. MPP is energy efficient and easily developable compared to the Active Noise Controllers (ANC) so that the conventional acoustic absorbers can be replaced with this one [13-16].

Micro Perforated Panel Absorbers (MPP)

Micro perforated panel absorbers (MPP) are preferred as a challenging material in acoustic noise reduction applications compared to the conventional granular, fibrous and the tubular structured passive acoustic absorbers. It is commonly utilized as a muffler in automobiles, a silencer in the equipments used for construction work and as an interior material in architectural acoustics. It has the potential to control the noise in the low frequency as well as the high frequency regions. MPP can be properly designed for noise reduction purposes according to the controlling frequency region of interest based on Maa's model. The dimensions of its geometrical parameters can be optimized based on the above model satisfying the requirements of the noise reduction problem under consideration [13-17]. Natural micro fibrous passive porous absorbers are also proven as efficient in noise controlling applications. Their availability in wide range of fiber diameter which controls their air flow resistivity and porosity make them efficient in noise reduction applications. Their poor life time and easily degradable nature are the main factors which hinder their demand in noise reduction industry compared to MPP and synthetic absorbers [17-19]. Other than these the natural passive absorbers are incapable of withstanding high temperature and they easily absorb the moisture present in the atmosphere. Contrary to this MPP absorbers have the potential to withstand high temperature, humidity and also it is possible to operate them in harsh environments [20]. Therefore the conventional type of porous passive acoustic absorbers like natural fibers, glass fibers and mineral wool can be replaced by this thin, robust, reclaimable nonpolluting aesthetic ones having long life time. MPP can be used alone or in combination with the conventional ones. When MPP is placed in front of the conventional porous absorbers it not only protects the porous material from getting damaged but also improves its acoustic performance [21].

Designing of MPP absorbers for passive sound absorption

D.Y. Maa introduced the theory behind the performance of the MPP. Maa's Theory can be used to predict and design an MPP for passive noise controlling according to the performing frequency region of interest. The important parts of the MPP consist of a very thin flat plate usually made of metals, plastic, card board or wooden panel having perforations made on it which is backed by an air cavity followed by a rigid wall at the end. The small perforations can be inserted in the panel with the help of the conventional laser technology or with the help of infiltration technique. The Micro perforated panel with small perforations can be designed and these designed ones can be printed using three dimensional printing technologies [22-23]. The air cavity enclosed in between the thin panel and the rigid wall of the MPP acts as Helmholtz Resonator hence it acts as an acoustic absorber. The perforations on the thin panel of the MPP are very small in dimension of the order of sub millimeter range. These perforations are separated from each other in such a way that the perforation ratio is not that much high in order to prevent the interaction between acoustic fields through the perforations. Maa's theory is applicable in the case of small values of perforation ratio and it is desirable to have approximately close values of the perforation diameter and thickness of the panel material.The limitation of Maa's theory is that it is applicable only in the case of circular perforations. The diameter of the perforations, the air cavity length, perforation ratio and the thickness of the panel determines the performance of the MPP as an acoustic absorber. The designing criteria of MPP are actually the optimization of the above geometrical parameters in a particular combination suitable for the band width of interest with peak absorption. MPP is commonly used in single layer, multiple layers and in combination with porous absorbers for better performance. The partioned air cavity or air cavity of different structures like the honey comb ones open opportunity in tuning the performance of the MPP so that the Micro perforated Slit Absorbers(MSA) can be replaced by these better performing ones[20,24-26].

Theory of MPP

The construction of MPP is not so complicated. It mainly consists of an air cavity trapped in between a rigid wall and a membrane called the micro perforated panel. This panel consists of sub millimeter range circular perforations made on it. The diameter of the perforations d, the separation between them b and the length of the air cavity D determine the performance of the MPP absorber. The schematic representation of the structure of the MPP is shown in figure (A).

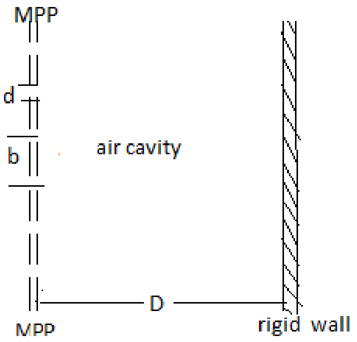

Figure (A)

When the sound passes through the MPP the corresponding acoustic field can be analyzed to extract the specific acoustic impedance. The wave equation can be solved in order to get the specific acoustic impedance (Z_1) based on the treatments by Lord Rayleigh and Crandall [28-29]. The solution for Z_1 in terms the perforation constant k, density of air ρ_0, the angular frequency ω, the thickness of the panel t is given by

$$Z_1 = j\omega\rho_0\, t \left[1 - \frac{2}{k\sqrt{-j}} \frac{J_1\left(k\sqrt{-j}\right)}{J_0\left(k\sqrt{-j}\right)}\right]^{-1} \ldots\ldots\ldots\ldots\ldots (1)$$

Where J_1 and J_0 are the Bessel functions of the first and zeroeth order respectively. The perforation constant k depends on the values of the radius of the perforations r_0, the density of air ρ_0, the frequency of the incident sound wave and the viscosity of the air η.

$$k = r_0 \sqrt{\frac{\rho_0 \, \omega}{\eta}} \;\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

The approximate solution for the relative acoustic impedance within the maximum error of 6% for values of k between 1 and 10 which is often applicable in the case of MPP is given by expression (3).This solution is obtained after applying the end correction at the orifices of diameter d for the normal incidence of acoustic field[26-27].

$$z = \frac{Z_1}{\sigma \rho_0 \, c} = r + j\omega_m \;\ldots\ldots\ldots\ldots\ldots (3)$$

Where σ is the perforation ratio $\sigma = 78.5 \frac{d^2}{b^2}$, r is the acoustic resistance and ω_m is the mass reactance.

$$r = \frac{32\eta t}{\sigma \rho_0 \, c d^2} k_r \;\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3a)$$

$$\omega_m = \frac{\omega t}{\sigma c} k_m \;\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3b)$$

Where k_r and k_m are given by

$$k_r = \left[1 + \frac{k^2}{32}\right]^{1/2} + \frac{\sqrt{2}}{32} k \frac{d}{t} \;\ldots\ldots\ldots\ldots\ldots (3c)$$

$$k_m = 1 + \left[3^2 + \frac{k^2}{2}\right]^{-1/2} + 0.85 \frac{d}{t} \;\ldots\ldots (3d)$$

The thin sheet of thickness t with micro perforations performs as an acoustic absorber in combination with an air cavity followed by a rigid backening support at the end. The normalized specific acoustic impedance of the air is cavity $Z_D = -j cot[\frac{\omega D}{c}]$. The effective relative acoustic impedance of the whole MPP system taking into account of the contribution from the relative acoustic reactance of the cavity mentioned above is given by

$$Z = z - j \cot\left[\frac{\omega D}{c}\right] = r + j\omega_m - j \cot\left[\frac{\omega D}{c}\right] \ldots\ldots\ldots (4)$$

Where D is the air cavity depth, ω the angular frequency and c is the velocity of sound. Incorporating all the above parameters the solution for normal incidence acoustic absorption coefficient α is obtained as given below.

$$\alpha = 1 - \left|\frac{1 - z}{1 + z}\right|^2$$

$$\alpha = \frac{4r}{(1+r^2) + \left(\omega_m - cot(\omega D/c)\right)^2} \;\ldots\ldots\ldots\ldots\ldots (5)$$

The frequency response of the acoustic absorption coefficient can be optimized in the frequency region of interest by optimizing the geometrical parameters of the MPP through the above mentioned theoretical approach. Here the influence of the perforation diameter, the air cavity depth, the thickness of the panel and the separation between the perforations in determining the acoustic absorption coefficient and its frequency response is investigated. The potential of the Micro Perforated Panel Absorber as a low frequency sound absorber with the optimized values of the above parameters is explored so that MPP can be utilized successfully replacing the Active Noise Controllers in the low frequency region.

Results and Discussions

The acoustic absorption coefficient is determined using the equations proposed by Maa's Theory (1-5) in the frequency range 0-4000Hz. The diameter of the perforation d is varied keeping the other geometrical parameters of the MPP at a particular fixed value and determined the acoustic absorption coefficient corresponding to this geometry. Here acoustic absorption is calculated in the frequency range from 0-4000Hz for five different values of d (d=0.2mm, 0.3mm, 0.4mm and 0.5mm). The thickness of the panel-t is kept at 0.2mm, the separation between the perforations-b is fixed at 2mm and the length of the cavity-D is kept at 6cm. The corresponding frequency response of the acoustic absorption coefficient is shown in figure.1. The maximum peak value for acoustic absorption coefficient is obtained for the perforation diameter of d=0.2mm. After that when the value of d is increased the absorption peak shifts to the higher frequency region with a lower value for the same. Above d=0.4mm the efficiency of the MPP is very low.

Figure.2 shows the frequency response of the peak value of the acoustic absorption coefficient for various values of the perforation diameter ranging from 0.2 to 0.6mm. From the

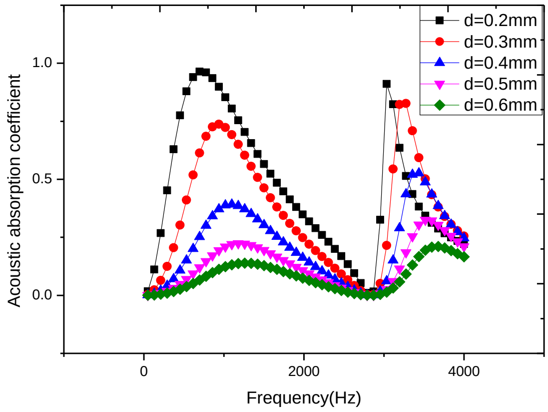

Figure 1. Variation of the frequency response of the acoustic absorption coefficient with hole diameter.

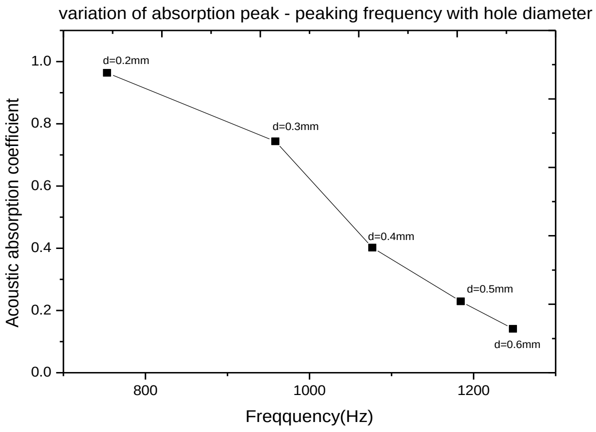

Figure 2. Variation of the peak acoustic absorption and the corresponding frequency with hole diameter.

figure it is clear that the peak value of the acoustic absorption coefficient increases when the perforation diameter decreases from 0.6mm to 0.2mm and the frequency at which the peak absorption observed is shifting to the lower frequency region. The efficiency of the MPP is low when the value of hole diameter is below 0.2mm. Figure.3 shows the poor frequency response of the acoustic absorption coefficient for very low value of the perforation diameter.

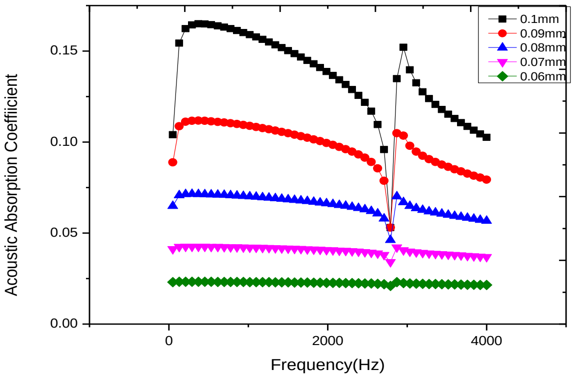

Figure 3. Variation of the frequency response of the acoustic absorption coefficient for very small values of hole diameter.

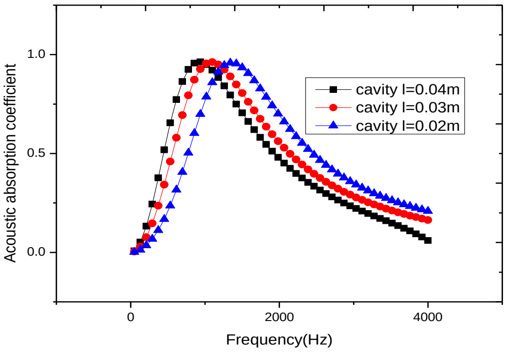

Figure 4. Variation of the frequency response of acoustic absorption coefficient for the air cavity length D=0.04m, 0.03m & 0.02m.

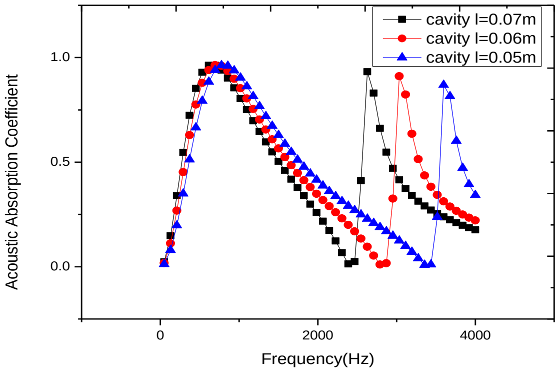

Figure 5. Variation of the frequency response of acoustic absorption coefficient for the air cavity length D=0.07m, 0.05m &0.06m.

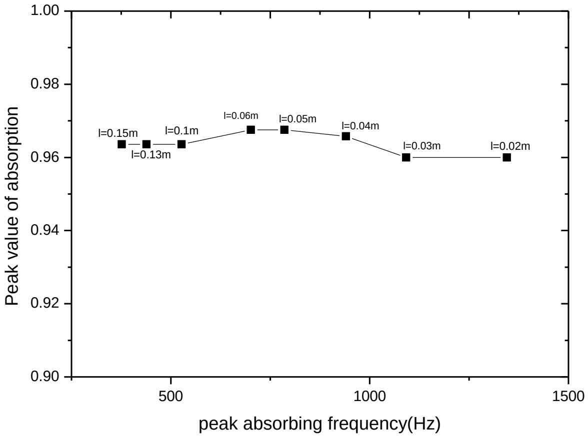

Figure 6. Variation of the peak value of the absorption coefficient and the peaking frequency for air different air cavity lengths.

Air cavity length also plays a crucial role in deciding the peak value of the acoustic absorption coefficient and the frequency at which it occurs. It is possible to shift the acoustic absorption peak to the lower frequency region by optimizing this value properly for the particular sets of values of perforation diameter, separation between the perforations and the panel thickness. The efficiency of the MPP decreases when the air cavity length is increased above a particular limit. Here the acoustic absorption coefficient is determined by varying the air cavity length in the frequency region 0-4000Hz. It is observed that when the air cavity length is very small a broad spectrum of absorption is obtained with absorption peak in the frequency region near to 1000Hz. Figure.4 shows the frequency response of the acoustic absorption coefficient corresponding to the small values of air cavity lengths 0.02m, 0.03m and 0.04m. Whereas when the air cavity length is above 0.04m multiple absorption peaks are obtained with absorption peaks in the lower and higher frequency regions as shown in Figure.5. The shift in the value of the peak acoustic absorption coefficient occurring in the lower frequency region is analyzed for different air cavity lengths ranging from 0.02m to 0.15m (Figure.6). The value of the acoustic absorption peak remained close to the high value of 0.96 for all the cases. When the air cavity length changes from 0.02m to 0.15m the corresponding peak value of acoustic absorption is obtained in the low frequency region below 500Hz. When the cavity length is 0.15m the frequency corresponding to the peak value of the acoustic absorption coefficient is close to 375Hz as seen in Figure.6. Thus very low frequency noise controlling below 500 Hz is possible with the help of this MPP by properly optimizing the air cavity length for the optimized values of panel thickness, perforation diameter and the separation between the perforations.

In order to understand the role of the separation between the perforations on the frequency response of the acoustic absorption coefficient the value of the same is varied from 1mm to 4.5mm. When the separation between the perforations is increased the peak value of sound absorption is increased.

The peak value of absorption reaches its maximum at 2mm and after that it decreases. The variation of the frequency response of acoustic absorption coefficient with hole-separation is shown in Figure.7 Absorption bands corresponding to lower and higher frequency regions are obtained. Here in the case of the absorption band corresponding to the lower frequency region the peaking frequency is shifted towards the lower frequency region below 1000Hz compared to that of the other band. The maximum value of absorption coefficient is 0.98 occurring at the frequency of 773Hz corresponding to the hole-separation of 2mm. After that the absorption peak decreases but the peaking frequency is again shifted towards the lower frequency side. When the hole separation is above 3mm the peak absorption is below 0.8 occurring in the lower frequency region below 500Hz. The variation of the value the peak absorption coefficient and the corresponding peaking frequency for various values of hole separation ranging from 1mm to 4.5mm is shown in Figure.8. Thus it is clear that the hole separation plays a crucial role in shifting the peak absorption towards the lower frequency region. In the case of the absorption band appearing in the higher frequency region a maximum value of acoustic absorption close to 1 is obtained at the frequency 3085Hz corresponding to the hole separation of 2mm. After that when the hole-separation is increased above the value of 2mm the peak value of absorption is sharply decreasing without appreciable shift in the peaking frequency. Thus the MPP becomes inefficient if the hole-separation is increased above a particular limit. The perforation diameter and the separation between them are crucial in deciding the performance of an MPP.

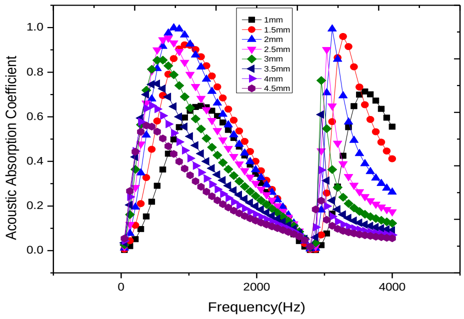

Figure 7. Variation of the frequency response of the acoustic absorption coefficient with hole separation.

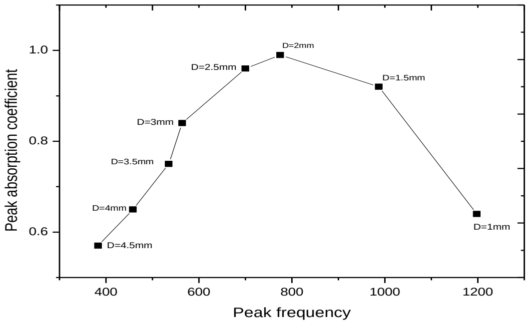

Figure 8. Variation of the peaking frequency and peak absorption with hole separation.

Maa's Model is investigated in order to understand the significant role of the thickness of the MPP in controlling the acoustic absorption coefficient. When the thickness of the MPP is increased from t=0.3mm to 10mm the performance of the MPP declines as the acoustic absorption coefficient is low in this region. The variation of the frequency response of the acoustic absorption coefficient with thickness of the MPP is shown in figure.9. Each of the frequency response curves has peaking region in lower frequency region and the higher one. Figure.10 shows the variation of the peak value of the absorption coefficient occurring in the lower frequency region and the corresponding peaking frequency for various values of the thickness of the MPP. When the thickness is increased the absorption peak suddenly decreases and shift towards the lower frequency side as shown in Figure.10.

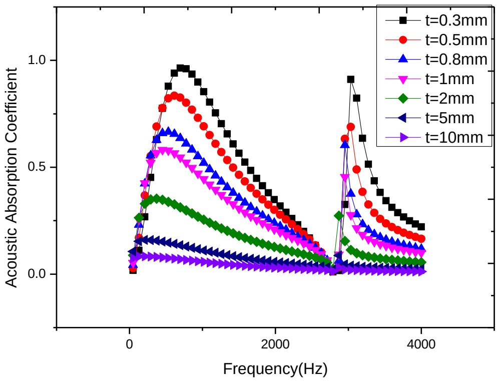

Figure 9. Variation of the frequency response of the acoustic absorption coefficient for various values of the thickness of the microperforated panel.

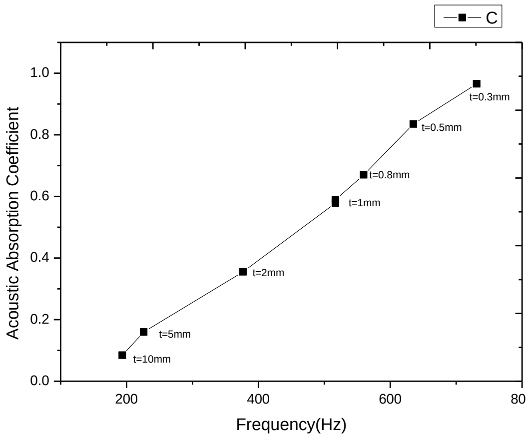

Figure 10. Variation of the peaking frequency and peak absorption for various values of the thickness of the microperforated panel.

For the case of absorption band occurring in the higher frequency region the peak value of absorption coefficient decreases with thickness of the MPP without having appreciable change in the value of the peaking frequency. Contrary to this the passive porous acoustic absorbers show an increase in acoustic absorption with increase in the thickness of the sample [29-30].This makes MPP the unique one in the category of passive acoustic absorbers because very thin MPP can be used to replace other thicker passive absorbers of the same efficiency. The thickness of the MPP can be reduced within the limit of the thickness to perforation diameter close to unity such that it performs with maximum efficiency for better noise reduction applications [14-16].

Conclusion

The potential of Micro Perforated Panel Absorber (MPP) as an efficient passive absorber compared to porous type passive absorbers and active noise controllers (ANC) is being explored in this particular study. The significance of the geometrical parameters namely the diameter of the perforations, air cavity length, and separation between the perforations in determining the frequency response of the acoustic absorption coefficient is established using the modeling studies based on Maa's theory . The potential of the optimized values of these geometrical parameters in enhancing the value of the acoustic absorption and shifting the frequency corresponding to the peak absorption according to the requirement makes the MPP the prominent noise reducer compared to the other active and passive noise absorbers. The relevance of MPP lies in using it as the noise reducer in the low frequency noise controlling applications where the ANC are proven as efficient ones. It is clear from this investigation that ANC can be replaced with this energy efficient MPP which performs without the use of any external energy sources.

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