Optimization of micro-perforated sound absorber using Particle Swarm Optimization (PSO)

W H Tan1,*, R Haslina1, E A Lim2 and H G Chuah3

1 School of Mechatronic Engineering, Universiti Malaysia Perlis (UniMAP), Pauh Putra Campus, 02600 Arau, Perlis, Malaysia.
2 Institute of Engineering Mathematics, Universiti Malaysia Perlis (UniMAP), Pauh Putra Campus, 02600 Arau, Perlis, Malaysia.
3 Department of Engineering, Computing and Build Environment, KDU Penang College Universiti, 32, Jalan Anson, George Town, 10400 George Town, Pulau Pinang, Malaysia.
*Corresponding Author: whtan@unimap.edu.my

Abstract. This study investigates the acoustic properties of micro-perforated panel (MPP) as an alternative to passive noise control. In order to obtain high sound absorption over broad frequency band, the analysis of sound absorption performance of MPP sound absorber should be conducted based on 3 major design parameters, such as perforation diameter, \(d\), air cavity depth, \(D\), and distance between perforations, \(b\), of MPP. Next, the optimization of sound absorption coefficient for MPP sound absorber need to be done by using the Particle Swarm Optimization (PSO) algorithm and the optimum parameters of a single layer MPP sound absorber should be obtained for achieving higher sound absorption which the sound absorption coefficient, \(\alpha > 0.5\) with a wider frequency band. The PSO is used in order to optimize the panel construction to provide maximum sound absorption coefficient in a determined wide band frequency range. Experiments are carried out at normal sound incidence and plane waves. A good agreement is achieved between the theory and the experiments.

1. Introduction

Micro-perforated panel (MPP) sound absorber is expected a significant sound absorption material [1–7]. The construction of MPP sound absorber is built from a perforated panel with an air space between the panel and rigid wall. The perforations on the panel are in sub-millimetre size in diameter. Figure 1 and 2 shows the construction of a MPP sound absorber. The construction of MPP sound absorber is considered relatively simple and uncomplicated to be built. The acoustic performance of a MPP sound absorber is determined by perforation diameter (\(d\)), thickness of panel (\(t\)), distance between perforations (\(b\)), and the air gap depth (\(D\)) as depicted in Figure 1 and 2.

In 1975, Maa [1] proposed the first idea of MPP sound absorber. Based on Maa’s theory, increase the density of perforation and decrease the perforation diameter able to achieve higher sound absorption for a wide frequency band [6]. In this study, optimization algorithm of particle swarm optimization (PSO) is applied to optimize the set of MPP sound absorber parameters for obtaining a better sound absorption coefficient.

![Figure 1. Layout of MPP sound absorber [5].](image1)

![Figure 2. Schematic diagram of MPP backed with air gap [6].](image2)
2. Acoustical theory for MPP sound absorber

Acoustic performance of a micro-perforated panel (MPP) sound absorber is completely determined by perforation diameter \(d\), thickness of panel \(t\), distance between perforations \(b\), and the air gap depth \(D\), which was first put forward by Maa [1].

Maa observed the discontinuity between the two cases. He developed an approximation solution for the perforation in sub-millimetre size, which made \(k\) lie between 1 and 10. This structure is named as MPP sound absorber.

\[
Z_1 = \frac{32\rho\mu t}{d^2} \sqrt{1 + \frac{k^2}{32} + j\omega pt} \left(1 + \frac{1}{\sqrt{32 + \frac{t}{d^2}}}\right)
\]  
(1)

where \(k = \sqrt{\frac{\omega}{c}} \cdot \left(\frac{d}{D}\right)\). According to Maa’s theory, acoustic resistance of perforations becomes significant as the perforations size are very small without additional porous material when comparing with the conventional formula of perforated panel sound absorbers. By comparing with exact values, model proposed by Maa agrees well with the error less than 6\% [1].

\[
Z_{MPP} = \frac{Z_1}{\sigma pc} = r + j\omega m
\]
(2)

With

\[
r = \frac{32\mu t}{c^2} \sqrt{1 + \frac{k^2}{32} + \sqrt{2}k \frac{d}{t}}
\]
(3)

\[
m = \frac{t}{c} \left(1 + \frac{1}{\sqrt{32 + k^2c^2} + 0.85 \frac{d}{t}}\right)
\]
(4)

where \(\sigma\) is the perforation ratio, \(\sigma = 78.5 \frac{d^2}{b^2}\). If perforation is square lattices arrangement, \(b\): distance between perforations, \(c\): sound velocity, \(r\): normalized specific acoustic resistance of MPP, and \(m\): normalized acoustic mass of MPP. The normal specific acoustic impedance of the air gap behind MPP, normalized by \(\rho c\), becomes

\[
Z_D = -j \cot \left(\frac{\omega D}{c}\right)
\]
(5)

Normalized specific acoustic impedance of a MPP sound absorber can be determined by

\[
z = Z_{MPP} + Z_D
\]
(6)

For normal incidence, the sound absorption coefficient of MPP sound absorber, \(\alpha\) is obtained by

\[
\alpha = 1 - \left[\frac{x-1}{x+1}\right]^2
\]
(7)

3. Experiment Setup

In this study, two-microphone method was used for the micro-perforated panel (MPP) sound absorber sound absorption coefficient measurement. This measurement setup consists of four main equipment that are needed while conducting the experiment. There are impedance tube, microphones, data acquisition (DAQ) device and a computer. The MPP is placed at the end of tube and sample insertion is adjusted to form an air gap. The opposite end of the tube is connected with a loudspeaker to generate the sound source signal. On the tube, a pair of microphones is mounted with the inner wall. The mounted microphones are used to measure the incident and reflected sound signal generated by the loudspeaker in the tube. Figure 3 shows the two-microphone impedance tube measurement setup used in this study.

![Figure 3. Two-microphone impedance tube measurement setup.](image)
4. Analysis of Experimental Measurement

In this experiment, four samples of micro-perforated panel (MPP) sound absorber were prepared for sound absorption coefficient measurement. Perforation ratio, \( \sigma \) of the MPP sound absorber was calculated by the formula \( \sigma = 78.5 \, d^2 / b^2 \). The structural parameters of MPP are listed in Table 1.

| Specimen | Specimen diameter, \( D \) (mm) | Specimen thickness, \( t \) (mm) | Holes spacing, \( b \) (mm) | Holes diameter, \( d \) (mm) | Perforation ratio, \( \sigma \) (%) |
|----------|-------------------------------|--------------------------------|-----------------|-----------------|-------------------|
| A        | 108                           | 1                              | 3               | 0.5             | 2.18              |
| B        | 108                           | 1                              | 7               | 0.5             | 0.40              |
| C        | 108                           | 1                              | 5               | 0.9             | 2.54              |
| D        | 108                           | 1                              | 5               | 0.3             | 0.28              |

4.1 Effect of air cavity, \( D \)

![Figure 4](image1.png)  
**Figure 4.** Sound absorption coefficient of Specimen A with multiple size air cavity

![Figure 5](image2.png)  
**Figure 5.** Sound absorption coefficient of Specimen B with multiple size air cavity.

![Figure 6](image3.png)  
**Figure 6.** Sound absorption coefficient of Specimen C with multiple size air cavity

![Figure 7](image4.png)  
**Figure 7.** Sound absorption coefficient of Specimen D with multiple size air cavity

Figure 4 to 7 show the sound absorption coefficient (SAC) curves of four MPPs with different depth of air cavity (10mm, 20mm and 30mm). It is showed that all SAC figures have a similar variation regardless of perforation ratio.

It is observed that the width of maximum SAC increases when the depth of air cavity increasing. At the same time, the maximum SAC is found shifts to lower frequency range. This observation can be explained due to both open ends of hole acted as an acoustic mass, and the fluid in air cavity is acted as an acoustic spring. A spring mass resonance is created for this manner. SAC Peak occurs when the stiffness of air cavity cancels the mass of holes. However, the increasing of air cavity depth will reduce the stiffness of air cavity and SAC peak will be moved towards the lower frequencies, and the bandwidth of SAC peak becomes wider. In addition, the results show a smaller perforation ratio (Sample D, \( \sigma = 0.28\% \), \( b = 5\)mm), the maximum SAC value increases simultaneously...
with the increasing of air cavity depth. On the other hand, maximum SAC decreases progressively as air cavity depth increases for higher perforation ratio (Sample A and Sample C). It can be noticed that the SAC peak of Sample B ($\sigma = 0.4\%$, $b = 7\text{mm}$) is the highest and remains constant for the changing of air cavity depth.

In spite of this, for a higher perforation ratio (Sample C, $\sigma = 2.54\%$, $b = 5\text{mm}$), the sound absorption capabilities are not satisfactory. Thus, the influencing parameters of thickness, perforation ratio and air cavity depth of MPP sound absorber should be combined in order to design a MPP sound absorber which able to obtain desired sound absorption capability. It is also alternate to attach porous material layer to wider the frequency bandwidth of SAC.

4.2 Effect of perforation ratio, $\sigma$.

![Figure 8. Sound absorption coefficient of MPP sound absorbers with air cavity, $D = 10\text{mm}$.](image1)

![Figure 9. Sound absorption coefficient of MPP sound absorbers with air cavity, $D = 20\text{mm}$.](image2)

![Figure 10. Sound absorption coefficient of MPP sound absorbers with air cavity, $D = 30\text{mm}$.](image3)

The effect of perforation ratio on sound absorption coefficient (SAC) of the four MPPs, when backed by an air cavity is shown in Figure 8 to10. In this study, the air cavity depths are 10mm, 20mm and 30mm.

Based on Figure 8 to 10, it is observed that increasing the perforation ratio of a MPP sound absorber yields a higher acoustic resonance frequency for the SAC peak. This observation is caused by increasing of perforation ratio results in the decrease of total acoustic mass for all of the perforations. Therefore, it increases the resonant frequency at which the SAC peak occurs. The outcomes also demonstrated that the SAC peak and the corresponding frequencies are similar for the case of an MPP sound absorber backed by an air cavity.

For the lower frequencies, MPP sound absorber with smaller perforation ratio will contribute a better SAC, whereas higher perforation ratio delivers a better SAC for the higher frequencies. It is necessary to adjust the perforation ratio of MPP sound absorber or combine with porous material layer to obtain the desired SAC peak frequency and a wider frequency range.

4.3 Sound absorption of micro-perforated panel sound absorber by Particle Swarm Optimization (PSO).
In MATLAB particle swarm optimization (PSO) program, the range value of hole spacing, \( b \), hole diameter, \( d \) and air cavity, \( D \) for Specimen A, Specimen B, Specimen C and Specimen D has been set. So, the exact best value which is the widest width of the graph for hole spacing, \( b \), hole diameter, \( d \) and air cavity, \( D \) can be generated based on the widest frequency bandwidth of the graph of each specimen. Based on the result of the MATLAB for the PSO, the value for hole spacing, \( b \), hole diameter, \( d \), air cavity, \( D \) and the best value for the widest frequency bandwidth result from the graph are shown in Table 2.

| Result                  | Length         |
|-------------------------|----------------|
| Hole spacing, \( b \)   | 6.6356 mm      |
| Hole diameter, \( d \)  | 0.8755 mm      |
| Air cavity, \( D \)     | 24.4078 mm     |
| Widest frequency bandwidth | 1999.2011 Hz   |

5. Conclusion
In this study, it is found that the acoustic resonant frequency depends on the depth of air cavity behind the micro-perforated panel (MPP). The acoustic resonant frequency of the corresponding value of sound absorption was reduced with increasing the depth of the air cavity behind the MPP inside the impedance tube. For the perforation ratio at lower frequencies, a smaller perforation ratio of the MPP layer gives a better sound absorption coefficient (SAC) whereas a higher perforation ratio gives a better SAC at higher frequencies. The effect of SAC for different holes diameter and constant holes spacing shows that reducing the size of the hole diameter can increase the SAC but narrow the frequency band in condition of uniform holes spacing and distance of the air cavity. Lastly, the optimization of SAC from the MPP sound absorber that is analysed by using particle swarm optimization (PSO) gives the result of the value for hole spacing, \( b \), hole diameter, \( d \) and air cavity, \( D \) and the best value for the widest frequency bandwidth. Therefore, the present work analyzed the absorption properties of MPP sound absorber by using PSO, in order to obtain high sound absorption over a broad frequency band. The attention was focused on the influence of the hole spacing, \( b \), hole diameter, \( d \) and air cavity, \( D \), since varying this parameter represents an easy way to modify the sound absorption properties of the panel.

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