The Evaluation of Deviation in Sound Absorption Coefficient for Micro – perforated Panel

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Abstract. In this paper, the sound absorption coefficient for micro-perforated panel (MPP) is conducted to determine the acoustic properties of MPP. Two different kind of MPP with the same parameter is used. One is Nylon material and another one is Brass material. Both are fabricated by using 3D Printing technology and Laser Cut process respectively. The sound absorption coefficient of both 3D Printed Nylon MPP and Laser Cut Brass MPP is measured with two-microphone method by using Impedance Tube. The calculated sound absorption coefficient is done by using MATLAB software based on the Classic Maa model. The measured sound absorption coefficient is compared with the calculated result for both MPP. The comparison results show some deviation, like measured results produce a big dip, absorption peak frequency shifted towards higher frequency and wider absorption bandwidth observed when compared to the calculated result. In conclusion, it is found out hole imperfection effect is one of the reasons to the deviation produce between the compared result.

1. Introduction
Micro-perforated panel is first introduced by Maa in year 1975. According to Maa, designer can design the MPP according to their target frequency by optimizing the parameters, such as perforation diameter (d), plate thickness (t), perforation ratio (σ) as well as the air cavity depth (D) [1]. Due to that reason, lots of research has been done from researchers over years studying on the MPP with different design used to suit their objectives, for an example cylindrical shape micro-perforated silencer [2].

In year 2000, Zhang et al., [3] have done a study of micro-perforated panel with different hole diameter (range from 0.17mm to 0.30mm) that aim to produce higher sound absorption. In the study, the authors had derived the equation for plate with two different hole diameter. However, instead of using the derivation to calculate the sound absorption coefficient, the authors calculate two different sound absorption coefficients of MPP with single diameter size (minimum and maximum respectively). Both calculated results are compared with the measured result of MPP with different hole diameter (the diameter size is between the minimum and maximum range). The comparison shows the measurement results gives much wider absorption band frequency compared to the both calculated results even though the absorption peak is slightly lower. In higher frequency range, the measured result looks more closer to calculated result for MPP (with maximum diameter size), but in overall there are some unexplained deviation can be observed along the frequency.
Maury et al., mentioned that it is important to consider the vibration effect of the MPP plate in calculating the sound absorption coefficient of MPP, especially for thin MPP [4]. In the study, two different sound absorption coefficients are calculated. One is taken from Maa that assumed the MPP is rigid and another one is calculated by using the author’s derivation for elastic MPP. The calculated results are compared to the experimental result. The comparison between the experimental and the calculated elastic MPP result in overall showed a better agreement compared to the calculated result by Maa model. The experimental result has extra peaks in lower and higher frequency when compared to the calculated results. The authors suggested, the extra peaks are due to the vibroacoustic effect. Thus, the vibration effect needs to be considered when determining the sound absorption coefficient of MPP.

Based on the literature review done, some of the deviations are well explained and some are not properly studied. One of the examples is found in Maury et al. study. The vibration is reported, the vibration effect is neglected in Classic Maa theory [5] due to assumption of rigid MPP [6]. In this study, based on the comparison result between the experimental and calculated sound absorption coefficient result for 3D Printed Nylon MPP and Lased Cut Brass MPP. An investigation will be done to determine the factor that cause the deviation between the comparison result besides vibration effect.

2. Theoretical Method

Micro-perforated panel is a plate that consist of small holes, in sub-millimeter distributed evenly on the plate. MPP works when it is placed in front of a rigid surface with air cavity in between, as shown in figure 1. MPP also can be represent in electrical equivalent circuit, as per shown in figure 1 (b). Sound wave, $P_1$ that impinging on the micro-perforated panel is represented by $2P_1$, the source of sound pressure. While $\rho c$ act as the internal air, the mass-resistance element (represent by R and M) of resonance system of the panel is in series with the the cavity reactance of the air cavity depth, $Z(D)$ [7]. The holes act as acoustic mass and the air cavity acts as acoustic spring, which creates a mass-spring resonance relation. Peak of sound absorption occurs when the frequency of sound same with the resonance frequency, causing the stiffness of the air cavity to eliminates the acoustic mass of the holes [8]. The sound absorption by micro-perforate panel always been related to Helmholtz resonator, as the absorption occurs due to the viscous and thermal boundary layer in resonator’s neck wall and cavity respectively [9].

![Figure 1. (a) Construction of MPP [10] and (b) MPP electrical equivalent circuit [7]](image)
Firstly, Maa [11] has introduce the specific acoustic impedance equation,

\[
Z_1 = j \omega rt \left[ 1 - \frac{2}{k \sqrt{-j}} \frac{J_1(k \sqrt{-j})}{J_0(k \sqrt{-j})} \right]^{-1}
\]  

(1)

The specific acoustic impedance in equation (1) can be represented by the approximate formula below,

\[
Z_1 = \frac{32 \eta t}{d^2} \left( 1 + \frac{k^2}{32} \right)^{1/2} + j \omega rt \left( 1 + \left( 3^2 + \frac{k^2}{2} \right)^{-1/2} \right)
\]  

(2)

The specific acoustic impedance is divided by characteristic impedance of air to obtain the relative acoustic impedance,

\[
z = \frac{Z_1}{\sigma \rho c} = r + j \omega m
\]  

(3)

The relative acoustic impedance is divided into real and imaginary part known as relative acoustic resistance, \( r \) and mass reactance, \( m \) respectively.

\[
r = \frac{32 \eta t}{\sigma \rho c d^2} k_r, \quad k_r = \left[ 1 + \frac{k^2}{32} \right] + \frac{\sqrt{2}}{32} k \frac{d}{t} \quad (4a, 4b)
\]

\[
\omega m = \frac{\omega r}{\sigma c} k_m, \quad k_m = 1 + \left[ 1 + \frac{k^2}{2} \right]^{-1/2} + 0.85 \frac{d}{t} \quad (5a, 5b)
\]

Where, \( k \) is the perforate constant, \( k = d \frac{\omega r}{\sigma c} \). By using equation (4) and (5), we can calculate the normal incidence sound absorption coefficient,

\[
a = \frac{4r}{(1 + r)^2 + (\omega m - \cot \left( \frac{\omega D}{c} \right))^2}
\]  

(6)

Equation (6) will be used later to predict the sound absorption coefficient of 3D Printed Nylon MPP and Lased Cut Brass MPP, then will be compared with the experimental result from Impedance Tube measurement in Result and Discussion section.

3. Methodology

3.1 Samples preparation
Figure 2 shows two MPP samples with same parameter fabricated. One is Nylon material produced by using 3D printing method, another one is Brass material fabricated by using laser cut. Parameter on both MPP are 0.8mm hole diameter with 0.8mm plate thickness, 0.6% perforation ratio and air cavity depth of 4.0mm.

![Figure 2. 3D Printed Nylon MPP (left) and Laser Cut Brass MPP (right)](image)

After the samples are fabricated, the sound absorption coefficient is measured by using Impedance Tube according to ISO 10534-2 with LMS Test.Lab software. It is a two-microphone method impedance tube with 34.8mm diameter, able to measure up to 5400Hz frequency. Total of three measurements are done for each MPP samples and the average result is calculated.

### 3.2 Hole Circularity measurement

The roundness of the hole diameter for each sample is measured by using Optical 3D Surface Metrology Alicona InfiniteFocus. From the measured hole diameter size, the hole circularity is analyzed for both MPP samples. Circularity by using equation (7) is calculated to determine how close the hole to a true circle [12, 13]. While error of circularity by using equation (8) is calculated to analyze the hole quality produce by each MPP samples [14].

\[
\text{Circularity, } \zeta = \frac{D_{\text{min}}}{D_{\text{max}}} \\
\text{Error of circularity} = R_{\text{max}} - R_{\text{min}}
\]

### 4. Result and Discussion

#### 4.1 Sound Absorption Coefficient result

Figure 3 shows the comparison in between the measured sound absorption coefficient by Impedance Tube and calculated sound absorption coefficient by Classic Maa model, by using equation (6) for both 3D Printed Nylon MPP and Laser Cut Brass MPP.
Based on observations in figure 3, there are peaks at frequency below 1000Hz. The similar observation is obtained by Chin et al. [8]. The authors explained that it is due to the fundamental modes of the MPP sample and the air resonance occurred inside the impedance tube. For the measured result in figure 3 (a), there is a big dip found at frequency 1518Hz caused by vibrational mode and phase difference between particle and plate velocity [15]. The peak frequency also shifted towards higher frequency for measured result. According to Tan and Ripin [16], the shifted peak is due to the vibration mode shape of the MPP. The similar peak shifts in figure 3 (b) is suspected due to the same reason. Similar observation found in both figure 3 (a) and 3 (b), which is a reduction of sound absorption peak for measured result when compared to the calculated results. The reduction of sound absorption peak is claimed due to the low acoustic resistance of MPP caused by the panel velocity [4].

Based on explanation above, the vibration mode of MPP can cause deviation between measured and calculated results like a big dip and shifting of absorption peak frequency towards higher frequency. However, there is another similar deviation observed between comparison results in figure 3. Where, both measured results in figure 3 (a) and 3 (b) produce wider sound absorption bandwidth compared to the calculated results by using Classic Maa equation. In the vibration mode of MPP effect, this kind of deviation is not explained. While, in year 2016, Ning et al., [17] reported that a similar result was produced by Wu and Zhao previously. Where the bandwidth of sound absorption coefficient is improved. The authors do a study on the performance of sound absorption for MPP with triangle cross-section perforation shape and burr. The wideband sound absorption coefficient is believed due to the presence of burr that changed the overall hole shape and geometry. However, in Classic Maa theory, the burr effect is never included as straight, constant diameter cylindrical holes are assumed [18].

Figure 3. Comparison between measured and calculated (Classic Maa) sound absorption coefficient for (a) 3D Printed Nylon MPP and (b) Laser Cut Brass MPP

4.2 Hole Circularity analysis
Continue from the discussion in 4.1, the deviation resulted from wider absorption bandwidth observed in the comparison results, figure 3 is suspected due to the hole imperfection that are not captured in the Classic Maa theory. Thus, the condition of all hole in both MPP has been observed under InfiniteFocus Alicona Microscope.
Figure 4. Scanned hole result for (a) 3D Printed Nylon MPP and (b) Laser Cut Brass MPP from InfiniteFocus Alicona Microscope

Figure 4 shows the hole from one of the scanned MPP hole under InfiniteFocus Alicona Microscope. From observation, it is clear that both holes are not perfectly circular as per used in theoretical calculation (Classic Maa theory). Mostly the effect of burr that results in non-circular or irregular shape of holes is due to the manufacturing technique [17]. When comparing both results in figure 4 (a) and 4 (b), the hole condition produced by 3D printing technology looks more critical compared to the hole produced by Laser Cut process. Hole of Laser Cut Brass MPP looks more closer to circular shape compared to 3D Printed Nylon MPP, more detail calculations will be done to check on the condition of the hole.

In addition, the measured hole diameter size in 3D Printed Nylon MPP by using InfiniteFocus Alicona Microscope are smaller with range between 0.35826mm to 0.57426mm compared to hole diameter size in Laser Cut Brass MPP with range of 0.90782mm to 1.01430mm. The result of hole diameter size in 3D Printed Nylon MPP can be related to the wide absorption bandwidth observed in figure 3 (a). Same finding is reported by Qian et al., where the reduction in perforation diameter results in good wideband sound absorber [19].

Figure 5. Circularity of Hole result

A detail calculation to explain the condition of holes produce in both MPP is represented by circularity and error of circularity results. By using equation (7), the circularity of each hole in both MPP samples is calculated. There are total of nine holes in each MPP samples. As per judged from the hole circularity results in figure 5, both results are not true circle and not consistent. However, the holes in
Laser Cut Brass MPP are closer to value 1, which means the holes are closer to perfect circular which is equal to 1 [20]. For Laser Cut Brass MPP, each hole circularity is mostly consistence between circularity of 0.9 and 1.0 compared to the holes in 3D Printed Nylon MPP, the circularity results vary between 0.6 to 0.9.

![Figure 6. Error of circularity result](image)

From figure 6, it can be observed that the 3D Printed Nylon MPP holes has higher error of circularity compared to the Laser Cut Brass MPP holes. Laser Cut Brass MPP with error of circularity as low as 0.01mm to as high as 0.04mm compared to 3D Printed Nylon MPP with lowest error of circularity at 0.04mm and the highest is recorded a 0.10mm. This result shows that the hole quality produce in Laser Cut Brass MPP is much better compared to the 3D Printed Nylon MPP. In overall, both results in figure 5 and 6 show that condition of hole in 3D Printed Nylon MPP is more critical compared to the hole in Laser Cut Brass MPP as the circularity and error of circularity shown for Laser Cut Brass MPP is closer to 1 and lesser error produce respectively.

All the results obtained from figure 4, 5, and 6 can be related back to the comparison result in figure 3. Imperfect, irregular hole shape and inconsistence hole size produce in both 3D Printed Nylon MPP and Laser Cut Brass MPP results in wider bandwidth frequency observed in figures 3 (a) and 3 (b). The same finding also reported by Ning et al., [17] where it mentions that irregular cross-sectional perforation (like triangle and square shape) gives wider absorption bandwidth compared to regular cross-sectional perforation (like circle shape). The reason is because irregular cross-sectional perforation gives large specific acoustic impedance ratio compared to regular cross-sectional perforation.

5. Conclusion
In this study, the comparison results between measured and calculated sound absorption coefficient for 3D Printed Nylon MPP and Laser Cut Brass MPP is done. Both comparisons show a deviation, which measured results gives wider absorption bandwidth compared to the calculated result by using Classic Maa equation. This is because the scanned hole, circularity and error of circularity result shows that the diameter size of fabricated hole is in range. Where, 3D Printed Nylon MPP records hole diameter size in range of 0.35826mm to 0.57426mm, circularity value varies between 0.6 to 0.9 and error of circularity from 0.04mm to 0.10mm. While, Laser Cut Brass MPP have hole diameter size in range of 0.90782mm to 1.01430mm, circularity value between 0.9 and 1.0 and error of circularity from 0.01mm to 0.04mm. In conclusion, the deviation is found due to the irregular shape and inconsistence size of the perforation hole in the MPP. The reason causing the sound absorption coefficient cannot be calculated correctly as it is not obeyed with the Classic Maa theory, where the hole is assumed to be uniform and perfect.
circular. Therefore, some correction factors need to be determined for irregular shape and inconsistent perforation hole.

6. References
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