Parameter Optimization and Finite Element Simulation of the Inclined Microperforated Panel Absorber

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Abstract. Microperforated panel absorber was widely used in the fields of noise reduction and sound absorption, because it had the extraordinary advantages. As deformation of the standard microperforated panel, inclined microperforated panel absorber was proposed and investigated in this research. The theoretical sound absorption model of the inclined microperforated panel absorber was constructed on the basement of the Maa's theory according to the electro-acoustic theory. Structural parameters of the inclined microperforated panel absorber were optimized on the basement of the constructed theoretical sound absorption model through the cuckoo search algorithm. The finite element simulation model of the inclined microperforated panel absorber with optimal parameters was built in the virtual acoustic laboratory, which could be considered as an effective method to measure and check the sound absorption performance of the inclined microperforated panel absorber. Through the theoretical modeling, parameter optimization, and finite element simulation, sound absorption performance of the inclined microperforated panel absorber was improved, which could be propitious to promote its practical applications in the fields of noise reduction and sound absorption.

1. Introduction
Microperforated panel absorber was widely used in the fields of noise reduction and sound absorption, because it had the extraordinary advantages, such as low fabrication cost, wide sound absorption width, and high sound absorption efficiency [1-4]. As the deformation of the standard microperforated panel, inclined microperforated panel absorber was proposed and investigated in this research, which aimed to improve sound absorption performance of the inclined microperforated panel absorber and promote its practical application in the prevention and control of noise pollution [5, 6].

Firstly, the theoretical sound absorption model of the inclined microperforated panel absorber was constructed on the basement of the Maa's theory [7, 8] according to the electro-acoustic theory [9, 10]. Secondly, structural parameters of the inclined microperforated panel absorber were optimized on the basement of the constructed theoretical sound absorption model through the cuckoo search algorithm [11, 12]. Finally, the finite element simulation of the inclined microperforated panel absorber with the optimal parameters was conducted in the virtual acoustic laboratory, which could be considered as an effective method to measure and check sound absorption performance of the inclined microperforated panel absorber [13, 14]. Through this theoretical modeling, parameter optimization, and finite element simulation, sound absorption performance of the inclined microperforated panel absorber was studied, which aimed to improve its sound absorption property and promote its application.
2. Theoretical modeling

Schematic diagram of the inclined microperforated panel absorber used in this study and its equivalent microperforated panel absorber is shown in the Figure 1. Cavity length of the inclined microperforated panel absorber was in a linear relationship. Therefore, in the right equivalent microperforated panel absorber in the Figure 1, change of the cavity length for each sound absorption element was linear, and the equivalent microperforated panel absorber could be considered as the parallel connection of each single sound absorption element. Through calculating the acoustic impedance of each single sound absorption element based on the Maa’s theory, theoretical sound absorption coefficient of the inclined microperforated panel absorber could be achieved according to the electro-acoustic theory.

![Figure 1. Schematic diagram of the inclined microperforated panel absorber and its equivalent.](image)

Acoustic impedance of the inclined microperforated panel absorber could be obtained by the Eq. (1). Here, $n$ is number of the perforated holes; $x$ is tolerance of the neighboring perforated holes, which can be obtained by the Eq. (2); $D_1$ and $D_n$ were the minimum value and maximum value of the cavity length respectively; $r$ is the acoustic impedance, which could be obtained through the Eq. (3); $m$ is the acoustic reactance, which could be achieved by the Eq. (4); $\omega$ is the acoustic angular frequency, which could be calculated by the Eq. (5), and here $f$ is the sound frequency in Hz.

\[
Z = \left( \frac{1}{r + j\omega m \cot \omega D_1/c} + \frac{1}{r + j\omega m \cot \omega (D_1+x)/c} + \ldots \right)^{-1}
\]

(1)

\[
x = \frac{D_n-D_1}{n}
\]

(2)

\[
r = \frac{0.147 t}{d^2} k_r
\]

(3)

\[
m = 1.847 \frac{fc}{p} k_m
\]

(4)

\[
\omega = 2\pi f
\]

(5)

In the Eqs. (3) and (4), $t$ is thickness of the panel; $d$ is diameter of the microperforated holes; $p$ is the perforation rate; $k_r$ is the acoustic impedance ratio; $k_m$ is the acoustic reactance ratio.

3. Parameter optimization

When thickness of the panel, diameter of the microperforated holes, distance between the neighboring holes, maximum cavity length was 0.5mm, 0.5mm, 3mm, and 150mm respectively, inclination angle
of the inclined microperforated panel absorber was optimized through the cuckoo search algorithm, as shown in Figure 2. Meanwhile, the investigated frequency ranges were 100-500Hz, 100-600Hz, 100-700Hz, 100-800Hz, 100-900Hz, 100-1000Hz, 100-1100Hz, 100-1200Hz, 100-1300Hz, and 100-1500Hz, respectively. Through the optimization of the inclination angle, the optimal inclined microperforated panel absorber was obtained, which aimed to improve its sound absorption property.

Figure 2. Optimization of the inclined microperforated panel absorber by the cuckoo search algorithm.

The optimal inclination angles obtained by the cuckoo search algorithm were summarized in the Table 1, and their values were 0, 0, 1.69°, 18.84°, 30.01°, 37.22°, 42.04°, 45.3°, 47.54°, 48.96°, 49.94° corresponding to the investigated objective frequency ranges of 100-500Hz, 100-600Hz, 100-700Hz, 100-800Hz, 100-900Hz, 100-1000Hz, 100-1100Hz, 100-1200Hz, 100-1300Hz, 100-1400Hz, and 100-1500Hz, respectively. Meanwhile, the average sound absorption coefficients of the optimal inclined microperforated panel absorber were 0.5876, 0.6193, 0.6219, 0.6125, 0.6004, 0.5859, 0.5695, 0.5522, 0.5367, 0.5268, and 0.5213, which improved 0.00%, 0.00%, 0.03%, 1.39%, 4.76%, 10.05%, 17.21%, 23.12%, 17.62%, 7.49%, and 1.64% relative to the original standard microperforated panel absorber. It was interesting to note that increase of the improvement rate was not kept linear with the increase of the objective frequency range, and it could reach its maximum 23.12% when the objective frequency range was 100-1200Hz, which was favorable to provide the effective guidance for application of the inclined microperforated panel absorber.

Table 1. Comparisons of theoretical sound absorption performance of the inclined microperforated panel absorber with that of the referenced standard microperforated panel absorber.

| Frequency range | Optimal inclined angle | Average sound absorption coefficient |
|-----------------|------------------------|-------------------------------------|
|                 | The inclined one        | The standard one                     |
| 100-500         | 0                      | 0.5876                              | 0.5876                          |
| 100-600         | 0                      | 0.6193                              | 0.6193                          |
| 100-700         | 1.69                   | 0.6219                              | 0.6217                          |
| 100-800         | 18.84                  | 0.6125                              | 0.6041                          |
| 100-900         | 30.01                  | 0.6004                              | 0.5731                          |
Comparisons of theoretical sound absorption coefficient of the optimized inclined microperforated panel absorber with that of the original standard microperforated panel absorber were shown in Figure 3. It could be found when the objective frequency range was 100-500Hz, 100-600Hz, and 100-700Hz, sound absorption coefficients of the optimized inclined microperforated panel absorber had almost no difference with those of original standard microperforated panel absorber, which were consistent with the results in the Table 1. When the objective frequency range was 100-1200Hz, distance between the optimized inclined microperforated panel absorber and original microperforated panel absorber gained its maximum, which was consistent with the data in the Table 1.

| Frequency Range | Absorption Coefficient | Theoretical | Simulation |
|-----------------|------------------------|-------------|------------|
| 100-1000        | 37.22                  | 0.5859      | 0.5324     |
| 100-1100        | 42.04                  | 0.5695      | 0.4859     |
| 100-1200        | 45.3                   | 0.5522      | 0.4485     |
| 100-1300        | 47.54                  | 0.5367      | 0.4563     |
| 100-1400        | 48.96                  | 0.5268      | 0.4901     |
| 100-1500        | 49.94                  | 0.5213      | 0.5129     |

Figure 3. Comparisons of sound absorption coefficient of the optimized inclined microperforated panel absorber with that of the original standard microperforated panel absorber.

4. Finite element simulation

Finite element simulation model of the investigated microperforated panel absorber was constructed, as shown in the Figure 4. Comparisons of theoretical sound absorption coefficient of the investigated microperforated panel absorber with the simulation results were summarized in Figure 5, which could prove effectiveness and accuracy of the parameter optimization results.
Figure 4. Finite element simulation model of the investigated microperforated panel absorber.

Figure 5. Comparisons of theoretical sound absorption coefficient of the investigated microperforated panel absorber with the simulation results for different objective frequency range.

5. Conclusions
Parameters optimization and finite element simulation of the inclined microperforated panel absorber was conducted in this study. Through the theoretical modeling, parameter optimization, and the finite
element simulation, sound absorption performance of the inclined microperforated panel absorber was improved, which was propitious to promote its practical application in the fields of noise reduction and sound absorption.

Acknowledgments
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