Flexible micro-perforated panels prepared by CNC machining

Dongyue Xie¹, Xiaoning Tang², Ming Hu¹, Deyi Kong³*, Yujie Qian⁴

¹ Hefei University of Technology, Hefei 230601, China
² State Key Laboratory Cultivation Base for New Textile Materials and Advanced Processing Technology, School of Textile Science and Engineering, Wuhan Textile University, Wuhan 430200, China
³ State Key Laboratory of Transducer Technology, Key Laboratory of Biomimetic Sensing and Advanced Robot Technology of Anhui Province, Institute of Intelligent Machines, Hefei Institutes of Physical Science, Chinese Academy of Sciences, Hefei 230031, China
⁴ IOT Engineering College, Hohai University, Changzhou 213022, China

*Corresponding author: kongdy@iim.ac.cn

Abstract: With the advantages of light weight, thin thickness and environment friendly, the micro-perforated panel (MPP) has been widely studied for noise reduction. Maa’s model pointed out that the MPP could obtain higher sound absorption over broader frequency band when the perforations were reduced to less than 100 μm. However, it is challenging to manufacture MPPs with the aperture of approximate 100 μm, thus its potential application has been restricted. In this study, we used a computer numerical control (CNC) milling machine to process MPP. Four different kinds of raw materials including paperboard, polyethylene terephthalate (PET), polyvinyl chloride (PVC), and polycarbonate (PC) were taken to prepare micro-perforated panels (MPPs). It has been indicated that MPPs with good sound absorption properties were successfully prepared by this facile method.

1. Introduction

Micro-perforated panel (MPP) was firstly developed for noise control in severe environment without porous materials based on the theory of Rayleigh and Crandall [1, 2]. Different from ordinary perforated panels with perforations in millimeters or centimeters, the perforations in the MPP were reduced to sub-millimeter size. Currently, various theoretical principles and algorithms have been investigated to characterize the acoustic properties. Maa established the formula for calculating the acoustic impedance of rigid MPP [3]. Subsequently, various calculation method have been developed to optimize the acoustic properties [4-6].

As reported by Maa [7, 8], it is effective to increase absorption bandwidth of single-layer MPP by reducing the diameter of the pore and increasing perforation ratio properly. In addition, single-layer MPP also has unique advantages in the noise control applications of extreme environment. However, it is difficult to machine holes with a sub-millimeter diameter. Especially, the preparation of flexible MPPs is an urgent problem to be solved. Generally, the preparation method of the MPP is either low in processing efficiency [7] or high in processing cost [9]. Therefore, it is necessary to develop a method which can fabricate flexible the MPP with the aperture diameter of approximate 100 μm.
In this work, we used a CNC milling machine to realize the processing of MPP. The structural characteristics of the fabricated perforation through different approaches were presented and discussed. The absorption coefficients of prepared flexible MPPs were compared with Maa’s model. It is hoped that this work could provide favorable approach for the future development of MPP absorber.

2. Theoretical basis and Measurements

2.1. Maa’s Model
A schematic diagram and equivalent circuit of the MPP are shown in Figure 1. Its structural parameters include the diameter \( d \) of the hole, the distance \( b \) between the centers of the two holes, the thickness \( t \), and the gap between the panel and the rigid wall. According to the Maa’s model, the acoustic impedance of MPP can be expressed as:

\[
Z = R + j \omega M
\]

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

2.2. Sound absorption measurements
The absorption coefficient is measured by an impedance tube of the type AWA6128A. Figure 2 shows the photograph and schematic diagram of test system. The test frequency is ranged from 1600 to 6500 Hz. The absorption coefficient can be calculated as follows:

\[
\alpha = \frac{4S}{(1+S)^2}
\]

\[
S = \frac{|P|_{\text{min}}}{|P|_{\text{max}}}
\]
3. Fabrication and Acoustic properties

In this section, we have investigated the fabrication of flexible MPPs by CNC milling method. Compared with laser or micro-electro-mechanical systems (MEMS) technology [10, 11], this method has the advantage of good controllability and easy operation. The detailed machining process and acoustic properties of prepared MPPs are shown below.

3.1. Preparation by Milling Method

Recently, CNC milling has gradually become a critical manufacturing method, due to its advantages such as relatively lower cost, capability of multi-axis machining, high precision and high machining accuracy [12]. In the present work, four samples with different structural parameters and materials were prepared as shown in Table 1. The first step of manufacture is the coding of machining information with the assistance of Mastercan software, which is linked to the geometrical features, as shown in Figure 3(a). Subsequently, drilling needles and samples were installed in the milling machine, and then the fabrication process was started according to the code. It should be noted that robust airflow was blown out during the fabrication process, thus to remove the scrap which adhered to the drilling needles. Finally, the obtained specimens were cleaned with ultrasonic wave to further wipe off the oil particles or debris during the preparation process. The manufacturing procedure was shown in Figure 3. The perforation diameter of MPPs could be precisely controlled by choosing the specification of different drilling needles.

The scanning electron microscope photographs of the MPPs are shown in Figure 4. It can be observed that the perforations with desired diameters were precisely prepared apart from the Paperboard-MPP, and the dimensions of obtained holes show good uniformity. The apertures of specimens such as PET, PVC, and PC appear to be quite uniform and straight holes, as expected. However, for paperboard-MPP, the holes do not appear to be fully straight due to the effect of the paper material, and the holes edges do not appear to be sharp, which would have a bit effect on the sound absorption.

| Structural parameters of prepared MPPs by CNC milling machine. |
|---|---|---|---|---|
| d(mm) | b(mm) | t(mm) | D(mm) | p(%) |
| Paperboard | 0.20 | 0.87 | 0.20 | 15 | 4.151 % |
| PET | 0.08 | 0.44 | 0.10 | 15 | 2.595 % |
| PVC | 0.10 | 0.38 | 0.20 | 15 | 5.436 % |
| PC | 0.10 | 0.60 | 0.30 | 15 | 2.181 % |

![Figure 3](image-url)
3.2. Acoustical Properties

Figure 5 shows the measurement results of the absorption coefficient of the MPPs. The absorption peak of prepared paperboard is lower than the values of simulation, as observed from Figure 5 (a). The reason could be attributed to the intrinsic air permeability of paper materials. Those tiny pores within the paperboard is unfavorable to increase sound absorption peak, due to the weaker resonant effects than plastic membrane. It can be stated that the sound absorption is improved, indicating the potential application of flexible MPPs for noise reduction. Moreover, the measured maximum absorption peak is equal or higher than the calculated values by Maa’s model for PET, PVC and PC. Obviously, the sound absorption coefficient of PC-MPP get improved significantly between 1500Hz and 3000Hz and the absorption bandwidth does also get widened. And the sound absorption peak of these three sample moves to a lower frequency. For instance, the absorption peak of PET-MPP moves from 4000Hz to 2800Hz. It could be explained by the vibrational effects of the flexible plastic membrane, which resulted in the absorption band gradually move to a lower frequency. The acoustic impedance of prepared MPPs was also measured to contrast with that of Maa’s classical rigid MPP, as shown in Figure 6. It’s clear that flexible MPPs have larger resistance than Maa’s, which could be illustrated that these samples have better sound absorption and a bit broader absorption width, such as PVC-MPP and PC-MPP as shown in Figure 5. In Maa’s model, there is only one sound absorption system for rigid MPP consists of micro-perforated pores and air gap. However, flexible MPP has two sound absorption systems at least, which are the one system that consists of micro-perforated pores and air gap, and the other resonant system that consists of the flexible panel and air gap. In addition, the acoustic-vibration of the flexible panel is not negligible. The effect of these differences has resulted the prediction error between the measured impedance and the predicted impedance by Maa’s model. The trend of sound absorption, which moves to a lower frequency, is beneficial to extend the absorption bandwidth effectively. It can be seen that the MPPs prepared by the CNC milling machine has good sound absorption performance.
Figure 5. Absorption coefficients of prepared flexible MPPs.

Figure 6. Acoustic impedance of prepared flexible MPPs.

4. Conclusions

In this study, an alternative technique has been used to fabricate flexible MPPs by CNC milling. Compared with laser or MEMS technology in preparing MPPs with perforations diameter of about 100 μm, the superiorities of CNC milling are as follows: 1) CNC milling method does not need a prepared template as required in MEMS technology and could produce MPPs only by the code depending on the geometrical features; 2) CNC milling method has an uncomplicated and maneuverable procedure, instead of extremely strict processing in MEMS or laser technology; 3) the holes of the MPP using CNC machine are of high quality, high precision, and good consistency of perforated ratio. However, when the aperture is reduced to less than 60 μm, this CNC milling method shows a poor effect that the MPP has a rough hole and a lower perforation rate. Additionally, the cost of cutter as being damaged should also be taken into account when the hole is less than 60 μm.

The MPPs with the sized level of about 100μm, which are prepared by proper materials such as PET, PVC, and PC, have distinct improvement on acoustic properties. Meanwhile, flexible MPPs with panel vibration generally have the high absorption coefficient and board absorption bandwidth.
Acknowledgments
The authors thank Prof. Xiaojie Wang from Institute of Advanced Manufacturing Technology of CAS for his kind help with the experiments of impedance in support of this work. This study was funded by National Natural Science Foundation of China (Project Numbers: 11774355, 11604077)

References
[1] Rayleigh, L., Nachtrieb, N.H. (1957) The Theory of Sound. Physics Today, 10(1):32-34.
[2] L. G H. (1927) Theory of Vibrating Systems and Sound. Nature, 120(3024):544-544.
[3] Maa D.Y. (1975) Theory and design of microperforated-panel sound-absorbing construction. Sci Sinica, 17(1): 55-71.
[4] Ruiz, H., Cobo, P., Jacobsen, F. (2011) Optimization of multiple-layer microperforated panels by simulated annealing. Applied Acoustics, 72(10):772-776.
[5] Qian, Y.J., Cui, K., Liu, S.M., et al. (2014) Optimization of multi-size micro-perforated panel absorbers using multi-population genetic algorithm. Noise Control Engineering Journal, 62(1):37-46.
[6] Liu, J., Hua, X., Herrin, D. W.(2014) Estimation of effective parameters for microperforated panel absorbers and applications. Applied Acoustics, 75:86-93.
[7] Maa D.Y. (1987) Microperforated-Panel Wideband Absorbers. Noise Control Engineering Journal, 29(3):77-84.
[8] Maa D.Y. (1998) Potential of microperforated panel absorber. The Journal of the Acoustical Society of America, 104(5):2861-2866.
[9] Xi, Q., Choy, Y.S., Cheng, L., et al. (2016) Noise control of dipole source by using micro-perforated panel housing. Journal of Sound and Vibration, 362:39-55.
[10] Wu, S.H., Du, L.D., Kong, D.Y., et al. (2014) Hybrid device for acoustic noise reduction and energy harvesting based on a silicon micro-perforated panel structure. Chinese Physics B, 23(4):044302.
[11] Qian, Y.J., Kong, D.Y., Fei, J.T. (2015) A note on the fabrication methods of flexible ultra micro-perforated panels. Applied Acoustics, 90:138-142.
[12] Safaiieh, M., Nassehi, A., Newman, S.T. (2013) A novel methodology for cross-technology interoperability in CNC machining. Robotics and Computer-Integrated Manufacturing, 29(3):79-87.