MADRID
inter.noise 2019
June 16 - 19
NOISE CONTROL FOR A BETTER ENVIRONMENT

Experiment study of double-layer membrane acoustic metamaterials with a compact magnet for low frequency wideband transmission loss

Zhao, Junjuan[1]
Wang, Yueyue
Wang, Wenjiang
Zhu, Liying
Li, Xianhui
Zhang, Bin
Beijing Municipal Institute of Labor Protection,
No.55, Taoranting Road, Xicheng, Beijing, 100054, China

ABSTRACT

Single layer tunable membrane acoustic metamaterial with magnet usually can achieve one low-frequency transmission peak at the same time. To further increase its bandwidth, a double-layer membrane acoustic metamaterial (DMAM) with a compact magnet is proposed in this paper to implement a compact design for transmission loss at multiple low frequencies. This DMAM comprises two interval membranes and a compact magnet, each membrane has a centralized light iron pallet, on which exists different magnetic effect. The performance of the DMAM is investigated detailly by experiments. The results demonstrate that a reasonable design of distance between the members and the magnet can easily realize unity multiple transmission loss peaks which make the wideband available, due to the regime of different nonlinear magnetic force affect.

Keywords: Membrane acoustic metamaterial, Environment Noise, Low frequencies
I-INCE Classification of Subject Number: 38

1. INTRODUCTION

The acoustic metamaterials have received much attention by researchers in physics and acoustical engineering during the last two decades [1-11]. To date, most membrane-type acoustic metamaterials (MAMs) once fabricated cannot adapt to real-life scenarios that are likely to change constantly, due to they are passive and hardly adjustable. A substantially different approach to mitigate these problems is to incorporate active designs [12-15]. Chen et al. [16] applied a gradient magnetic field to actively tune the membrane-type acoustic metamaterials (MAMs). This enables the shifting of the membrane eigenfrequencies during operation by selecting appropriate external magnetic field gradients. However, in the experiments, a large permanent magnet was used to generate the required magnetic field, which greatly

---

[1] junjuanzhao@sina.com

increases the overall mass and size of this active membrane-type metamaterial (AMAM). A different realization of an AMAM was recently proposed by Xiao et al. [17], who showed that the MAMs can be easily tuned by applying an external voltage, who used a setup similar to that of a condenser microphone with an acoustically transparent fishnet electrode and the added mass on the MAM acting as the counter electrode. By applying an external DC voltage the eigenfrequency of the MAM could be decreased due to the additional attractive force between the electrodes. This new design requires the supply of a constant voltage in every unit cell of the AMAM. For possible fields of application, where a big surface needs to be covered with such AMAMs, large amounts of wiring are required for providing each unit cell with the suitable amount of voltage, thus increasing the mass and installation effort of the AMAM structures. Furthermore, in some cases it might be infeasible to use electrical wirings inside noise protection devices due to safety regulations. Langfeldt et al. [18] designed a new realization of an AMAM that employs a centralized actuation principle for adjusting the dynamic MAM properties without requiring individual electrical circuits in each MAM unit cell. This design requires that the materials of the membrane and the frame must be airtight so that the air volume between the MAMs and the frame can be pressurized using an external source of pressurized air connected to the MAM via tubings or channels inside the frame. However, the fully sealed design lacks feasibility under some complex environments, and the slightest rupture of the membrane can cause the structure to lose its original purpose.

To implement a compact, energy-saving and non-contact tuning design for membrane-type acoustic metamaterials, our preliminary work [19] presents a new approach that involves stacking MAMs using a magnet that is very small but has strong magnetism and can be tuned using a screw conveniently. Experimental methods are employed to study the acoustical properties of these MAMs with magnetic-iron (MMAMs). Single layer tunable membrane acoustic metamaterial (SMAM) with magnet usually can achieve one low-frequency transmission peak at the same time. To further increase its bandwidth, a double-layer membrane acoustic metamaterial (DMAM) with a compact magnet is proposed in this paper to implement a compact design for transmission loss at multiple low frequencies.

2. STRUCTURE

The basic structure of a DMAM unit is shown in Fig. 1. It comprises two interval membranes, a compact magnet and two support frames; the membranes with radius R = 50 mm and thickness t = 0.14 mm, are fixed on a solid ring support frame's two sides. A circular rigid iron platelet with radius r = 5 mm and mass m = 300 mg is attached to the centre of the membrane. The solid ring support frame is a circular aluminium rings with an outer diameter of 100 mm, a thickness of 2.5 mm designed to fit snugly in the testing apparatus, and its height of d_1 = 5 mm which is also the distance of the two membranes. The other solid ring support frame, a circular aluminium rings with an outer diameter of 100 mm, a thickness of 2.5 mm and height of d_2 = 20 mm designed to hold and tune a central magnetic-iron by a trigeminal structure at its bottom and the magnetic-iron top height is h.

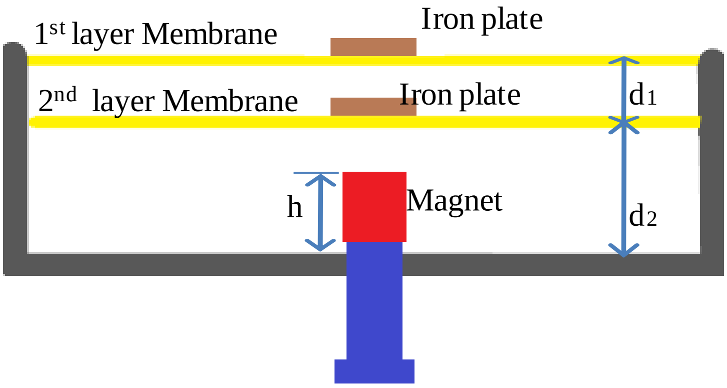

Fig. 1 Schematic of the DMAM.

3. EXPERIMENTS AND ANALYSIS

The acoustical properties of the membrane structure was measured under normal incidence using a Bruel & Kjaer Type 4206 large sample tube according to the standard procedure detailed in ISO (10534-2). This type of sample tube has an inner diameter of 100 mm and is rated for a frequency range of 50 - 1600 Hz. The measured transmission loss of the DMAM with and without magnetic-iron was tested, the test for the DMAM using a magnetic-iron with top magnetic field 4830 Gs at different height *h* were carried out. The results are depicted in Fig.2. This compact design can achieve two transmission loss peaks at low frequencies. The two transmission loss peaks can be tuned with the central magnetic-iron be screwed near to the iron platelet. The second transmission peak due to the 2nd-layer is seen to shift to a higher level with increasing magnetic-iron top height in a wide range about from 100 to 800 Hz. The first transmission peak of the membrane structure due to 1st-layer has been shifted from 100 Hz to 200 Hz whose frequency range is smaller than the one belong to the 2st-layer for the different *h* and magnetic effect. Remove the 1st-layer membrane, the structure becomes single layer tunable membrane acoustic metamaterial (SMAM) with magnet. Compared with SMAM, shown in fig.3, DMAM has higher and more transmission loss peaks.

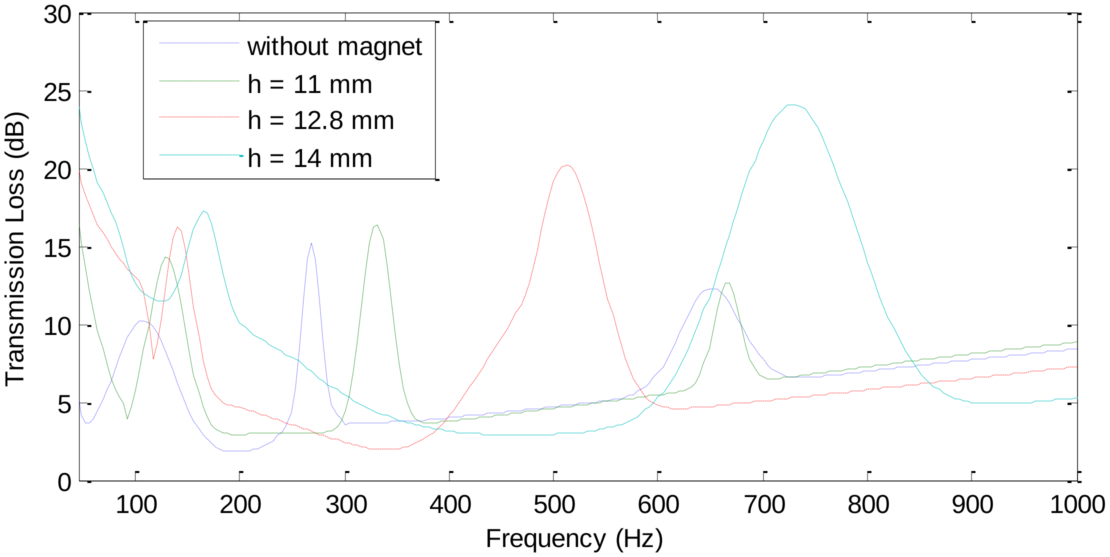

Fig.2 Transmission losses of the DMAM

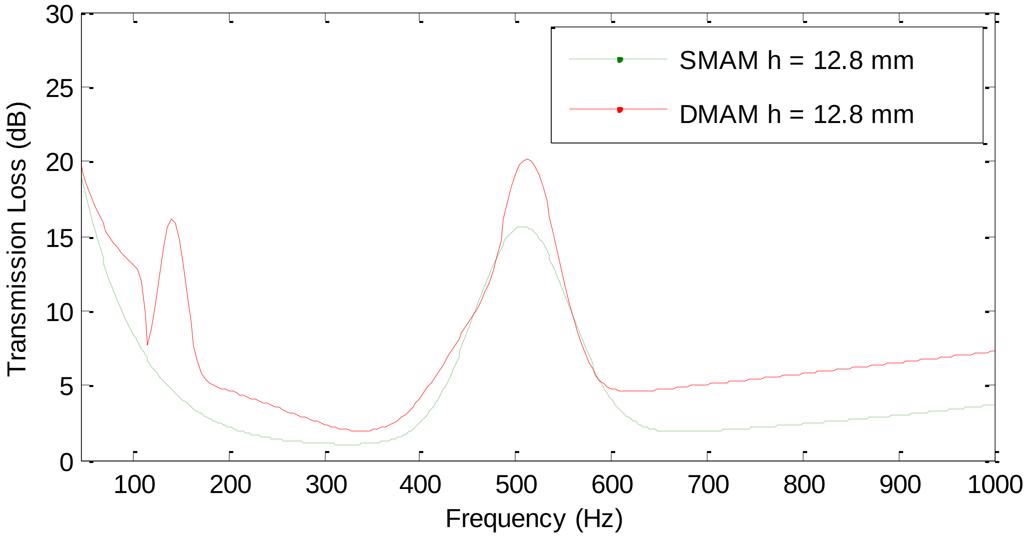

Fig.2 Transmission losses of DMAM and SMAM with h = 12.8 mm

4. CONCLUSIONS

In summary, this paper shows that a double-layer membrane acoustic metamaterial (DMAM) with a compact magnet can be realized to implement a compact design for transmission loss at multiple low frequencies, and the peaks can be easily tuned by applying a magnetic-iron whose top height can be tuned through a screw. The acoustical properties of the double-layer membrane-type metamaterials with magnetic-iron are investigated in experiments. It is revealed that the second transmission peak due to the 2nd-layer is seen to shift to a higher level with increasing magnetic-iron top height in a wide range about from 100 to 800 Hz, while the first transmission peak of the membrane structure due to 1st-layer has been shifted from 100 Hz to 200 Hz. The results demonstrate that a reasonable design of distance between the members and the magnet can easily realize unity multiple transmission loss peaks which make the wideband available, due to the regime of different nonlinear magnetic force affect.

5. ACKNOWLEDGEMENTS

This work is supported by the National Natural Science Foundation of China (Grant No. 11704035); Natural Science Foundation of Beijing Municipality (Grant Nos. 1172007 and 1164013); Beijing Municipal Science and Technology Commission | Beijing Nova Program (Grant No. Z181100006218018).

6. REFERENCES

1. N. Fang, D. Xi, J. Xu, M. Ambati, W. Srituravanich, C. Sun, X. Zhang, “Ultrasonic metamaterials with negative modulus”, *Nature Materials*, 5, 452-456,(2006).
2. S. H. Lee, C. M. Park, Y. M. Seo, Z. G. Wang, C. K. Kim, “Acoustic metamaterial with negative modulus”, *Journal of Physics: Condensed Matter*, 21, 175704, (2009).
3. C. Ding, L. Hao, X. Zhao, “Two-dimensional acoustic metamaterial with negative modulus”, *Journal of Applied Physics*, 108, 074911, (2010).
4. J. Fey, W. M. Robertson, “Compact acoustic bandgap material based on a subwave length collection of detuned Helmholtz resonators”, *Journal ofApplied Physics*, 109, 114903, (2011).

5. J. Li, C. T. Chan, “Double-negative acoustic metamaterial”, *Physical Review E*, 70, 055602, (2004).
6. S. Guenneau, A. Movchan, G. Pétursson, S. A. Ramakrishna, “Acoustic metamaterials for sound focusing and confinement”, *New Journal of Physics*, 9, 399, (2007).
7. S. H. Lee, C. M. Park, Y. M. Seo, Z. G. Wang, C. K. Kim, “Composite acoustic medium with simultaneously negative density and modulus”, *Physical Review Letters*, 104, 054301, (2010).
8. M. Yang, G. Ma, Z. Yang, P. Sheng, “Coupled membranes with doubly negative mass density and bulk modulus”, *Physical Review Letters*, 110, 134301, (2013).
9. B. Liang, B. Yuan, J. C. Cheng, “Acousticdiode: rectification of acoustic energy flux inone-dimensional systems”, *Physical Review Letters*, 103,104301, (2009).
10. S. Zhang, C. Xia, N. Fang, “Broadband acoustic cloak for ultrasound waves”, *Physical Review Letters*, 106, 024301, (2011).
11. J. Mei, G. Ma, M. Yang, Z. Yang, W. Wen, P. Sheng, “Dark acoustic metamaterials as super absorbers for low-frequency sound”, *Nature Communications*, 3, 756, (2012).
12. Baz, “An active acoustic metamaterial with tunable effective density”, *Journal of Vibration and Acoustics*, 132, 041011, (2010).
13. W. Akl, A. Baz, “Multi-cell active acoustic metamaterial with programmable bulk modulus”, *Journal of Intelligent Material Systems and Structures*, 21, 541-556, (2010).
14. W. Akl, A. Baz, “Analysis and experimental demonstration of an active acoustic metamaterial cell”, *Journal of Applied Physics*, 111, 044505, (2012).
15. B. I. Popa, L. Zigoneanu, S. A. Cummer, “Tunable active acoustic metamaterials”, *Physical Review B*, 88, 024303, (2013).
16. X. Chen, X. Xu, S. Ai, H. Chen, Y. Pei, X. Zhou, “Active acoustic metamaterials with tunable effective mass density by gradient magnetic fields”, *Applied Physics Letters*, 105, 071913, (2014).
17. S. Xiao, G. Ma, Y. Li, Z. Yang, P. Sheng, “Active control of membrane-type acoustic metamaterial by electric field”, *Applied Physics Letters*, 106, 091904, (2015).
18. F. Langfeldt, J. Riecken, W. Gleine, et al, “A membrane-type acoustic metamaterial with adjustable acoustic properties,” *Journal of Sound & Vibration*, 373:1-18, (2016).
19. J. Zhao,Y. Wang,W. Wang, et al, “Experimental analyses of Membrane-type acoustic metamaterials with tunable properties by a compact magnetic-iron”. *Internoise 2018*, Chicago, USA, (2018).