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Magnetic tunable sound absorption channels controlled by anisotropic magnetic switches

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ABSTRACT

Acoustic structures with active control capabilities are crucial in practical noise reduction. In this work, magnetic tunable sound absorption channels were developed to achieve magnetic acoustic control. The magnetic switch made of hard magnetic composites were inserted in the channel and their magnetic anisotropy was utilized to shift the frequency of peak sound absorption. The sound absorption channels were composed of several lateral Helmholtz units with different lengths, which possessed tunable sound absorption peaks by varying the volume of the channels. The peak sound absorption frequency was inversely proportional to the length of the Helmholtz units and multiple units with similar lengths could produce continuous sound absorption peaks in one sound absorption channel. Owing to the magnetic anisotropy, the magnetic switches performed different force and movement statuses under magnetic fields with different directions. The surface treated magnetic switches could slide in the channels smoothly by magnetic fields with different directions, which could turn the sound absorption channels in the whole testing frequency range. Therefore, the magnetic sound absorption channels exhibit excellent tunability under applying the external magnetic fields and promise a great potential in complex magnetic control.

1. Introduction

Smart acoustic structures with active control capability and sound absorption tunability are highly demanded to solve the diversified noise problem. Traditional Helmholtz resonance structures can produce independent sound absorption peaks and their sound absorption peaks directly depend on the volume of Helmholtz unit [1,2]. However, the sound absorption frequency ranges of Helmholtz units were usually untunable once the structures were prepared, which immensely limited its applications. The smart sound absorption structures with active control capability are of great potential to break this dilemma. Hard magnetic polymer materials composed of hard magnetic particles in soft polymer matrixes often possessed large remanence and coercivity [3,4]. They possessed complex microstructural anisotropy and showed unique response to the magnetic field direction [5,6], which provided diverse approaches for active control. The hard magnetic polymer materials have been widely investigated in magnetic sensing [7–9] and magnetic controlled movement. In consideration of their wonderful magnetic anisotropy and tunable mechanical properties, the hard magnetic materials are expected to be potential to achieve magnetic active control in sound absorption.

In this work, magnetic tunable sound absorption channels with subwavelength Helmholtz units were developed to achieve magnetic acoustic control. The magnetic switches processed by hard magnetic polymer materials were inserted in the channels. The magnetic switches can be driven by external magnetic fields in different directions because of their magnetic anisotropy. Two kinds of magnetic switches were designed and they provided different control modes for magnetic sound tunability, which exhibited high application prospect of the magnetic tunable sound absorption channels.

2. Experiment

The sound absorption channel composed of several lateral Helmholtz units with different lengths was processed by 3D printing (Fig. 1b). The fabrication processes of magnetic switches were schematically illustrated in Fig. 1a. The PDMS matrix, curing agent and NdFeB particles were mixed up and the mixture was vacuumed to remove trapped bubbles for 30 min. The ratio of the matrix to the curing agent was 10:1.5 and the NdFeB mass fraction was set as 50 wt%. After that, the

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final mixture was poured into a mold and cured in a 1100 mT magnetic field for 20 min to prepare the magnetic switches.

3. Result and discussion

3.1. Sound absorption properties of sound absorption channels

The sound absorption curves of sound absorption channels with different structural parameters were measured as shown in Fig. 1. The length of the Helmholtz unit was the most effective adjustment parameter for the peak sound absorption frequency. The peak sound absorption frequency was inversely proportional to the Helmholtz unit length and the peak sound absorption frequency shifted from 3378 Hz to 1326 Hz when the Helmholtz unit length increased 28 mm (Fig. 1c). The size of unit cross sections also had influence on the sound absorption frequency (Fig. 1d). The varied length and width of the Helmholtz unit changed the resonant mass and acoustic impedance, which adjusted the sound absorption peak frequency and amplitude. Furthermore, sound absorption channels with multiple Helmholtz units had several peak sound absorption frequencies (Fig. 1e).

3.2. Sound absorption channels with magnetic switches

The magnetic switches showed high potential in sound tunability due to their anisotropic magnetism and controllable movement under magnetic fields (Supplementary data Section 2). The magnetic switches were inserted in sound absorption channels to realize magnetic control of sound absorption frequencies. Two kinds of magnetic switches, pop-up magnetic switches and sliding magnetic switches, were designed to be applied in sound absorption channels. The surfaces of magnetic switches were rough and surface treatment for them was necessary. The magnetic switches were treated by the plasma in the plasma cleaner for 30 s and then wrapped with PTFE films (Fig. 2a).

For the pop-up magnetic switches, the schematic diagram was displayed in Fig. 2b. The magnetic switches had different magnetization directions, which were parallel, perpendicular and at an angel of 45° to the surface. The magnetic switches with different magnetization directions would only be controlled by magnetic fields paralleled with them while the magnetic fields in other directions had no influence on them. Three magnetic switches were all open in the initial state in Fig. 2c. When a vertical magnetic field applied on the magnetic switches, switch 1 would be turned off and the Helmholtz unit length would decrease, while the other switches would not be affected. The switch 1 could be turned on if an opposite magnetic field was applied. The horizontal magnetic field and 45° magnetic field controlled the switch 2 and switch 3 respectively. As the magnetic fields in different directions were applied on the sound absorption channel, the unit length decreased and the peak sound absorption frequency shifted to the high frequency range (Fig. 2d). Therefore, the pop-up magnetic switches provided a step tunability of sound absorptions. Only the magnetic field in a specific direction can drive the magnetic switches and adjust the sound absorption curves.

The sliding magnetic switch also utilized the magnetic field directions. It changed the Helmholtz unit length by sliding in the unit and the schematic diagram was displayed in Fig. 2e. There was a magnet on the back of the sound absorption channel horizontally and the magnetic switch could slide with the magnetic pole of the magnet when the magnet rotated (Fig. 2e). Thus, the sliding magnetic switch can continuously tune the peak sound absorption frequency of the sound absorption channel and the magnetic control tunability was displayed in Fig. 2f. The peak sound absorption frequency also shifted from 4874 Hz to 1780 Hz in the rotation process. The sliding magnetic switch provided a continuous adjustment mode for magnetic control tunability, which was of great potentials for acoustic magnetic control.

3.3. Numerical solutions for sound absorption channels

The sound absorption coefficient α can be obtained by a classical formula for the simplified model in Fig. 3a (Supplementary data Section 3 in detail).

$$\alpha = 1 - |r_p|^2 \quad (1)$$

The numerical solutions for two kinds of magnetic switches were

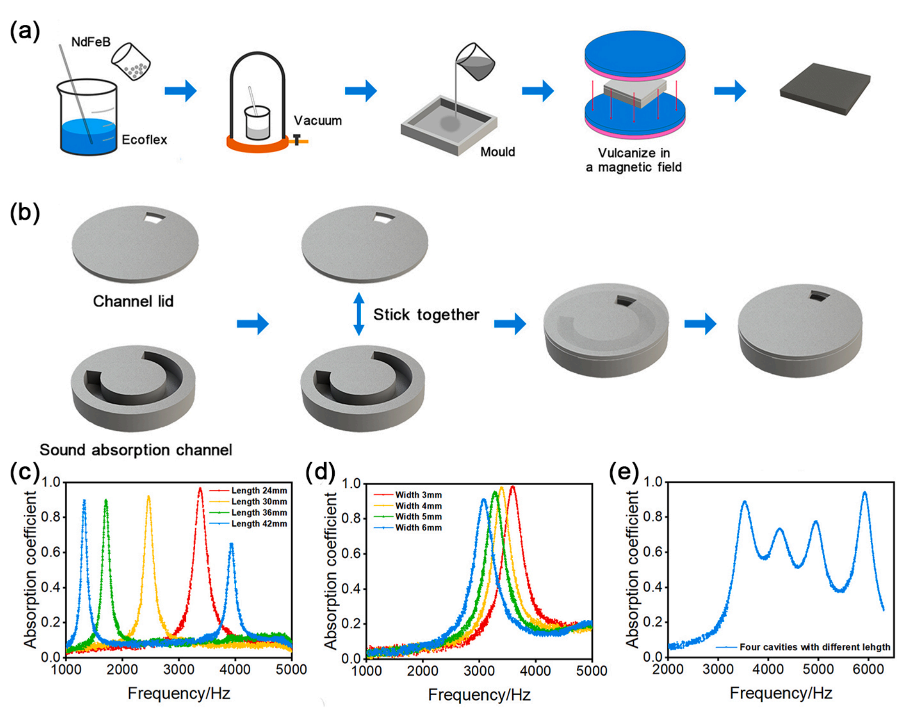

Fig. 1. Schematic diagram for the preparation of magnetic switches (a) and the sound absorption channels (b), sound absorption curves of the channels with different unit lengths (c), different unit widths (d) and four units of similar lengths (e).

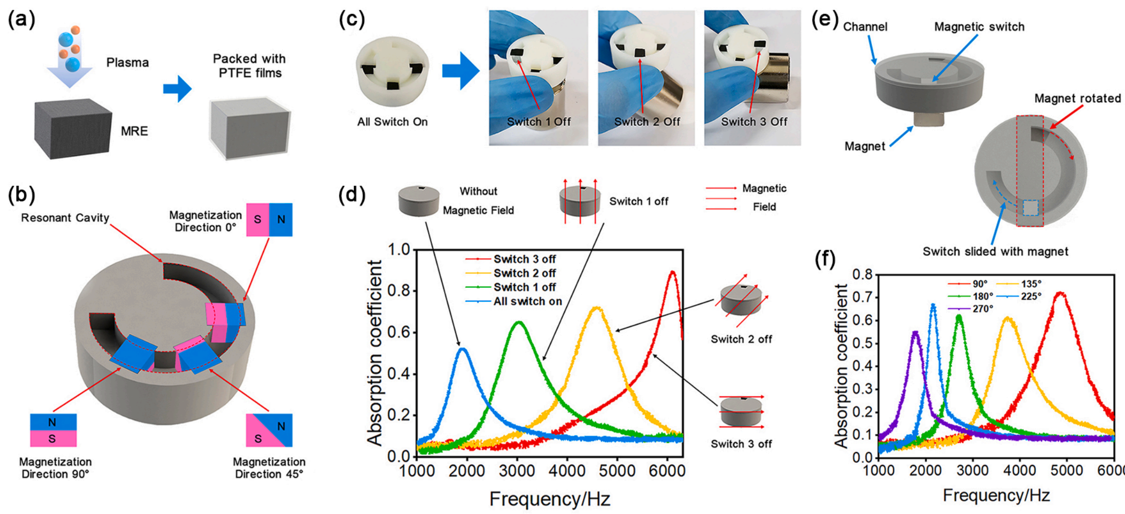

Fig. 2. Surface treatment (a), installation diagram (b), the magnetic control process (c) and magnetic control tunability (d) of the pop-up magnetic switches, schematic diagram (e) and magnetic control tunability of the sliding magnetic switches (f).

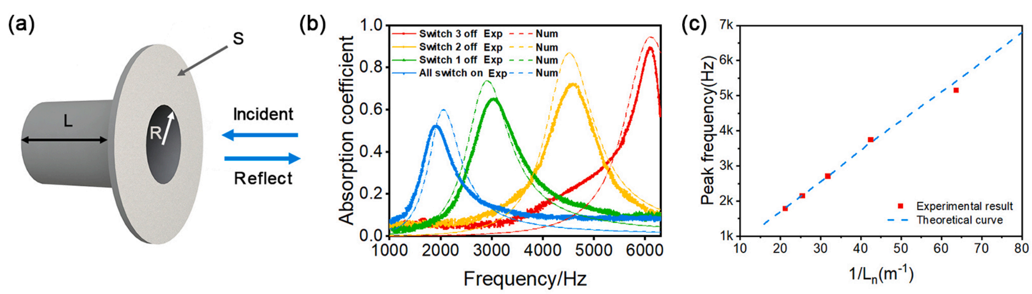

Fig. 3. Simplified model for Helmholtz unit (a), numerical calculation of the pop-up magnetic switches channels (b) and sliding magnetic switch channels (c).

calculated as shown in Fig. 3. The solid curves and dash dot curves represented the experiment results and numerical solutions respectively. The numerical solutions and experiment results all performed unimodal sound absorption curves and their sound absorption peaks almost located in the same frequency range (Fig. 3b). The sound absorption peaks shifted to the high frequency range when the magnetic switches decreased the Helmholtz unit length as expected. The sliding magnetic switch could tune the sound absorption peaks arbitrarily in the testing frequency range by changing the directions of the external magnetic fields. The peak frequency was proportional to the reciprocal of unit length (Fig. 3c). Therefore, the sound absorption properties could be tuned in a wide frequency range by the magnetic fields and the magnetic control tunability was accurately predicted in this work, which promised the sound absorption channels with great potentials in the field of active acoustic control.

4. Conclusion

This work reported a kind of magnetic sound absorption channels with high sound absorption coefficient, wide magnetic tunable frequency range and multiple sound absorption peaks. The magnetic switches magnetized in different directions were inserted in the channels. They could be controlled by external magnetic fields and changed the Helmholtz unit length, which tuned the sound absorption peak frequency in a wide frequency range. Two kinds of magnetic switches were designed in this work. The sliding magnetic switch was driven to slide in the channel by the rotating magnet. It could tune the sound absorption peaks arbitrarily in the testing frequency range, which promised great potentials in the field of active acoustic control. The pop-up magnetic switches would be turned on/off only when influenced by a magnetic field in a certain direction. It provided a conditional magnetic control mode, which would be applied to design complex acoustic devices and magnetic acoustic sensors.

CRediT authorship contribution statement

Chuanlin Sun: Investigation, Formal analysis, Validation, Writing – original draft, Methodology, Visualization, Writing – review & editing. **Yinduan Gao:** Writing – review & editing. **Xufeng Cao:** Formal analysis. **Shouhu Xuan:** Conceptualization, Writing – review & editing. **Xinglong Gong:** Resources, Supervision, Project administration, Funding acquisition.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.matlet.2021.131201.

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