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ACOUSTIC METAMATERIALS FOR ATTENUATING UNWANTED WAVE PHENOMENA IN LOUDSPEAKER ENCLOSURES

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ABSTRACT

The rapid development of sound-absorbing acoustic metamaterials has opened new ideas for their application. Innovations shared in metamaterial designs — such as reduced material thickness compared to traditional solutions and precise control over absorption bandwidth — show promise in the design of loudspeaker enclosures. This presentation will detail recent advancements at AGH University of Krakow, demonstrating the use of acoustic metamaterials to attenuate standing waves within loudspeaker enclosures and to mitigate back-propagation effects from the driver diaphragm. We will discuss the methodologies for designing metamaterial structures using Transfer Matrix Method simulations, optimization techniques, and neural networks to establish a reliable design and manufacturing process. Results from anechoic chamber experiments conducted for test enclosures equipped with metamaterials will be presented. These cavity-based materials, in both broadband and multi-resonance configurations, offer solutions to problematic wave phenomena within enclosures and present advantages over traditional porous materials, such as improved speaker sensitivity by 1 dB and the elimination of VAS increase due to the use of rigid materials instead of porous ones.

Keywords: electroacoustics, standing waves, loudspeaker sensitivity, resonances, 3D printed metamaterials, acoustic measurement

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1. INTRODUCTION

The utilization of acoustic metamaterials is rapidly expanding across various fields of acoustics. They are particularly noted for their effectiveness in low-frequency absorption when compared to porous or fibrous materials of the same size [1]. This characteristic enables the use of metamaterial absorbers in applications where a low material thickness is essential. One such application is in loudspeaker enclosures, which is the focus of this paper. Previously, acoustic metamaterials in electroacoustics were primarily employed as broadband sound-absorbing structures to mitigate diaphragm back propagation [2], [3]. However, they had not been previously utilized to address the issue of standing waves. This paper presents preliminary research on the application of metamaterial absorbers for standing wave attenuation within loudspeaker enclosures. By employing cavity-based acoustic metamaterials that are tuned to the multiple resonant frequencies of the test enclosure, we demonstrate that metamaterials can effectively reduce standing wave interference. Despite a smooth frequency response in the resonant frequency region, the use of rigid metamaterial structures mitigates the adverse effects of fibrous materials, which usually reduce loudspeaker sensitivity.

2. MULTI-RESONANCE CAVITY-BASED ACOUSTIC METAMATERIALS

Acoustic metamaterials are often designed as cavity-based structures, which may include a combination of quarter-wavelength absorbers [4], [5] or Helmholtz-type absorbers [6], [7]. In this study, we used a set of Helmholtz resonators with a common inlet canal. The desired sound absorption was optimized for the frequency ranges of 215 Hz and 320 Hz, which were previously identified as the first two standing wave frequencies in the measured enclosure. The sample design process utilized Particle Swarm Optimization (PSO) algorithms alongside the Transfer Matrix Method (TMM), following methodologies established in prior research [8], [9], [10]. The finalized model was encased in a cylinder with a diameter of 100 mm and a depth of 100 mm, ensuring both metamaterial sample and fibrous material used in this investigation had the same depth. Figure 1 illustrates the shape of the canals used in the tested sample and the printed model.

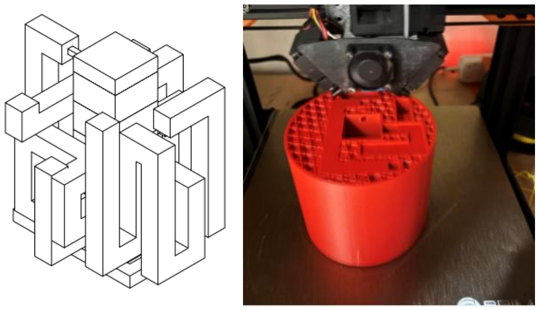

Figure 1. The scheme of the used metamaterial sample (left) and the printed model (right)

To confirm that the manufactured sample met the absorption criteria, its sound absorption coefficient was measured in an impedance tube using the transfer function method. The final sample shape was adjusted to fit into a standard impedance tube with a diameter of 100 mm.

3. MEASUREMENTS OF LOUDSPEAKER ENCLOSURE IN ANECHOIC CHAMBER

To evaluate the influence of the metamaterial samples placed within the loudspeaker enclosure, we conducted acoustic measurements. The enclosure was prepared in three variants: 1) empty, with no absorbing materials inside; 2) with polyester fibers, using a fibrous material of 100 mm depth; and 3) with metamaterials, incorporating six samples of cavity-based metamaterials tuned to the frequency ranges matching the first two modes of air inside the enclosure. Figures 2 and 3 show images of the enclosure's interior with fibrous materials and metamaterials, respectively. Figure 4 depicts the measurement setup.

Acoustic measurements were carried out with a free-field microphone (GRAS46AE) positioned 1 m from the enclosure, aligned with the loudspeaker, similar to loudspeaker sensitivity measurements. A sine sweep signal was utilized to acquire the frequency response of the loudspeaker in the enclosure.

Figure 2. Test enclosure – polyester fibers variant

Figure 3. Test enclosure – metamaterial variant

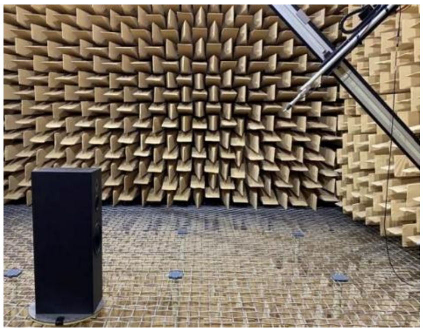

Figure 4. Test enclosure during the acoustic measurements in an anechoic chamber

The frequency response of the loudspeaker was assessed to evaluate the effectiveness of the metamaterial absorbers. The results are presented in Figure 5, which displays the Sound Pressure Level (SPL) measurements alongside the sound absorption coefficients of the metamaterial sample obtained in the impedance tube, which is a common method for this type of material research [11], [12].

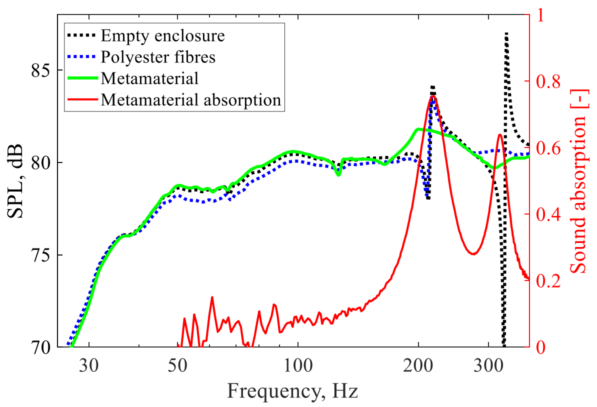

Figure 5. Frequency response of the measured loudspeaker enclosure in three variants

This study aimed to reduce the first two modal frequencies of the air mass confined within the enclosure. It is evident that the metamaterial samples absorbed the resonant frequencies at 215 Hz and 320 Hz, which were observed in the measurements of the empty enclosure, resulting in a smoother frequency response. As shown in Figure 5, the first resonant frequency at 215 Hz was only absorbed with the use of metamaterial samples, while the polyester fibers did not effectively address this low-frequency issue. Moreover, the use of fibrous materials resulted in a significant drop in loudspeaker sensitivity, whereas the incorporation of rigid metamaterial samples allowed for a recovery of the loudspeaker sensitivity.

During the research, it was observed that the absorption bandwidth may be a critical factor for the effective attenuation of standing waves within the enclosure. Designing a single, perfectly tuned resonator would be inefficient as a wider absorption range is typically necessary. This need is evident in the absorption curve, particularly around the 215 Hz point of the tested metamaterial sample. Consequently, an optimized metamaterial design is essential to achieve the desired sound absorption curve.

4. SUMMARY

The preliminary research data presented in this paper demonstrates that cavity-based metamaterial absorbers can effectively reduce the standing wave phenomenon in loudspeaker enclosures. This solution has two main advantages:

- Metamaterials enable absorption of lower frequencies without requiring an increase in the thickness of the absorbing materials.
- The rigid metamaterials used in this research eliminate the sensitivity drop often associated with fibrous materials, resulting in a 1 dB gain in sensitivity.

Metamaterial absorbers hold significant potential for further research in electroacoustics. However, it is crucial to address potential issues that may arise from their application. During the project, it was observed that full-cylinder samples placed inside the enclosure reduced the overall volume, which could negatively impact the loudspeaker's low-frequency response.
Therefore, sound absorption measurements for the samples used are necessary, and it is important to maintain the impedance tube size. It would be beneficial to design samples that do not substantially alter the enclosure volume and could be constructed without an external cylinder. Additionally, further development and testing on various enclosures are required to ensure that the design and manufacturing processes are consistent and that the technology can be successfully transitioned to the development stage.

5. ACKNOWLEDGMENTS

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