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THE EFFECT OF SOUND-ABSORBING WALLS IN THE DESIGN OF CAVITY- BASED METAMATERIALS

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ABSTRACT

Cavity-based metamaterials are a type of acoustic metamaterials, usually designed for sound absorbing or sound scattering performance. They consist of an arrangement of ducts and slits, forming acoustic resonators: Helmholtz resonators and quarter-wavelength resonators. Designing perfectly absorbing structures is usually a problem of matching the impedance of the structure with the impedance of the surrounding medium, which is realized through the manipulation of the open area of the unit cell and the viscothermal losses inside the ducts. When the structure is perfectly matched, complete sound absorption is observed for a given frequency range. However, the structures are designed under the assumption that the walls are perfectly rigid, i.e., they do now show sound-absorbing properties. The paper discusses the influence of the sound absorption of the walls on the sound absorption of the whole metamaterial unit in the case when the designed structure is and is not perfectly matched. Large differences are observed between the results, which is reflected by the measurement results.

Keywords: *electroacoustic absorption, standing waves attenuation, additive manufacturing postprocessing*

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1. INTRODUCTION

Acoustic metamaterials have recently gained much popularity in the field of acoustic research. They are specific structures, designed and engineered to meet particular sound absorption criteria. The structure of cavity-based metamaterials is usually built of ducts and slits, coiled in complex shapes in order to maximize the use of the available space [1]. Numerous references with the formulation of innovative structures designs and simulation methods have been published [2][3][4], while only a few of them cover the fundamentals for the actual sample preparation and measurements. Usually, the prototype samples are manufactured in the 3D printing process and some works on the resulting surface roughness and its influence on the simulated sound absorption coefficient values have been published [5]–[7]. In the current project, we have experienced a great dispersion in the measured and simulated sound absorption values in a prototyped single-cell metamaterial structures, and one of the explanations for this phenomenon was the additional sound absorption of the bare material walls manufactured with 3D printing. This paper will investigate this topic in both numerical and experimental ways.

2. METAMATERIAL STRUCTURE USED FOR THE EXPERIMENTS

The paper is a part of the research focused on the practical application of metamaterial structures in electroacoustics, where the small dimensions of artificial structures may open new ways of loudspeaker enclosures design. We used the Helmholtz type resonator implementation described in reference [4] as a test structure. Following the equations and design principles, a 3D computer model was prepared for

physical sample preparation and numerical tests in the FEM environment COMSOL Multiphysics, shown in Figure 1. The blue region marks the area for further additional sound absorption application. The acoustic field was generated with *background pressure field* in the air above the sample, perpendicular to the sample surface. The boundaries of the model were simulated *sound-hard boundaries* to reflect the impedance tube measurement conditions. *Plane wave radiation* condition was applied at the end of the model in order to avoid sound reflection from the termination of the model. Thermoviscous losses were modeled with *narrow region acoustics* conditions which use the fluid model for viscous and thermal boundary-layer-induced losses in channels and ducts of constant cross section. Such conditions were applied within the ducts forming the Helmholtz resonator, concerning all current state-of-art recommendations [8].
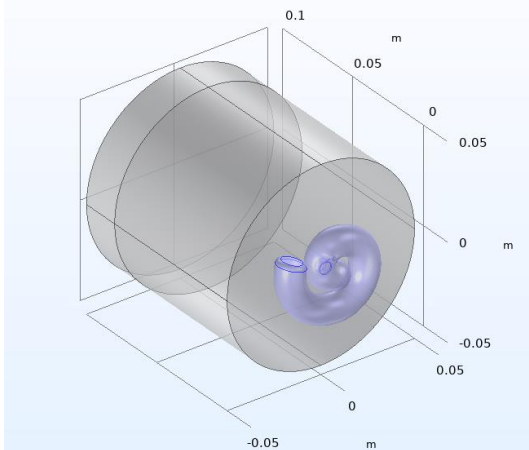

Figure 1. 3D model of used metamaterial structure in COMSOL Multiphysics environment.

In the next step, the measurement sample was prepared. The printing process contained a complex postprocessing stage, and in the pre-research stage, multiple samples were measured. It was proved that the printing settings, sample sealing method, or postprocessing, such as the polishing and sealing, influence the measured values of sound absorption coefficient. The physical sample manufactured with 3D printing FDM technology is shown in Figure 2.
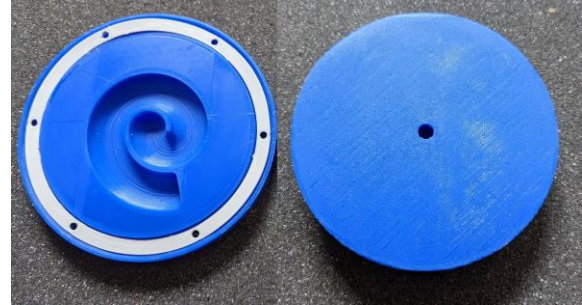

Figure 2. The reference metamaterial sound absorbing structure is used in measurements in impedance tubes.

3. THE COMPARISON OF RIGID AND ABSORBING METAMATERIAL STRUCTURE MODELS

With the prepared samples, sound absorption simulations and measurements were performed. The standardized B&K impedance tube was used for the measurements in the ISO 10534-2 standard [9][10]. The calculations were performed in COMSOL, similar to previously described research [5][8]. To investigate the influence of additional absorption on the performance of the structure, we have modeled the example metamaterial in different physic applications changing the sound absorption coefficient of the resonator walls from 0.00 (perfectly rigid) to 0.02. The comparison of the modeling results with the impedance tube measurements is shown in Figure 3.
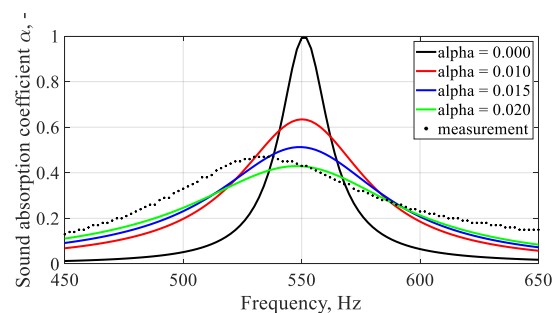

Figure 3. The sound absorption coefficient of the structure modelled with different wall sound absorption coefficient values compared with impedance tube measurements.

Analyzing the results, we may observe that even minimal additional absorption significantly affects the resonator absorption peak values, lowering them from 1.00 to 0.42.

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Also, the Q factor of the resonant structures is decreasing, leading to a better match with the measurement data. The measurement results also provided the resonant frequency shift, which seems not to be caused by the real structure minimally absorbing walls and should be investigated in the future. This could be modelled with the use of impedance conditions instead of sound absorption coefficient.

4. SUMMARY

By directly comparing FEM modeling results and impedance tube measurements of an example metamaterial structure, it was proved that the mismatch between the measurement and simulation results could be caused by additional sound absorption applied by the non-perfectly rigid walls of the prepared sample. The real samples properties should be considered while the designed structures are aimed to be used in applied research, as the misconceptions in the design process may lead to further implementation errors. The methods of absorption reduction for raw 3D printed objects should be investigated in the future to allow the further reduction of additional absorption application effect.

5. ACKNOWLEDGMENTS

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