DOI: 10.61782/fa.2023.0251

forum acusticum 2023

THE DIFFERENCES IN FEM MODELING OF BASIC METAMATERIAL CELLS FOR SOUND ABSORPTION OPTIMIZATION

Bartlomiej Chojnacki[1*] **Aleksandra Chojak**[1] **Wojciech Binek**[1]
Julia Idczak[1] **Jan Pawlik**[1]
[1] AGH University of Science and Technology, Department of Mechanics and Vibroacoustics, Mickiewicza Av. 30, 30-059 Cracow, Poland

ABSTRACT

Increasing popularity of acoustic absorbing metamaterials is followed by the problem of defining the performance of the unit cells used for the further development of the structures. The review of the state-of-the-art solutions revealed problems in the replication of the common designs and the attempt to replicate some of the designs showed great dispersion in the received results compared to the references. Typically, the reference papers do not provide detailed information on the modeling, which may be the reason for the encountered problems. The paper will present the numerical modeling results in COMSOL Multiphysics for the essential metamaterial unit cells comparison of the sound absorption coefficients – the slits, Helmholtz resonators series, or quarter-wavelength resonators. The different modeling techniques, physics application, and mesh sensitivity influence will be investigated. The paper will discuss the results and the advantages of using the given FEM strategy with a comparison with the impedance tube measurement results performed for the validation of the numerical models.

Keywords: *electroacoustic absorption, standing waves attenuation, quarter-wavelength absorbers, Helmholtz resonators*

[*]***Corresponding author***: bchojnacki@agh.edu.pl.

1. INTRODUCTION

Because of the rising popularity of acoustic metamaterial absorbers, a vast number of scientists attempts to recreate the reference-based structures on their own or adapt previously developed solutions for novel applications. In this research, the authors plan to use metamaterial absorbers for electroacoustic applications such as standing wave attenuation inside the speaker enclosures [1]. The preliminary research provided a great dispersion between the physical models measured in an impedance tube and the reference data or modeling results performed with analytical equations. In this paper, we have investigated some basic modeling strategies for quarter-wavelength absorbers and Helmholtz resonators with FEM modeling to investigate possible reasons for complex metamaterial performance.

2. METHODS OF METAMATERIAL CELLS MODELING

The state-of-the-art references describe multiple options for modeling metamaterials [2–4]. The most common method is the Transfer Matrix Method (TMM), based on analytical models of essential metamaterial unit cells such as resonators or slits [5][6]. They are popular because of their computational efficiency, which is required for the optimization. However, these methods usually do not consider the interactions between the metamaterial cells or their arrangement inside the physical models. Typically, the final shape of the structure is based on the authors' invention without precise acoustic interpretation and description. One of the problems are the possible shifts in resonance frequency of the resonators used for the metamaterial construction. A comprehensive study on bending quarter-wavelength resonators was performed by Cambonie et al. [7]. The following research investigated different methods for bending the resonators and some of the state-of-the-art solutions. We used the impedance tube FEM simulation in COMSOL Multiphysics to calculate the absorption coefficient of the selected metamaterials. An example of the used geometry is shown in Figure 1.

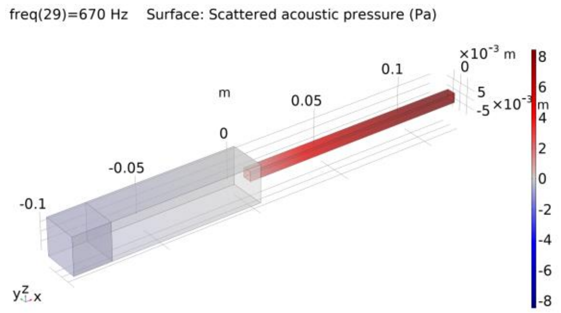

Figure 1. Example of the graphical interface of impedance tube simulation in COMSOL Multiphysics

In the model formulation, some fundamental aspects of FEM modeling were considered, e.g., the type of the acoustic physics modules available in COMSOL [8]. Typically, two following options are considered:

- narrow region acoustics,
- thermoviscous acoustics.

In this model, we have considered the thermoviscous acoustics to be the most reliable as it applies all the required physics for narrow regions computation. However, it is essential to note that it requires higher computation power; simple models used in this research require over nine hours of computation.

3. FEM MODELING OF DIFFERENT RESONATORS GEOMETRIES

The aim of the research was to determine if multiple bands of quarter-wavelength resonators or the cavity curves in Helmholtz resonators affect the final performance of the absorbing structure. In the current state-of-the-art absorbing metamaterial structures, the construction of high-efficiency meta-absorbers often reduces the spatial problem of matching the small volume with the highest possible amount of resonators, without considering the possible modification of their performance due to the shape modification. We used a few simple geometries for a quarter-wavelength case and the geometry based on the Helmholtz resonator described in the reference [3]. Geometrical constraints for the considered structures were: total dimension of the unit-cell: circle of a 100 mm radius, and the total depth of the structure – 100 mm. Such dimensions enabled further experiments with the use of the impedance tube measurements [9]. The FEM models of the structures under study are shown in Figure 2. For each of those, the sound absorption coefficient was calculated.

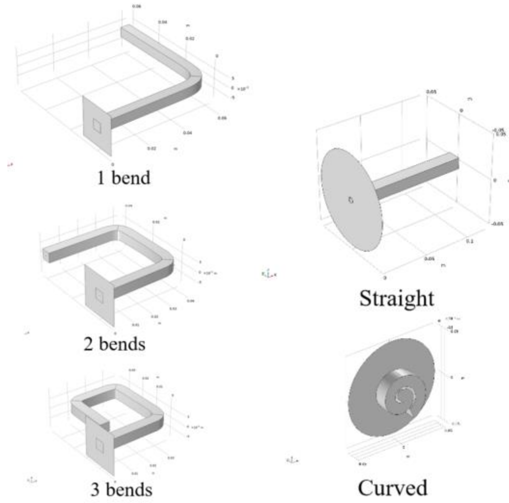

Figure 2. The resonators geometries used in FEM modeling

According to the research described in [7], a single quarter-wavelength resonator bend provides the resonant frequency shift no higher than 60-70 Hz depending on the bend angle and radius. Helmholtz resonators have not been investigated so far. Figure 3 shows the effect of absorption modeling for the first set of models – quarter-wavelength resonators.

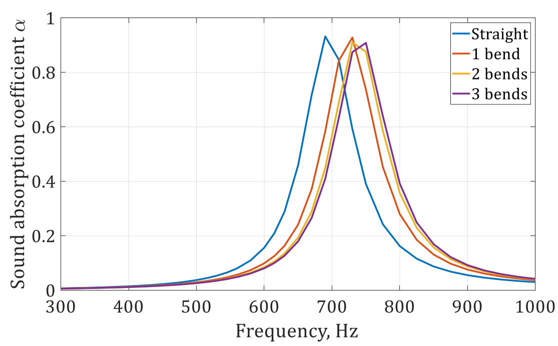

Figure 3. The sound absorption coefficient for quarter-wavelength resonators with multiple bends

The first and second bends caused similar effects to those observed by Cambonie et al. [7], with the resonant frequency shift around 70 Hz. The third bend did not cause any significant effect on the absorption. A similar analysis was performed for the Helmholtz resonator case as shown in Figure 4.

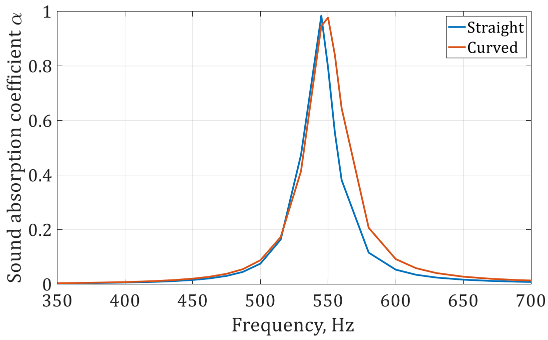

Figure 4. The sound absorption coefficient for Helmholtz resonators in a straight and curved version

In the case of the Helmholtz resonator, we only observed a slight curve shift within a few Hertz range, but the fundamental curve shape remained unchanged.

4. SUMMARY

In this research, the authors tested different shapes of the resonator geometries with the use of FEM modeling. The effect of the resonance frequency shift with different spatial arrangements of the resonators was examined. Such phenomenon must be considered while designing more complex structures. Suppose specific values are considered in the optimization process. In such a case, the shifts in resonance frequencies by 70 Hz may decrease the system's performance. It is required to consider possible resonant frequency shifts in quarter-wavelength resonators due to the metamaterial geometry optimization, e.g., by testing the final geometries in FEM models to avoid further problems with replication. Also, it is advised to base more on the Helmholtz resonators than quarter-wavelength ones, as Helmholtz seems unaffected by the geometry modifications. Further works should focus more on the Helmholtz resonators, especially in different cavity shapes behind the aperture, to confirm and extent the current research findings.

5. ACKNOWLEDGMENTS

The project was funded and supported by the Polish Government, National Centre of Research and Development, agreement no. LIDER/11/0065/L-12/20/NCBR/2021.

6. REFERENCES

[1] Futtrup C, Losses in loudspeaker enclosures, 130th Audio Eng. Soc. Conv. 2011, 12011, 98–118,.

[2] Jiménez N, Romero-García V, Pagneux V, Groby JP, Rainbow-trapping absorbers: Broadband, perfect and asymmetric sound absorption by subwavelength panels for transmission problems, Sci. Rep., 7 (3)1, 2017, 1–13,.

[3] Li Y, Assouar BM, Acoustic metasurface-based perfect absorber with deep subwavelength thickness, Appl. Phys. Lett., [Internet] 108 (3)6, 2016, 063502,. [cited 2022 18]Available from: https://aip.scitation.org/doi/abs/10.1063/1.4941338

[4] Tang Y, Ren S, Meng H, Xin F, Huang L, Chen T, et al., Hybrid acoustic metamaterial as super absorber for broadband low-frequency sound, Sci. Rep., [Internet] 7 (3)1, 2017, 43340,. Available from: https://doi.org/10.1038/srep43340

[5] Yang M, Sheng P, Sound Absorption Structures: From Porous Media to Acoustic Metamaterials, Annu. Rev. Mater. Res., 472017, 83–114,.

[6] Rubacha J, Analysis of the Possibility of Shaping the Sound Diffusion Coefficient of Diffusers Based on Acoustic Metamaterials, Vib. Phys. Syst., 33 (3)2, 2022, .

[7] Cambonie T, Mbailassem F, Gourdon E, Bending a quarter wavelength resonator : Curvature effects on sound absorption properties, Appl. Acoust., [Internet] 1312018, 87–102,. Available from: https://www.sciencedirect.com/science/article/pii/S0003682X17303146

[8] GmbH. C, COMSOL Multiphysics Acoustic Module Documentation, v. 5.3, 2018, .

[9] Kosała K, Experimental Tests of the Acoustic Properties of Sound-Absorbing Linings and Cores of Layered Baffles, Vib. Phys. Syst., 32(1)2021, .