



Evaluation of wedge-shaped acoustic black holes for vibration damping with different analysis softwares

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Abstract: The increasing demand for noise and vibration damping materials in the form of metamaterials also puts acoustic black holes in the focus. A properly designed acoustic black hole achieves localization of vibration energy above a certain cut-on frequency. This enables the reduction of the acoustic radiation of an underlying flexible structure. This work sets up a calculation process for wedge-shaped metamaterials. Parametric studies evaluating natural frequency and modal deflections are carried out for tuning and optimizing the design towards a specific frequency range of operation. Sound radiation and energy flows are calculated for confirming the physical interpretation.

Keywords: acoustic black holes, metamaterial, vibration damping, acoustics

INTRODUCTION

Rising noise levels due to urban expansion and industrialization demand containment of these as a protective measure for people's health and the environment (Murphy et al. 2014, Bugliarello et al. 1976). Continuous research into noise-absorbing materials has also brought acoustic metamaterials and acoustic black holes (ABH) into focus (Zhao et al. 2019). As early as 1988, Mironov calculated the wedge-shaped ABH for absorbing incident vibration energy (Mironov 1988). He showed analytically that no acoustic energy can escape the ABH if the thickness of the tapered end approaches zero and the ABH is infinitely long. The wedge-shaped ABH serves here as a basis for further research and investigation for the adaptation with focus on certain frequency ranges. A beam serves as a simplified base structure. The ABH was designed, simulated and evaluated attached to one end of the beam. The workflow for the investigation is shown in Figure 1. The geometry was designed in the CAD-software *Solidworks* which is then linked dynamically to the finite element software *COMSOL Multiphysics*. This allows for live geometrical update if a design parameter changes. Detailed parametric studies of the ABH design were achieved by driving *COMSOL* via *Matlab* commands and processing the results. The aim of this work is to develop a process for designing and evaluating the performance of different wedge-shaped ABH. More detailed investigations achieved meaningful results for tuning the design of an ABH to specific frequency ranges, which also helped in the interpretation of the physics behind an ABH. The interplay between CAD, multiphysics and computational software enables an even deeper understanding of how the structural and acoustical energy flows evolve.

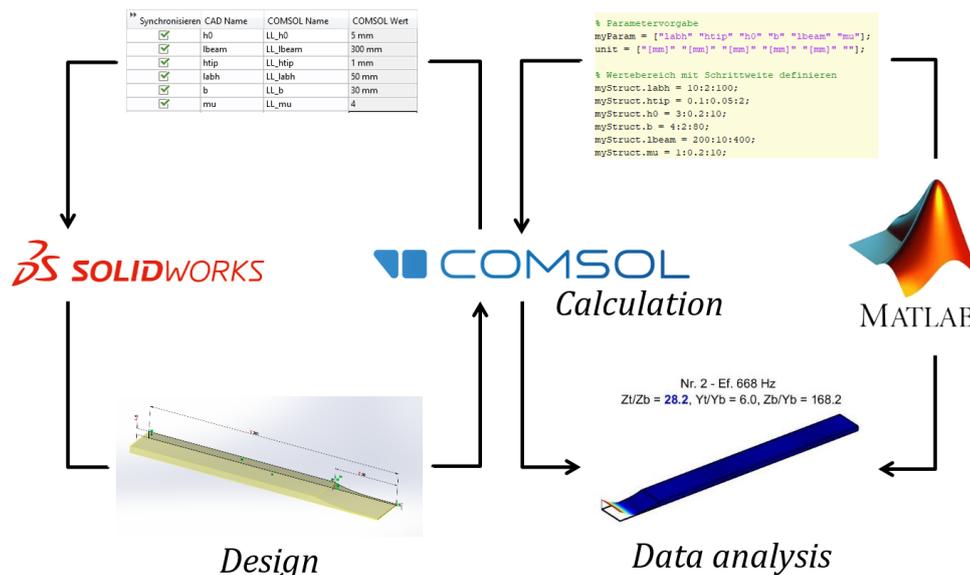


Figure 1 – Work flow for the ABH construction and evaluation with different softwares

ABH-WEDGE CALCULATION

According to Mironov 1988, Zhao et al. 2019 has shown that the bending wave velocity for beams and plates approaches zero if the thickness decreases following the relation

$$h(X) = aX^m \quad (1)$$

where h is the thickness, a is a constant, m is the exponent of the power law curve, and X is the distance from the tip of the ideal power law curve. In reality, however, it is impossible to achieve a thickness of zero due to the limitations of manufacturing techniques, leading to a residual thickness h_1 at the free end. This alters the equation of the power law curve (1D-ABH) to

$$h(x) = \varepsilon x^m + h_1 \quad (2)$$

where the exponent m is a positive rational number ≥ 2 , the parameter ε represents a constant, x is the distance from the tip of the powerlaw curve with residual thickness. Figure 2 represents this schematically. A beam with the length l_{beam} and width b is added to the ABH wedge. For the specific thickness T of the beam, the length of the ABH is influenced by the parameter ε . This results in the ABH power law curve

$$h(x) = \frac{T - h_1}{L_{abh}^m} x^m + h_1 \quad (3)$$

In the extreme case that $h_1 \rightarrow 0$, then $L_{ABH} \rightarrow \infty$, but only if $m \geq 2$. Following that the wavenumbers at the ABH locations tend towards infinity and the reflection coefficient towards zero, which means that no wave can escape from the ABH location (Zhao et al. 2016).

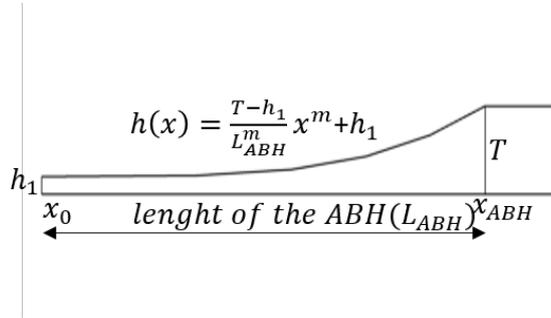


Figure 2 – Parametrized ABH wedge (following Zhao et al. 2017 & Zhao et al. 2019)

ABH EVALUATION

Various designs were conducted and simulated for the ABH with beams. The natural frequencies of one simple configuration are shown in Figure 3. It can be clearly seen that at some frequencies the ABH absorbs the vibration energy, which is indicated by strong oscillations of the ABH while the beam (base structure) itself remains almost at rest. These results were used to generate dispersion curves for different design variations. Such curves help finding a proper ABH design for a specific frequency of interest. In addition, time-domain studies were used to calculate the energy flow in the beam structure after excitation and thus demonstrate the effectiveness energy localization. Finally, multiphysical couplings between solid mechanics and pressure acoustics were calculated in *COMSOL*. This is shown for a certain natural frequency in Figure 4. Here, the sound radiation of the beam structure was calculated in an air cuboid, again highlighting the effectiveness of the ABH.

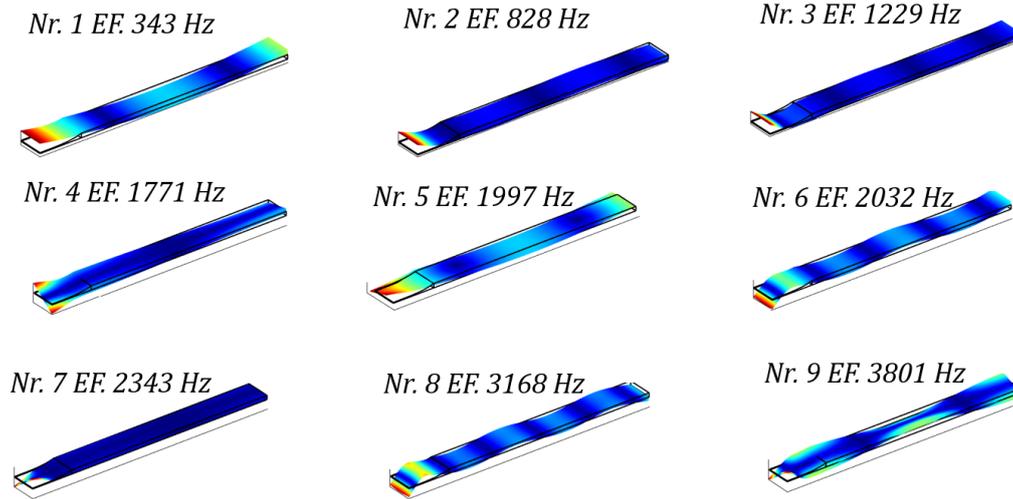


Figure 3 – Natural frequencies and corresponding modeshapes of the beam with ABH

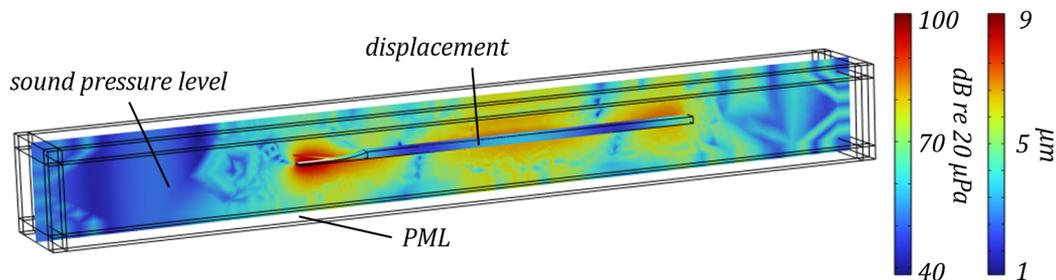


Figure 4 – Acoustic radiation as sound pressure level and displacement of the beam with ABH limited with perfectly matching layers (PML)

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