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Computational analysis and design optimization for acoustic devices

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Abstract
This thesis focuses on material distribution topology optimization for acoustic waveguides. The limitations of the material distribution approach are discussed in the context of acoustic waveguides with extensive viscous and thermal boundary losses. An extension of the material distribution method is introduced which is capable of incorporating these boundary losses in the optimization process. Furthermore, a computational analysis of waveguide acoustic black holes (WABs) is also provided followed by a topology optimization approach for the conceptual design of a WAB with enhanced wave-focusing capabilities, utilizing the novel method introduced in the first part of the thesis.

The thesis commences with a comprehensive literature review to set the context for the subsequent research. The material distribution topology optimization is then discussed in detail, focusing on the design of a transition section for impedance matching between two cylindrical waveguides with different radii to maximize planar wave transmission. The linear wave propagation in the device is modeled using the Helmholtz equation and solved utilizing the finite element method to obtain acoustic pressure distribution. Nonlinear density filters are used to impose a size control on the design, and the design optimization problem is formulated and solved utilizing the method of moving asymptotes (MMA) with the sensitivity information provided through an ad-joint method. Selected results are provided for the considered design optimization problem. We expanded the analysis to encompass viscothermal acoustics and introduced a novel material distribution method capable of incorporating complex interface conditions. The new method is then applied to design acoustic absorbers with the aim of maximizing boundary losses in a targeted frequency range. The selected results represent the effectiveness of the proposed method.

The thesis further explores the limitations of the classical ribbed design of WABs in achieving true wave-focusing capabilities. To address this, a design optimization problem is formulated to obtain a conceptual design of a WAB. Utilizing the novel material distribution method for viscothermal acoustics introduced in this thesis, the optimization problem is solved, and the optimized design is compared with the results of a classical lossless approach and the ribbed design WAB. The numerical simulations demonstrate the superior wave-focusing capabilities of the optimized design, especially when incorporating boundary losses in the optimization process.

Keywords
Design optimization, computational analysis, viscothermal acoustics, material distribution topology optimization, acoustic black holes, finite element method

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