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A computational multiscale homogenization framework accounting for inertial effects: application to acoustic metamaterials modelling

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Abstract

A framework, based on an extended Hill-Mandel principle accounting for inertial effects (Multiscale Virtual Work principle), is developed for application to acoustic problems in the context of metamaterials modelling. The classical restrictions in the mean values of the micro-displacement fluctuations and their gradients are then accounted for in a saddle-point formulation of that variational principle in terms of Lagrange functionals. A physical interpretation of the involved Lagrange multipliers can then be readily obtained.

The framework is specifically tailored for modelling the phenomena involved in Locally Resonant Acoustic Metamaterials (LRAM). In this view, several additional hypotheses based on scale separation are used to split the fully coupled micro-macro set of equations into a quasi-static and an inertial system. These are then solved by considering a projection of the microscale equations into their natural modes, which allows for a low-cost computational treatment of the multiscale problem. On this basis, the issue of numerically capturing the local resonance phenomena in a FE^2 context is addressed. Objectivity of the obtained results in terms of the macroscopic Finite Element (FE) discretization is checked as well as accuracy of the homogenization procedure by comparing with direct numerical simulations (DNS). The appearance of local resonance band-gaps is then modelled for a homogeneous 2D problem and its extension to multi-layered macroscopic material is presented as an initial attempt towards acoustic metamaterial design for tailored band-gap attenuation.

Keywords: Multiscale modelling, Computational homogenization, Inertial problems, Acoustic metamaterials, Local resonance phenomena

1. Motivation

The field of computational multiscale modelling has experienced a significant development in the last decades and its progressively penetrating many different application fields within simulation-based techniques. Hierarchical multiscale techniques, based on homogenization theory, have specially captured the attention of the computational mechanics community given their ability to account for microstructural physical phenomena and their impact at a macroscopic scale. Moreover, homogenization-based multiscale simulations are regarded significantly inexpensive from a computational viewpoint compared to (single scale) direct numerical simulations (DNS) or concurrent multiscale techniques [19, 1] in which micro and macro levels are simultaneously processed in the computations. This feature is obviously more evident when the separation between lower and upper scales increases.

Our focus is centered in computational homogenization techniques in which the constitutive information driving the macroscopic analysis is computed from consecutive interactions between the macro and microscale. In other

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