Advanced modelling and design of vibro-acoustic metamaterials

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Vibro-acoustic metamaterials have recently emerged and shown potential as lightweight and compact solutions for high noise and vibration attenuation in targeted frequency ranges, called stop bands [1]. These stop bands arise from the inclusion or addition of resonators in or on a flexible host structure on a sub-wavelength scale. In the past decades, their versatility and effectiveness in treating vibration, acoustic radiation and transmission problems has been proven through a variety of predominantly academic demonstrators. In view of transforming these metamaterials into widely applicable and affordable noise and vibration engineering solutions, a variety of challenges needs to be overcome. Aside from robust and mass-manufacturability as well as broadband tunability, also fast and accurate performance predictions of realizable metamaterial solutions are required to further shorten the analysis, design and optimization times.

To analyze and design the vibro-acoustic performance of vibro-acoustic metamaterials, periodic structure theory is mostly used. By modelling a single unit cell, often using the finite element (FE) method, and applying the Bloch theorem, dispersion curves can be computed and stop bands are predicted as frequency ranges without free wave propagation (inverse approach) or as frequency zones with pronounced wave attenuation (direct approach). However, although the predicted stop bands are representative for the frequency range of noise and vibration attenuation, the accurate and efficient vibro-acoustic performance prediction of practically realizable metamaterials requires more advanced modelling.

In this talk, several recent developments in metamaterial modelling at KU Leuven are presented. These developments all start from FE unit cell models (Figure 1): (A) since FE unit cell models of complex metamaterial structures can become large, model order reduction (MOR) methods to accelerate dispersion curve computations have been investigated and extended towards vibro-acoustic unit cell models [2-4]; (B) to predict the sound transmission loss (STL) and sound absorption performance of infinite periodic structures with complex multi-physical unit cell designs, a fully coupled hybrid wave-based FE method has been introduced [5] and MOR methods for fast STL predictions have been proposed [6]; (C) to bridge the gap between structural stop band predictions and STL performance, an approach has been presented to compute the sound transmission contributions by individual wave modes of an infinite periodic structure [7]; (D) to efficiently account for finite structure effects on the vibro-acoustic performance, sub-structuring [8] and wave-based [9] MOR approaches have been proposed for fast finite periodic structure forced response computations starting from FE unit cell models; and (E) to tailor the metamaterial design in view of achieving desired vibro-acoustic performance, optimization approaches which leverage the aforementioned advanced modeling strategies have been proposed [4, 10].

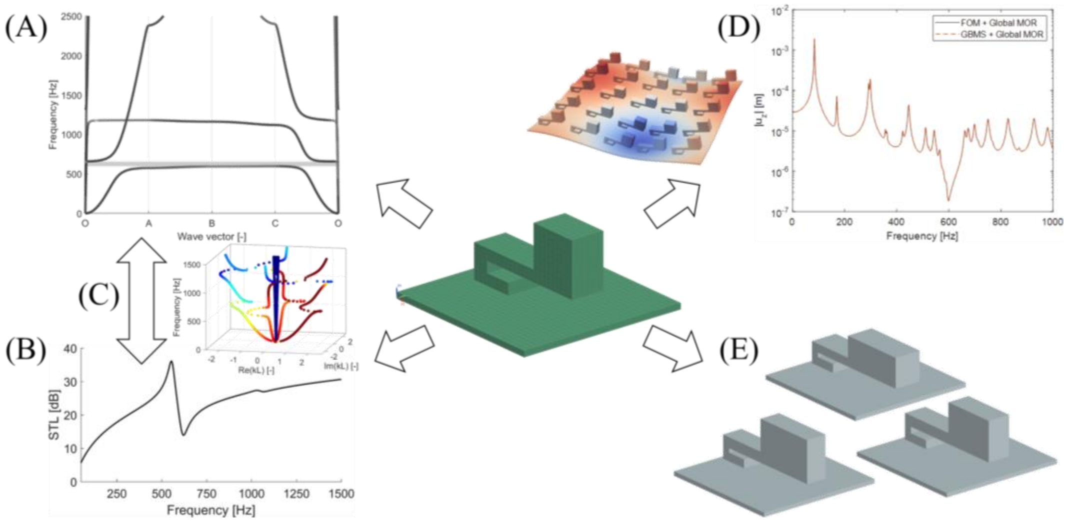

Figure 1: schematic overview of recent advanced, FE unit cell (center) based modelling methods: (A) fast (vibro-acoustic) dispersion curve predictions [2-4], (B) (fast) infinite periodic structure STL computations [5,6], (C) wave mode contributions to STL [7], (D) (fast) finite structure forced response computations [8,9], (E) metamaterial (design) optimization [4,10].

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