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Adaptive metacomposites: design strategy and experimental validation

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Abstract: Recent advances in modeling of multiphysics periodic systems allow designers to investigate new concepts for vibroacoustic absorption. In this work, we present a strategy to design adaptive metacomposites, namely host structures with periodic piezoelectric patches shunted with semi-passive electric circuits, together with experimental implementation.

The concept of metacomposite is presented in this paper, based on the coupling of two strategies for vibroacoustic control. The first one is related to periodic structures theories usually connected to metamaterial developments. In this case, it is well known that the dynamic behavior is fully connected to periodicity ratios, while corresponding pass bands and blocked bands can be of real use in vibration control. The second concept is associated to vibration control through piezoelectric and smart materials. Specifically, shunted piezoelectric smart materials are employed for the metacomposite achievement by integrating into the metamaterial electronics and numerical components allowing implementation of adaptive and controlled behavior. The notion of programmable matter within the meaning of work presented in [1] is extended to vibroacoustic programming. The paper main novelty is then the design through full numerical analyses of a smart structure [2] with broad band control abilities. Wave based methods and numerical simulation tools are adapted to the proposed concept, for both structural vibrations and acoustic phenomenon [3]. The metacomposite efficiency is illustrated from the low frequency range to the mid frequency band as well.

The metacomposite considered in this paper are illustrated in figure 1. The generic piezocomposite cell is first used for the optimization of electrical shunt $Z(\omega)$ by considering an infinite periodic distribution of the cells, and finally validated in the context of the integration of a finite structure.

The Floquet-Bloch approach [4,5] has been widely used for developing homogenization techniques and spectral asymptotic analyses. Nevertheless these approaches have been only developed for undamped or lightly damped mechanical systems. In these cases, most of the published works present techniques based on the mesh of a real k-space following the boundary of the first Brillouin zone for obtaining the corresponding dispersion curves and the associated Floquet vectors. For undamped systems, only propagative or evanescent waves exist corresponding to a family of eigen solutions purely real or imaginary. Discrimination between each class of waves is easy. If a highly damped system (whose FE matrices are complex and frequency dependent) and a frequency-dependent electrical shunt impedance are considered, the obtained eigenvalue problem is not quadratic and a complex specific numerical methodology has to be implemented. Furthermore, evanescent parts of propagating waves appear as the imaginary part of pulsation. It then becomes much more difficult to distinguish the propagative and evanescent waves as all solution appear complex. Another much more suitable possibility for computing damped system, dedicated for time/space deconvolution and for computation of diffusion properties as defined in [2], is to transform the discretized form of the weak formulation into a generalized eigenvalue problem where the pulsation ω is a real parameter corresponding to the harmonic frequency. Wave numbers and Floquet vectors are then computed. An inverse Fourier transformation in the k-space domain can be used to evaluate the physical wave's displacements and energy diffusion operator when the periodic distribution is connected to another system [6].

Using this methodology, optimal impedance of the electrical shunt is derived to minimize group velocity of flexural waves in the metacomposite. Optimal values correspond to negative capacitance and resistance which are synthetized using a dedicated semi-active circuit (ie. including passive components and an operational amplifier), as shown in figure 1.

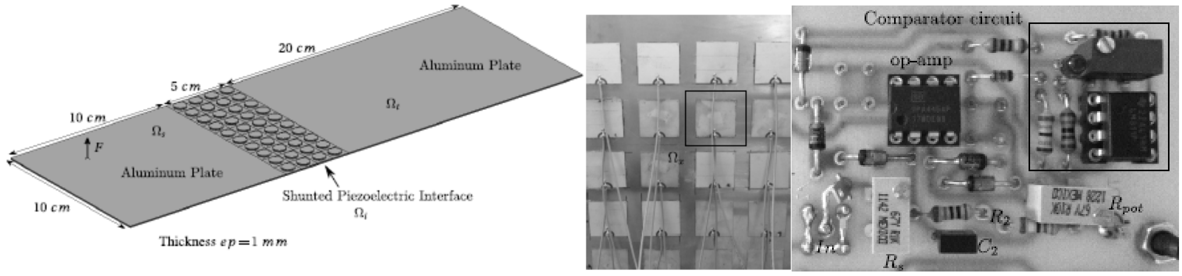

Figure 1 Concept of adaptive metacomposite: host structure, piezo patches and shunt circuit

The system is then implemented in a finite test structure, namely a plate host structure equipped with the optimized metacomposite barrier. The plate is excited with a wide band excitation on one side of the barrier (point P1), and measurements are performed at points P1 and P2 located on the other side of the barrier. Figure 2 shows the third-octave band plots of vibration amplitude reduction when comparing the system with/without activating the shunt circuits.

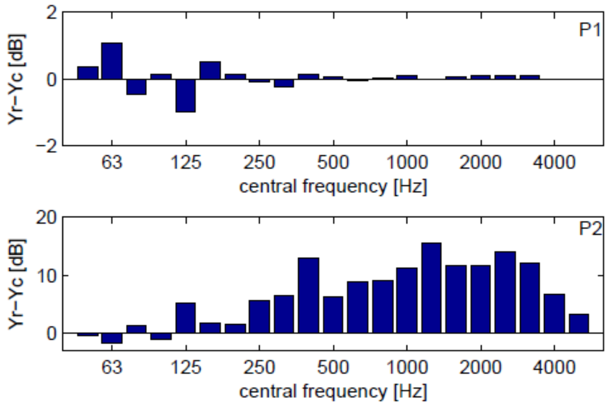

Figure 2 Third-octave band plots of vibration amplitude reduction at points P1 (excitation side) and P2 (receiving side)

At excitation point P1, almost no change in the vibration level is observed, which indicates that the presence of the barrier does not affect the input power. On the other side of the metacomposite, it can clearly be observed that the system is very efficient on a very wide frequency band, namely 125 to 5000 Hz with more than 10 dB reduction from 1000 Hz to 3500 Hz. Efficiency bounds are related to physical limits of the system, namely the length of the barrier and the design of the piezo-shunt system. These results validate the concept of metacomposite together with the associated design strategy which has been used in this work.

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References

[1] T. Toffoli and N. Margolus. *Programmable matter: Concepts and realization*. Physica D: Nonlinear Phenomena, 47(1-2):263 – 272, 1991.

[2] M. Collet, M. Ouisse, M. Ruzzene, and M.N. Ichchou. *A Floquet-Bloch decomposition of the elastodynamical equations: application to bi-dimensional wave's dispersion computation of damped mechanical systems*. International Journal of Solids and Structures, 48:2837– 2848, 2011.

[3] M. Collet, M. Ouisse, M.N. Ichchou and R. Ohayon. *Semi-active optimization of 2D wave dispersion into shunted piezo-composite systems for controlling acoustic interaction.* Smart Materials and Structures 21 (2012)

[4] G. Floquet. *Sur les équations différentielles linéaires á coefficients périodiques.* Annales de l'Ecole Normale Supérieure, 12:47–88, 1883.

[5] F. Bloch. *Über die Quantenmechanik der Electron in Kristallgittern*. Zeitschrift für Physik, 52:550–600, 1928.

[6] M. Collet, K.A. Cunefare, and N.M. Ichchou. *Wave Motion Optimization in Periodically Distributed Shunted Piezocomposite Beam Structures.* Journal of Int Mat Syst and Struct, 20(7):787–808, 2009.