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Locally resonant metamaterials utilizing Dynamic Directional amplification

MORIS KALDERON[1*], MARINA KALOGERAKOU[1], ANDREAS PARADEISIOTIS[1], IOANNIS ANTONIADIS[1]

1. National Technical University of Athens, School of Mechanical Engineering, Department of Mechanical Design & Automatic Control, Dynamics & Structures Laboratory, Heroon Polytechniou 9, 15780 Zografou, Athens, Greece [0000-0001-6939-726X], [-], [0000-0002-1593-9892], [-]

* Presenting Author

Abstract: Locally resonant metamaterials (LRM) with unit cells exhibiting local resonance present unique wave propagation properties at wavelengths well below the regime corresponding to bandgap generation based on spatial periodicity. However, they show certain constraints in designing systems with wide bandgaps in the low-frequency range. To face the main practical challenges encountered in such cases, including heavy oscillating masses, a simple dynamic directional amplification (DDA) mechanism is proposed. This amplifier is designed to present the same mass and use the same damping element as a reference two-dimensional (2D) Mass-in-Mass metamaterial. Thus, no increase in the structure mass or the viscous damping is needed. The proposed DDA can be realized by imposing kinematic constraints to the structure's degrees of freedom (DoF), improving inertia and damping on the desired direction of motion. A discrete element lattice model based on mass, stiffness and damping is used to establish dispersion behaviour and frequency response. Depending on the location of the DDA, inner our outer mass, both up-shift and down-shift in the bandgap frequency range and their extent are shown to be possible. The numerical results of an indicative case study show significant improvements and advantages over the reference LRM, such as broader bandgaps and increased damping ratio. Finally, a conceptual design indicates the usage of the concept in potential applications, such as mechanical filters, sound and vibration isolators, and seismic isolators.

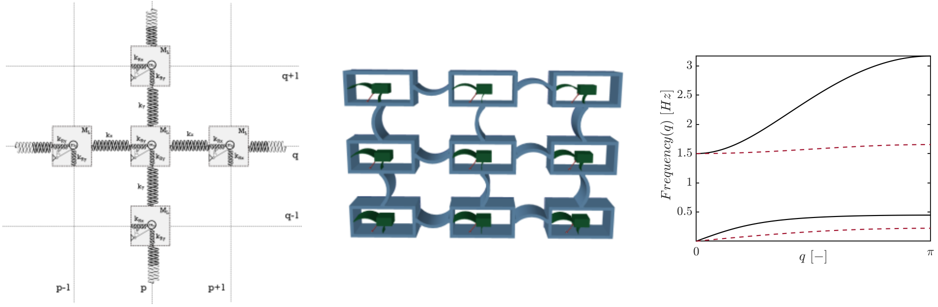
Keywords: metamaterial, local resonance, band gap, dynamic directional amplifier; damping

1. Introduction

Acoustic metamaterials (AMs) exhibit unusual dynamic properties not readily realizable in natural or other manmade structural materials from properties of their material constituents alone, owing to their local engineered configurations or "microstructures. Nonetheless, conventional locally resonant AM (LRAM) [1], may require very heavy internal parasitic masses, as well as additional constraints at the amplitudes of the internally oscillating locally resonating structures, which may prohibit their practical implementation [2]. Therefore, aiming for wide low frequency bandgaps based solely on LRAM is a challenge. Here, a simple dynamic directional amplifier [3] is introduced as a means to increase artificially the dynamic mass of the structure. The DDA mechanism is realized without additional masses or complex geometries since the amplification can be achieved by coupling the kinematic DoFs of the mass with a rigid link improving inertia and damping [4] on the desired direction of motion. The objective of this study is to indicate the characteristics of the directional amplification induced bandgaps and provide the theoretical framework.

2. Results and Discussion

Figure 1(a) shows the infinite periodic unit-cell lattice of the LRAM-DDA and figure 1(b) the corresponding conceptuptual implementation. An indicative example is presented based on the analysis conducted by Dertimanis et. al [5]. The selected parameters are M_L=1Mgr, M_R=8Mgr, k_L= k_R=79kN/m and correspond to a seismic isolation application Figure 1(c) illustrates the dispersion cuves of the LRMA without (black curves) and with the DDA mechanism, where the latter one increase the normalized bandwidth from $b_w = 1$ to 1.53 $(b_w = f_H - f_L)/f_{av})$.



(a) **(b)** **(c)**

Fig. 1. (a) 2-D Mass-in-Mass lattice with Dynamic Directional Amplifiers (DDA), **(b)** Conceptual design of the proposed Metastructure, **(c)** Dispersion curves: irreducible Brillouin zone. The black curve corresponds to the structure without the DDA and the red curve to the structure with the DDA.

3. Concluding Remarks

The proposed enhanced LRAM shows improved filtering properties in the low frequency regime. The provided indicative implementation of this concept shows promise towards developing low-cost metamaterial designs suitable for acoustic and seismic wave manipulation.

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