Mechanical metamaterials with local inertia amplification: nonlinear dispersion properties

Valeria Settimi*[1], Marco Lepidi[2], and Andrea Bacigalupo[2]

[1]DICEA - Polytechnic University of Marche – Italy
[2]DICCA - University of Genoa – Italy

Abstract

Architected metamaterials yielding superior dynamic performances can be conceived by realizing local mechanisms of inertia amplification in the periodic microstructure [1]. A periodic cellular waveguide characterized by an intracellular pantograph mechanism is considered as minimal physical system simulating an inertially amplified metamaterial [2]. A discrete tetra-atomic model is formulated to describe the undamped free dynamics of the cell microstructure. The ordinary differential equations of motion feature quadratic and cubic inertial nonlinearities, induced by the axial indeformability of the pantograph arms connecting the principal massive atoms with the secondary massive atoms, serving as inertial amplifiers. Nonlinear dispersion properties governing the free undamped propagation of harmonic Bloch waves have been investigated by means of a general asymptotic approach in absence of internal resonances [3]. Particularly, the multiple scale method up to the third order is adopted to analytically determine the nonlinear functions relating dispersion properties (wavefrequencies and waveforms) and oscillation amplitude of the propagating wave. Specifically, the nonlinear wavefrequencies and waveforms are determined as analytical closed-form functions of the parameters, quadratically depending on the oscillation amplitudes. The acoustic and optical frequencies exhibit the typical softening behavior caused by dominant cubic nonlinearities in inertially nonlinear systems, even if hardening acoustic frequencies can be identified in particular regions of the parameter space. The invariant manifolds associated with the nonlinear acoustic and optical waveforms show synclastic or anticlastic distortions of the linear (planar) manifolds in the space of principal coordinates. Validation of the analytical outcomes is performed by directly integrating the nonlinear equations of wave motion for different initial conditions. The obtained numerical solutions are shown to lie on the manifold surfaces with fine qualitative and quantitative approximation, confirming the goodness of the analytical approach.

References

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*Speaker