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Metamaterials For Vibration Mitigation: From Linearity To Vibro-Impact

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Engineering vibration has traditionally comprised a very active research area, motivated by the abundance of associated technological applications. In this domain, the safety margins linked to the protection of humans, machines and structures, from undesired/uncontrolled motions of diverse frequency characteristics dictate design. The attenuation of engineering vibration has been treated using a mix of passive, active and even semi-active methods. Passive vibration control typically dominates its active counterpart, for being simple, mature and of sufficiently lower lifecycle costs. An inherent disadvantage, however, of passive devices is their inability to adapt, or at least to perform on par in wide frequency ranges; their properties remain fixed to their initial design and implementation. Tuned–mass dampers are a notable example of such a limited performance. To address this issue, semi-active and hybrid methods have been introduced with promising results, but at the cost of additional equipment and lower semi-active force amplitudes. As an alternative, a new concept for passive vibration mitigation has emerged by the exploration of metamaterials. These comprise a special class of periodic structures, characterized by fascinating filtering effects: when the frequency of the incoming excitation falls into their "blind" zone, the propagation of motion is arrested in any direction, thus forming a "band-gap". This work reviews the main attributes of metamaterials as vibration isolation devices. Starting from the notion of dispersion curve in a continuous medium, the linear metamaterial case is first considered via discrete-space, mass-and-mass/mass-in-mass configurations. It is shown how the, so called, frequency band-gap is shaped and which are the associated challenges in regards to its breadth, as well as to the arbitrary selection of the low-frequency threshold; a critical quantity in many engineering applications. As a rule, low wave speeds are required for obtaining a low-frequency band-gap, which is particularly relevant for structural vibration mitigation, and may be succeeded via heavy inclusions in a soft medium and/or a large lattice constant. Since weight, low stiffness and large sizes are unfavorable for lattices that are to be used for practical purposes, the tutorial proceeds by exploring the introduction of nonlinearities into the metamaterial. The effects of soft nonlinearities on the forming of dispersion curves are first outlined, followed by the demonstration of the meta-impactor: a strongly nonlinear metamaterial that comprises of an impact damper as the unit cell. A number of case studies of different scales are presented, ranging from wind turbines to buildings and meta-surfaces.