Dynamic Response Assessment of Impact Meta-Dampers

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Summary. Recently, the concept of metamaterials, initially studied for electromagnetic applications has gained interest within a civil engineering context [1, 3]. It has been shown that periodic arrangement of resonators, referred to as unit cells, can provide beneficial properties in vibration absorption, within a specific range of frequencies, the so-called bandgap. In order to take advantage of the full potential these unique structures can offer, a wider breadth of the bandgap is pursued, while additionally shifting the lower bound to lower frequencies renders metamaterials appealing for civil engineering applications. One promising solution to this requirement is the use of nonlinear resonators, which form part of the metamaterial configuration. In the current work, periodic structures consisting of impact damper resonators are investigated, thus introducing a highly nonlinear behaviour. The performance of a single impact damper has already been investigated [4] and its dynamic response has been proven to be advantageous for vibration attenuation. Further exploiting this phenomenon, the current study is extended to multiple degree of freedom (MDOF) systems, which are investigated both numerically and analytically. The MDOF systems occur as concatenation of a finite number of impact damper unit cells. Several characteristics of the proposed configuration are explored as variable parameters for optimization purposes. For the assessment of the system's efficiency, different metrics are being studied, including the frequency response function and the total energy loss as a result of the metastructure contribution. The results confirm the potential of utilization of the metamaterial concept, building on impact phenomena, for vibration attenuation.

Introduction

A significant concern in large-scale civil structures lies in response under dynamic loading, e.g. earthquakes. For this reason, the research community has been constantly working on designing systems, which are able to ensure structural safety, by minimizing the effects of the excitation on the structure. Recently, a novel idea has begun to draw attention in civil engineering applications, building on the concept of metamaterials or metastructures. These are structures characterized by extraordinary filtering properties, attained as a result of diversified mechanisms, such as their microscopic geometry, periodic arrangement, etc [5]. When the frequency of the incoming excitation lies within the constructed filter limits, the propagation of motion is arrested, thus forming a "bandgap". The challenge that arises, however, lies in the range of the bandgap as well as in the proper adjustment of the lower frequency threshold, which is essential in many engineering applications. In the current work, strong nonlinearities, in the form of impacts, are introduced, in order to address this challenge. Nonlinear attachments to the primary system are generally termed as nonlinear energy sinks (NES). There is extended research and literature in the field of NES, as for reference in the work of Vakakis et al. [4], which also investigates impact dampers as a nonlinear attachment from the non-smooth events point of view. Moreover, in the work of Ibrahim et al [2], analytical approximations of the dynamic behaviour of impacts are provided. Important is the contribution of Masri and colleagues on impact dampers, regarding their general motion [6], their stability analysis [7], as well as their dynamic response to random excitation [8]. Furthermore, the concept of impact dampers is closely associated with particle dampers. In fact, a lattice of several impact dampers can be considered to be a single particle damper. A detailed investigation on the latter, under random excitation, is provided in the work of Lu et al. [9].

Meta-impactor

The idea of the meta-impactor is inspired by the beneficial effect that a single impact damper can have on a structure, under dynamic loading [4]. The attempt is to protect a specific mass with the metamaterial configuration. The concept of the current work is based on the consecutive arrangement of impact damper unit cells (Figure 1). The unit cells consist of a rigid container, containing a laterally unconstrained mass, free to impact on the respective bounds. Furthermore, the resonators are connected elastically to each other, as well as to the protected mass on one end, and to a fixed support on the other. In the current study, the response of the system is investigated under input of a harmonic force F.

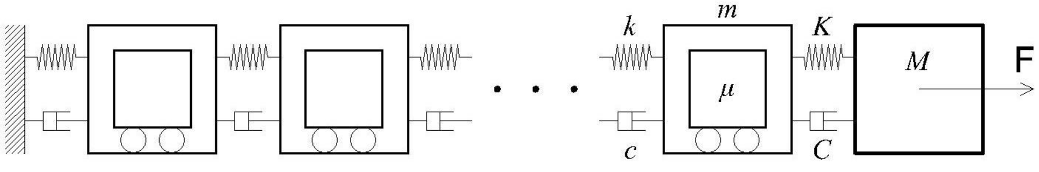

Figure 1: Metamaterial lattice configuration

Analysis

The response of the system is studied both numerically and analytically. As for the first part, every impact is analyzed as a non-smooth event, while the equations of motion are affected by a discontinuity. This approach provides results, which are directly linked to the specified parameters of each system (mass, stiffness, damping, etc.) and are restricted to discrete combinations of those parameters. Multiple analyses with varying parameters are carried out for optimization purposes, an example of which is shown in Figure 2. In order to better assess the behaviour of the metamaterial, an analytic parametric approach is pursued. For this reason, the non-smooth interaction between the container and the inner mass is approximated by a continuous highly-nonlinear function. In this setting, the analysis can be carried out parametrically, taking into consideration the variability of the system's characteristics.

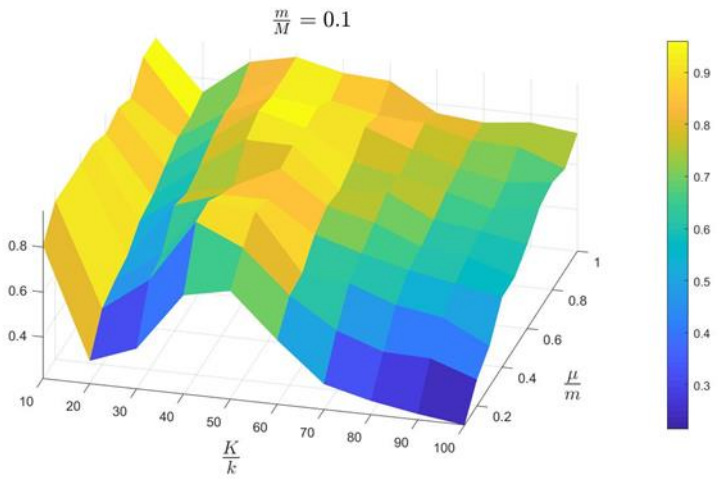

Figure 2: Percentage of energy absorption of the total input energy at 1 Hz for a 2 unit cell lattice and varying masses/stiffness ratios

Conclusions

The purpose of this study is to evaluate the performance of metamaterial lattices, consisting of impact damper unit cells, for vibration mitigation. The assessment of the performance is determined, depending on the frequency response function of the system, as well as on the calculation of the total energy absorption. Furthermore, the results of the numerical and analytical procedures are compared, revealing consistency of the analytical approximation. This is particularly helpful for further simulations and subsequent analyses of the resulting dynamics. The concept of metamaterials is proven effective, given a proper design and optimization process, and is suited for shielding of structures from vibrations.

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