Flexible mechanisms as quasi-zero stiffness metamaterial resonators

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Abstract. There is an ever-increasing interest in resonant metamaterials (RMM), as they promote vibration attenuation in small packaging. In linear RMMs, the bandwidth and depth of the attenuation are linked to the resonator mass, which results in significant added mass. In this context, nonlinear RMMs can provide interesting dynamic properties that result in frequency band broadening or more efficient energy absorption with different excitation levels. Properties include resonance frequency shifts and quasi-zero stiffness, which can provide better isolation and more efficient attenuation to the host structure. This work investigates the design and experimental validation of nonlinear resonators based on flexible mechanism topologies. The use of flexible elements tackles the dissipation mechanisms which inhibit the desired nonlinear phenomena in conventional linkage systems. The additive-manufactured resonators are tested under various static and dynamic conditions, with the aid of a Digital Image Correlation (DIC) system, to validate the design procedure.

Introduction

Vibration attenuation can be achieved via periodicity, which results in highly attenuated waves via an effect similar to band rejection [1], often referred to as *bandgaps*. Resonant metamaterials promote similar vibration attenuation with smaller packaging [2]. However, the frequency band and depth of the attenuation are directly linked to the resonator mass in linear metamaterials, which can result in significant added mass.

Results and Discussion

By leveraging nonlinear elements to provide frequency band broadening or more efficient energy absorption, we investigate the parametric design and physical realisation of quasi-zero stiffness resonant elements. Such nonlinear systems can provide resonance frequency shifts, resulting in better isolation and more efficient attenuation to the host structure [3, 4]. The proposed design can be seen in Fig. 1. The concept starts with a support structure and a flexible beam, to which a concentrated mass will be added at the centre. Both structures are additive-manufactured in ABS and work under prestress: The lateral poles are manufactured in the inverse shape of a tip-loaded cantilever, such that when assembled, they will be approximately straight up (Fig. 1b), while the flexible beam is designed to work on its post-buckling state [5]. When perceiving base excitation at low levels, the device behaves like a linear tuned mass damper (TMD) in either of its bi-stable positions. However, when the load is increased for certain frequency regions, the system undergoes its quasi-zero stiffness region and, eventually, flips between the stable poles.

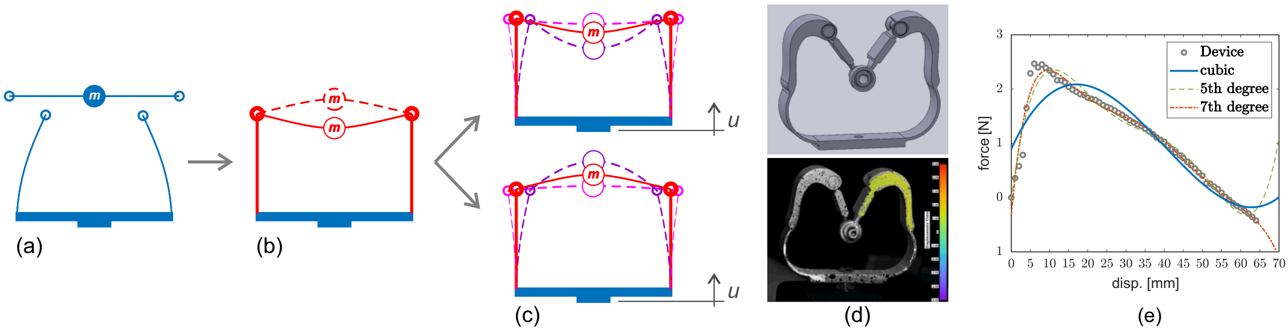

Figure 1: Bistable flexible mechanism: (a) unloaded parts, (b) prestressed assembly, (c) vibration around equilibria, (d) CAD concept and DIC measurements and (e) experimental nonlinear stiffness and curve fits.

Figure 1(d) shows the additive manufactured resonators model and DIC image processing, while (e) shows the experimental nonlinear stiffness achieved with such a design. Preliminary results [3] indicate that using such nonlinear resonators can increase the bandwidth of local resonance-type bandgaps.

References

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