A Nonlinear Metamaterial Induced by Nonlinear Damping Effect with Inertia Amplifiers

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Abstract. In this paper, we studied a nonlinear metamaterial based on the nonlinear damping effect. The proposed design combines a linear host cantilever beam and periodically distributed inertia amplifiers as nonlinear local resonators. Firstly, the geometric nonlinearity induced by the inertia amplifiers is studied to reveal the amplitude-dependent damping effect. Secondly, a modal analysis method is implemented to form a lumped parameter model for the nonlinear metamaterial. This model is further solved by a numerical harmonic balance method under periodic base excitation. Finally, the nonlinear energy transfer inside the proposed design is studied to investigate the nonlinear interaction between local resonators and different vibration modes. The theoretical results show that the bandgap is amplitude-dependent, broadened, and gradually degenerated due to the nonlinear damping effect. It also further leads to an efficient modal dissipation capacity of the host structure, which has significant potential in shock wave mitigation.

Introduction

Recently, locally resonant metamaterials have been proven effective for vibration mitigation. However, their bandgaps decided by the underneath linear structures are usually narrowed when compared with the well-known nonlinear energy sinks [1]. Therefore, the pursuits to introduce nonlinearities into metamaterials have combined the advantages of these two research areas and raised novel concepts in the sense of structural dynamics, such as broadband vibration attenuation, non-reciprocity in periodic lattice, and breather energy localization. Based on this idea, we investigate a nonlinear metamaterial theoretically and experimentally for broadband and shock wave mitigation built on inertia amplifiers [2], which introduces the nonlinear damping effect into the metamaterial.

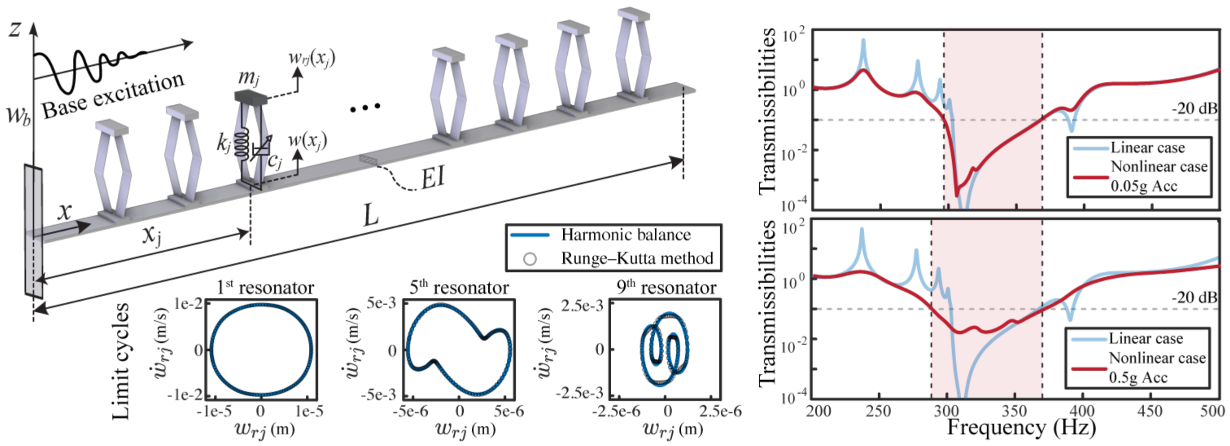

Figure 1: The schematic of the nonlinear metamaterial, the transmissibilities of the host beam, and the limit cycles of nonlinear local resonators.

Results and discussion

The schematic of the nonlinear metamaterials is shown in Fig. 1, which combines a linear host cantilever beam with inertia amplifiers as nonlinear local resonators. A modal analysis, together with a numerical harmonic balance method, is employed to solve the steady-state frequency response of the host beam and local resonators under harmonic excitation. The nonlinear transmissibilities show that the bandgap has been broadened due to the nonlinear damping effect. It also leads to the degeneration of bandgap with the increase of excitation level. In addition to the bandgap range, the modal frequency peaks have also been attenuated due to the nonlinear interactions with local resonators, which is verified by the limit cycles of the local resonators. With the wave propagation from the left to the right side of the host beam, the limit cycles of local resonators indicate more modal frequency interactions. This nonlinear interaction between the host beam and local resonators features an efficient modal dissipation capacity, and could be potentially used in shock wave mitigation.

References

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[2] Van Damme B., Hannema G., Sales Souza L., Weisse B., Tallarico D., & Bergamini A. (2021) Inherent non-linear damping in resonators with inertia amplification. *Appl. Phys. Lett.* **119**:061901