Self-adaptive wave propagation and synthetical vibration reduction of strongly nonlinear mechanical metamaterials

Xin Fang[*], Peng Sheng*, Chen Gong** and Li Cheng[**]

[*]National University of Defense Technology, Changsha, Hunan, China; E-mail: xinfangdr@sina.com

[**]Department of Mechanical Engineering, Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong, China

Abstract. We find and demonstrate that the band structure or bandgap inside a nonlinear metamaterial self-adapts to propagation space and time, which breaks the understanding indicated by Bloch theorem. Moreover, we realized the synthetical vibration reduction (low-frequency, broadband, light-weight, highly efficient, and strong environmental suitability) desired in most engineering applications.

Introduction

Nonlinear acoustic/elastic metamaterials (NAMs) refer to mechanical metamaterials possess strongly nonlinear dynamic effects that trigger many peculiar behaviors. Their unusual properties for controlling elastic wave are attracting rising attention. Many new unusual properties remain unveiled. Moreover, strongly nonlinear metamaterials can present ultralow and ultrabroad band attenuation of vibration and sound radiation. However, it is very challenging to conceive a vibration control measure that simultaneously possess the capability of low-frequency, broadband, light-weight, highly efficient, and strong environmental suitability. Such synthetical vibration reduction is highly desired in most engineering applications such as the aircraft, spacecraft and high-speed trains need.

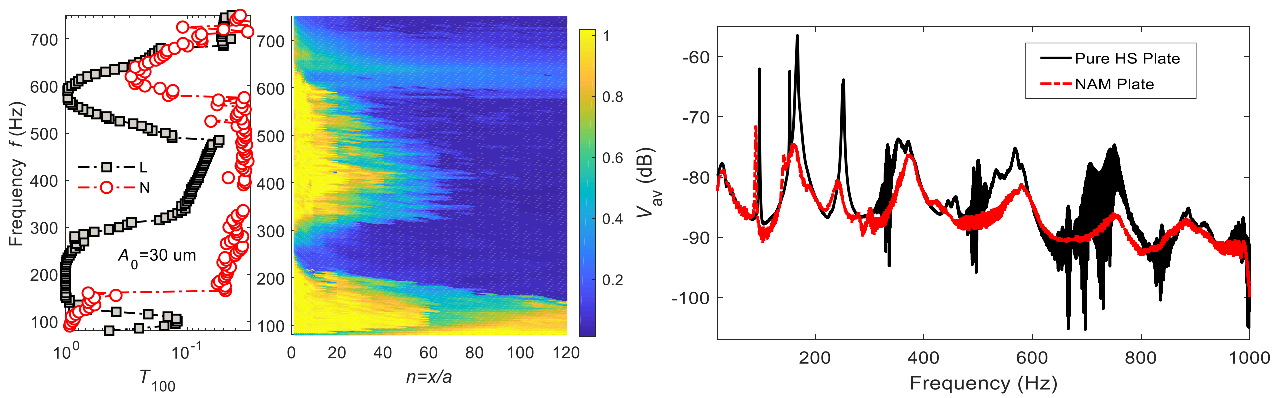

Figure 1: Self-adaptive wave propagation and synthetical vibration reduction effects

Results and discussion

This paper reports two aspects of the latest progress on nonlinear metamaterials: (1) Band degeneration and self-adaptive propagation. Bandgap and band properties play important roles in wave manipulation of metamaterials. We find that the strongly nonlinear metamaterials present particular band degeneration and bifurcation, accompanied with the wave mode transfer in their unit cells. More importantly, we find and demonstrate that the band structure or bandgap inside a nonlinear metamaterial self-adapts to propagation space and time, which breaks the understanding indicated by Bloch theorem. The self-adaptivity is a general physical property for different nonlinear metamaterials. (2) Synthetical unusual vibration reduction. We systematically investigate the vibration and sound radiation of strongly nonlinear elastic metamaterial plates or beams. We find that the double-ultra effect is sensitive to the bridging coupling between nonlinear local resonances, but is non-sensitive to the attached mass, indicating an exceptional way to achieve "light-weight". Furthermore, we optimize the vibration reduction of metamaterial beams, stiffened plate and sandwich honeycomb plate. Our experiments demonstrate that the nonlinear metamaterial design can reduce the vibration in 0~1000 Hz of stiff structures by 10-20 dB with only 6%~20% attached mass. The synthetical unusual vibration reduction is achieved. All these indicate the significant application prospect of strongly nonlinear metamaterials.

References

[1] Fang X., Wen J., Bonello B., Yin J., Yu D. (2017) Ultra-low and ultra-broad-band nonlinear acoustic metamaterial. *Nature Commu.* 8: 1288

[2] Fang, X., Wen, J., Benisty H., Yu, D. (2020) Ultrabroad acoustical limiting in nonlinear metamaterials due to the adaptive-broadening bandgap effect. *Phys. Rev. B* 101, 104304

[3] Sheng P., Fang X., Dai L., Yu D., Wen J. (2023) Synthetical vibration reduction of the nonlinear acoustic metamaterial honeycomb sandwich plate. *Mech. Syst. Signal Pr.* 185: 109774