Multiple Internal Resonance Activation of Weakly Coupled Structure for Energy Harvesting Applications

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Abstract. Energy harvesters (EHs) have gained significant attention as potential sources of renewable energy that can help in reducing CO_2 emissions. Their potential can be attributed to their capability of converting normally wasted kinetic energy into usable electrical energy to power sensors located in remote areas, inaccessible locations, or harsh environments. Air conditioning (AC) units are one of the widely available sources of wasted vibration energy. Hence, developing high-performance energy harvesters that utilize the vibration of AC units is desired to power indoor air quality sensors and structural health monitoring systems. However, the performance of energy harvesters is hindered by the low amplitude of the source vibration and the broad frequency spectrum. Here, we propose a novel design based on 3D-printed weakly coupled structural elements with planned dynamic characteristics. The structures are designed to enable the activation of the 1:1, 1:2, and 1:3 internal resonances. This broadens the frequency response and increases its amplitude. This work addresses, experimentally and numerically, the effect of local and global mode interactions to enhance the frequency response bandwidth.

Introduction

Ambient vibrations have a wide range of frequency spectrum and relatively low amplitudes. Hence, nonlinear vibration energy harvesting (NVEH) has been introduced to overcome these challenges by broadening the frequency response bandwidth, improving the power output, and enhancing the responsiveness to a general form of excitations. Different NVEH techniques have been reported in the literature including the utilization of oscillators / resonators with on Duffing nonlinearity, bi-stability, multi-stability, parametric, and stochastic characteristics [1-3]. The present work aims to investigate the broadening of the frequency bandwidth in VEH by using weekly coupled structures that are intentionally designed to have 1:1, 1:2, and 1:3 internal resonances. The nonlinearity is introduced by selecting the appropriate material with quadratic nonlinearity and structural elements with cubic geometric nonlinearity.

Results and Discussions

To demonstrate the concept, we utilize two clamped-clamped beams that are weakly coupled near the built-in supports, as shown schematically in (Fig. 1-a), where the plate has a thickness of 1 mm. Using finite element analysis, the dimensions of the structure are carefully tuned such that the first two global modes are in close proximity (Fig. 1-b), hence, their ratio is close to 1:1. At the same time, the ratio of the third and the first modes are tuned to the 2:1 ratio. These commensurate ratios are the necessary for the activation of the 1:1 and 2:1 internal resonances. This leads to widening the frequency response. To study the plate dynamics, we use a shaker to actuate the plate with different acceleration levels and a laser Doppler vibrometer to record the response. As shown in (Fig. 2-c, and d), the experimental results demonstrate the possibility of widening the frequency response bandwidth and simultaneously activating higher-order modes. In the final version of this conference paper, the result are compared with the conventionally used singly clamped-clamped structures. Also, we develop an analytical model to simulate the device's response and explore the behavior at different operating conditions that cannot be realized with the current experimental setup.

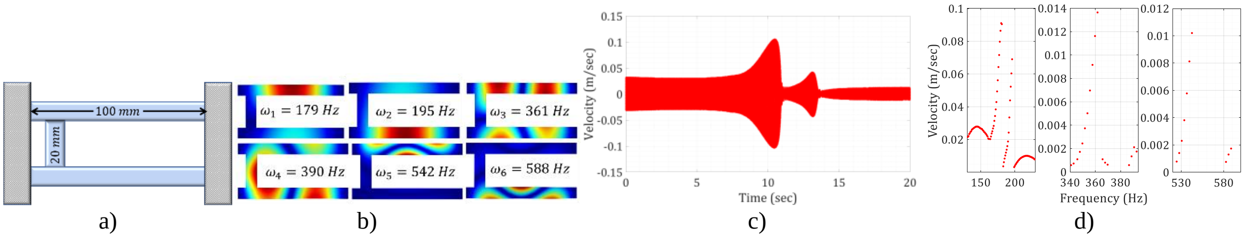

Figure 1: a) Schematic of the used structure, b) the first six global mode shapes, c and d) Time domain of forward frequency sweep and the corresponding frequency response.

References

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