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Nonlinear targeted energy transfer of two coupled cantilever beams coupled to a bistable light attachment

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ABSTRACT

In order to control the sound radiation by a structure, one aims to control vibration of radiating modes of vibration using "Energy Pumping" also named "Targeted Energy Transfer". This principle is here applied to a simplified model of a double leaf panel. This model is made of two beams coupled by a spring. One of the beams is connected to a nonlinear absorber. This nonlinear absorber is made of a 3D-printed support on which is clamped a buckled thin small beam with a small mass fixed at its centre having two equilibrium positions. The experiments showed that, once attached onto a vibrating system to be controlled, under forced excitation of the primary system, the light bistable oscillator allows a reduction of structural vibration up to 10 dB for significant amplitude and frequency range around the first two vibration modes of the system.

1. Introduction

Despite active work along the years, reducing noise is an attractive topic because it allows, for example, improved fatigue resistance with a consequent reduction in maintenance costs and noise reduction resulting in increased comfort. Many active and passive devices have been developed to improve the vibroacoustic behaviour of mechanical assemblies such as double-leaf walls.

In the passive domain, for example, the absorption of acoustic waves is typically accomplished through the absorbent material placed on the domain walls. The effectiveness of the device depends strongly on the frequency of the waves to be absorbed. To mitigate structural vibration, the Frahm absorber [1], consisting of a mass–spring–damper system, tuned to the frequency of vibration to eliminate is very efficient but has a limited frequency range of effectiveness [2]. Passive nonlinear Energy Pumping is a way to overcome such a limitation. Since the seminal work by Gendelman et al. [3,4], because of its various and numerous applications, the problem of passive nonlinear energy pumping has become a subject of growing interest [5]. The simplest case requires consideration of a linear mechanical or acoustical system connected to a secondary oscillator having a strongly nonlinear stiffness (typically a cubic one). This attachment is usually termed as nonlinear Energy Sink (NES). This kind of nonlinearity corresponds to a resonance of the NES that varies with the amplitude of excitation. This enables a passive nonlinear energy transfer that is realized through resonance capture at high energy value [4]. Passive nonlinear energy transfer from the primary system to the NES occurs under resonance condition once the NES amplitude

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rises above a certain threshold; reverse energy flow from the NES to the primary system is prevented because of resonance escape due to the energy decrease induced by dissipation. The existence of such threshold in purely cubic or quintic NES can be viewed either as advantage or as disadvantage depending upon application. But the main feature of energy pumping lies in the fact that the higher the frequency of the primary linear system to control, the higher the amplitude for efficient nonlinear passive dissipation.

To date a wide variety of NESs have been proposed and tested: pure cubic spring in mechanical systems [5], membrane acting as cubic or quintic spring in acoustical systems [6], loudspeaker used as a suspended piston acting as an essentially nonlinear oscillator [7]. A numerical work by Gourdon and Lamarque [8] suggests that a NES described by a nonlinear Duffing equation with negative stiffness, acting as a chaotic system, is able to achieve energy pumping for low energy level. The recent theoretical and numerical work by Savadkoohi et al. [9] and Manevitch et al. [10,11] showed that a bi-stable nonlinear oscillator manifests significant advantages with respect to energy pumping efficiency. We have developed an experimental nonlinear bi-stable absorber made of a small mass fixed at the midspan of a buckled beam, similar to that proposed in [11], that provides improved efficiency in frequency and excitation range over existing passive devices.

In order to control the sound radiation by a panel, one aims to control vibration of radiating modes of vibration using energy pumping. This principle is here applied to a simplified model of a double leaf panel. This model is made of two beams coupled by a spring. One of the beams is connected to the nonlinear resonator. This nonlinear resonator is made of a 3D-printing support on which is clamped a buckled thin beam with a mass fixed at its middle. The main feature of this nonlinear resonator lies in the buckling that allows a bi-stable comportment easy to control, in the following it is denoted by bi-stable attachment (BSA). Our experimentations show that this simple device leads up to more than 10 dB attenuation for the first two vibration modes of the system.

An optimization made on a simplified model of the device by a parametric study of the influence of dissipation is conducted. We show that for a wide range of configurations with one nonlinear dynamic absorbers, a reduction up to more than 10 dB of the vibration of the primary system around its first two resonances is obtained.

Section 2 is devoted to the description of the experiment. In Section 3 a simplified model is established. In Section 4 experimental and numerical results show the efficiency of the nonlinear absorber to attenuate the vibration of the primary linear system. The conclusions are given in Section 5.

2. Experimental fixture

Since our aim was to describe the main feature of a double leaf wall close to its mass-air-mass resonance, we have chosen to make a simplified but representative experiment. A photograph of the fixture is given in Fig. 1 and a sketch of it is given in Fig. 2. Each panel is replaced by a cantilever viscously damped beam whose dimension had been chosen to recover the feature of the panel. Each beam is made of steel with Young modulus E_b=185 GPa, volume mass density $\rho_b = 7621$ kg/m^3 and viscous damping $\mu_b = 0.1$ kg/s. Its dimensions are given by its thickness that is h_b=4.2 mm and its height that is e_b=2.52 cm; its length L=35 cm is comparable to the half size of a double leaf panel made with BA13 plaster plates fixed on vertical studs whose spacing is generally recommended to be close to 60 cm. The two beams are connected by a coupling spring with mass m_c=6 g and stiffness $r_c = 2200$ kg s^{-2} corresponding to the stiffness of the air gap separating two panels in usual conditions. This spring is located close to the free end of the beams at x_N=34.5 cm. The excitation is made by a non-contact driver located at $x_0 = 3.5$ cm of the clamped end of a beam. The BSA consists in a small mass (here a mass $m_0 = 2.6$ g had been chosen) fixed at the middle of very thin buckled viscously damped steel beam with Young modulus E=200 GPa

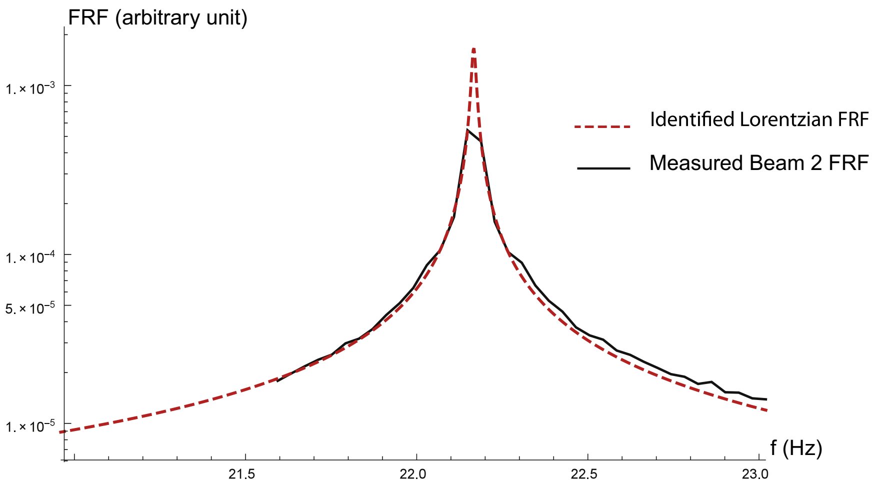

Fig. 1. Photograph of the experiment. In that experiment, only one BSA is active. The second remains fixed.