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Mitigation of nonlinear vibrations with a digital piezoelectric tuned vibration absorber

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Abstract This work presents an experimental implementation of a piezoelectric tuned vibration absorber realized using a digital impedance. The flexibility provided by this approach allows to synthesize arbitrary linear and nonlinear shunt circuits. The superiority of a nonlinear absorber over its linear counterpart is demonstrated. The principle of similarity is also validated.

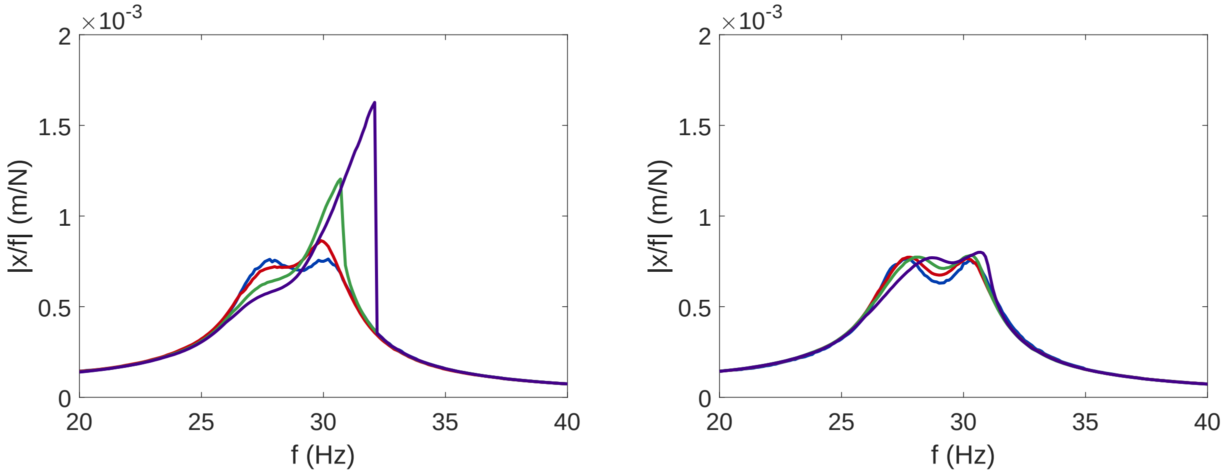
A piezoelectric transducer coupled to a structure may convert a part of its mechanical energy into electrical energy. This energy can then be dissipated through an impedance, often called shunt circuit. This approach, termed piezoelectric shunt damping, can be used to reduce undesirable high-amplitude vibrations. Depending on the complexity of the circuit and on the required parameters for its physical constituents, its practical realization may be challenging. A solution to circumvent these issues is to use a synthetic impedance made up of a digital processing unit and a current source [1]. Owing to the flexibility offered by the digital processing unit, almost any impedance can be synthesized, including nonlinear ones with arbitrary functional forms. In this study, the digital impedance is used to realize both a linear and a nonlinear piezoelectric tuned vibration absorber to mitigate the resonance of a nonlinear structure.

The structure under test was a cantilever beam, to which is attached a thin lamina, responsible for an overall hardening behavior. Considering only the first bending mode of the beam, this structure can be modelled as a Duffing oscillator. The beam is covered with an array of piezoelectric patches, which are connected to a digital vibration absorber. Under an external forcing f, the displacement x and piezoelectric charge q of controlled system are governed by the following system of equations

$$\left\{ \begin{array}{rl} m\ddot{x} + c\dot{x} + k_{oc}x + k_3 x^3 - \theta q & = f \\ L\ddot{q} + R\dot{q} + \frac{1}{C_p^\varepsilon} q + C_n \mathrm{sign}(q)|q|^n - \theta x & = 0 \end{array} \right. , \tag{1}$$

where m, c, k_{oc} and k_3 are the mass, damping, linear stiffness and cubic stiffness coefficient of the host structure, respectively, θ is a piezoelectric coupling coefficient, C_p^ε is the piezoelectric capacitance and L, R and C_n are the inductance, resistance and nonlinear capacitance of the shunt circuit, respectively.

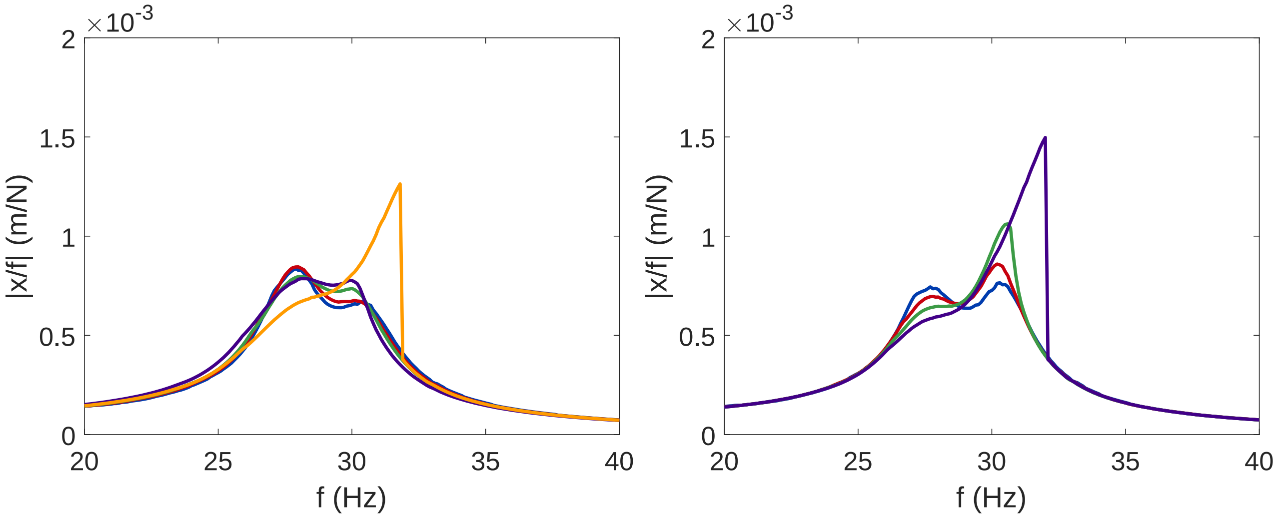
A linear absorber placed on a nonlinear structure and tuned to its linear resonance frequency may be detuned at high forcing amplitudes, on account of the frequency-energy dependence of the structure. This detuning may lead to a substantial decrease in performance, which may become critical given the high amplitudes at stake. Using a *nonlinear principle of similarity* [2] (i.e. the same functional form should be used in the absorber as that in the host structure), the range of forcing amplitudes over which the absorber is effective can be extended [3]. The superior performance of the nonlinear absorber over its linear counterpart is visible in Figure 1, where the nonlinear frequency response function (NFRF) of the controlled structure is depicted. Whereas the linear absorber is detuned at high forcing amplitudes, its nonlinear counterpart is able to track the changes in the resonance frequency of the host structure and maintain its nominal performance.



(a) (b)

Figure 1: Experimental NFRFs of the controlled system using a linear (a) or a nonlinear (b) shunt circuit (n=3): f=0.2N (—), f=0.4N (—), f=0.6N (—) and f=0.8N (—).

Other nonlinear functional forms were also tested in the absorber. As can be observed in Figure 2, the use of a quadratic or quintic nonlinear capacitance in the absorber clearly leads to an amplitude-dependent performance. The relevance of the principle of similarity is thus experimentally validated.



(a) (b)

Figure 2: Experimental NFRFs of the controlled system using a quadratic (n=2) (a) or a quintic (n=5) (b) capacitance in the shunt circuit for different forcing amplitudes: f=0.2N (—), f=0.4N (—), f=0.6N (—), f=0.8N (—), and f=1.0N (—).

References

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