Optimal energy harvesting from a stochastically excited nonlinear energy sink

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Abstract. Simultaneous vibration absorption and energy harvesting (EH) from a nonlinear energy sink (NES) subjected separately to random excitation and harmonic excitation is considered. Response statistics of the vibrating system and EH mechanism are obtained by the equivalent linearisation method. Multi-objective optimisation with a Dynamic Weighted Aggregation (DWA) technique is adopted to obtain optimum electrical and mechanical parameters and coupled electro-mechanical parameters with the twin objectives of vibration control and EH. 2-D Pareto optimal fronts are constructed to identify optimum feasible solution sets and optimum design parameters.

Introduction

Energy harvesting from a linear or nonlinear dynamic vibration absorber [1] essentially used as a passive vibration control device to reduce the vibration of a harmonically or stochastically excited primary system has been considered extensively in the literature [2]. The nonlinearity of the absorber and random nature of the excitation help to increase the effective frequency range of the absorber cum energy harvester. The vibration reduction of the primary system and effective energy harvesting often represent conflicting objectives. The simultaneous objectives of minimum primary system vibration and maximum energy harvesting and determination of optimal absorber and energy harvester parameters have however not been treated as much in the literature.

This paper considers the simultaneous optimisation of vibration absorber and energy harvesting of a stochastically excited linear oscillator with a Duffing type nonlinear vibration absorber as shown in Fig. 1a. This often represents conflicting objectives and has been the subject of active research. The coupled electro-mechanical equations of the two degree of freedom system can be expressed as [1, 3]

$$\begin{aligned} m_1\ddot{x}_1 + c_1\dot{x}_1 + k_1x_1 - c_2(\dot{x}_2 - \dot{x}_1) + G(x_1,x_2) &= f(t), \\ m_2\ddot{x}_2 + c_2(\dot{x}_2 - \dot{x}_1) - G(x_1,x_2) - \theta v &= 0, \\ C_p\dot{v} + \frac{v}{R} + \theta\dot{x}_2 &= 0, \end{aligned} \tag{1}$$

where m_1, m_2, v, R, c_1, c_2, θ, R and C_p are the system parameters and $f(t)$is the excitation term.

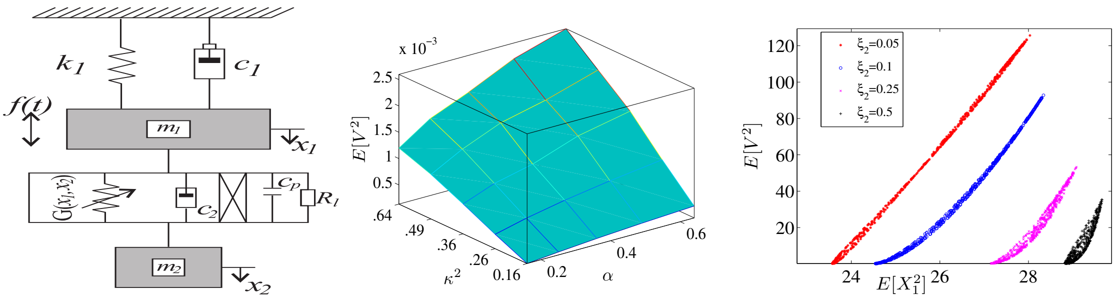

Figure 1: (a) Schematic of energy harvesting coupled with vibration absorber (b) variation of mean square for voltage (b) Pareto front for different values of absorber damping ξ_2,($\xi_2 = c_2/2\omega_2 m_2$).

Results and discussions

Response statistics of the vibrating system and EH mechanism are obtained by the equivalent linearisation method. Multi-objective optimisation with a Dynamic Weighted Aggregation (DWA) technique is adopted to obtain optimum electrical and mechanical parameters and coupled electro-mechanical parameters with the twin objectives of vibration control and EH. 2-D Pareto optimal fronts are constructed to identify optimum feasible solution sets and optimum design parameters. The system with optimal parameters shows considerable improvement both in terms of vibration absorption and energy harvesting compared to the non-optimal systems. It is found that electrical output is larger for decreased values of the system damping and mass ratio and for increased values of the non-dimensional time constant α and coupling strength κ^2, see Fig. 1b. In Fig. 1c the Pareto fronts are presented for various values of ξ_2. Further optimal parameters ξ_1, ξ_2, α, κ^2 and f are obtained by constructing the Pareto optimal front.

References

[1] Erturk,A., and Inman, D.J. Piezoelectric Energy Harvesting. John Wiley Sons, Chichester,UK 2011.

[2] Daniel, K., and Liu, K. A nonlinear energy sink with an energy harvester: Transient responses. Journal of Sound and Vibration. **333(20)**:4859-4880,2014.

[3] Ali, S.F., Adhikari, S. Energy Harvesting Dynamic Vibration Absorbers. Journal of Applied Mechanics. **80**:1-9,2013.