Probabilistic analysis of an asymmetric bistable energy harvester

João Pedro Norenberg*, **Americo Cunha Jr.****, Samuel da Silva *** and Paulo Varoto****
*São Paulo State University, SP, Brazil, ORCID 0000-0003-3558-4053
**Rio de Janeiro State University, RJ, Brazil, ORCID 0000-0002-8342-0363
***São Paulo State University, SP, Brazil, ORCID 0000-0001-6430-3746
****University of São Paulo, SP, Brazil, ORCID 0000-0002-1240-1720

Abstract. A nonlinear bistable vibration energy harvester is an efficient system to convert vibration energy into electricity to power mobile electronic devices, but they present a complex dynamic behavior and sensitivity to slight variations of the parameters. This work aims to show a comprehensive analysis of uncertainties in asymmetric bistable energy harvesters to obtain statistical information about how the variability of each parameter affects the harvesting process.

Introduction

Numerous efforts have been dedicated to nonlinear energy harvesters to convert vibrational energy into electricity using piezoelectric layers. Bistable energy harvesters have been extensively dedicated in the last decade [1]. Even though they are powerful at a broadband frequency, these systems present complex dynamic behaviors due to nonlinearity. In addition, investigating this system can still be a major challenge when introduced into an environment of uncertainty. Therefore, this work studies the effects of uncertainty parameters of the asymmetric bistable energy harvester.

To obtain a sophisticated and reliable model, asymmetries are introduced to take into account the geometry and manufacturing imperfections of the system. The system comprises a clamped-free ferromagnetic elastic beam in a vertical configuration attached to a rigid base, where a pair of magnets is asymmetrically placed on the lower part. The piezoelectric layers are glued on the beam's highest part, responsible for converting the kinetic energy into an electrical signal, which is dissipated in the resistor. An external periodic force excites the rigid base. The harvester is attached to a plane with a sloping angle ϕ, creating an asymmetry force of the gravity of the system. The lumped-parameter equation of motion for this system, presented in [2], are:

$$\ddot{x} + 2\,\xi\,\dot{x} - \frac{1}{2}\,x\,(1 + 2\delta x - x^2) - \chi\,v = f\,\cos(\Omega\,t) + p\sin\phi \qquad \text{and} \qquad \dot{v} + \lambda\,v + \kappa\,\dot{x} = 0, \tag{1}$$

where x is the amplitude; v is the voltage; ξ is the damping ratio; f is the amplitude of excitation; Ω is the frequency of excitation; λ is a reciprocal time constant; χ and κ represented the piezoelectric coupling terms; δ is a coefficient of the quadratic nonlinearity; p is the equivalent dimensionless constant of gravity.

Results and discussion

Each variable is described by a uniform distribution as defined by [3]. Figure 1 shows the joint-CDF (joint cumulative distribution function) of the mean power conditioned to each parameter of interest under different nominal excitation conditions. This figure shows the correlation of each parameter with the mean power, providing information on how to improve the power recovered.

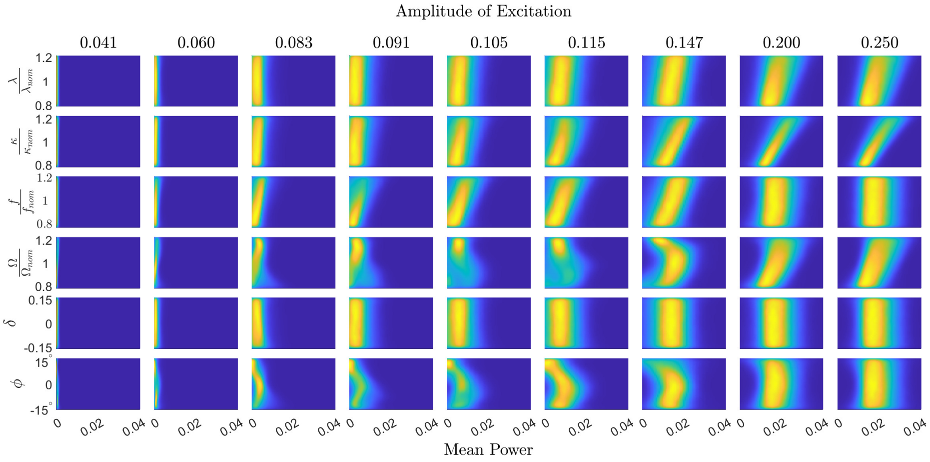

Figure 1: Joint-CDF of mean power conditioned for each parameter of the model for different values of the amplitude of excitation.

References

[1] Erturk A., Hoffmann J., Inman D.J. (2009) A piezomagnetoelastic structure for broadband vibration energy harvesting, *Appl. Phys. Lett.* **94**:254102.
[2] Norenberg J.P., *et.al.* (2022) Nonlinear dynamic analysis of asymmetric bistable energy harvesters. *Preprint: Research Square*.
[3] Norenberg J.P., *et.al.* (2022) Global sensitivity analysis of asymmetric energy harvesters, *Nonlinear Dyn.* **109**:443–458.