Response characteristics of energy harvesters under galloping and base excitations

Jiale Han[*], Dongmei Huang[*] and Wei Li[**]
[*]*School of Mathematics and Statistics, Xidian University, Xi'an, 710071, China*
[**]*School of Mathematics and Statistics, Xidian University, Xi'an, 710071, China*

Abstract. In this study, the performance of the galloping energy harvester is analyzed theoretically using the complexification-averaging method, and the original system equations can be transformed into a set of first-order differential equations. Based on the distributed parameter model of the energy harvester and to solve equations with coupled terms, the analytical expressions to determine the limit vibration frequency and limit vibration amplitude are derived. Further, the influence of parameters on nonlinear behaviors are studied. The frequency island with the variation on the stiffness coefficient and coupling parameters can be found. Additionally, study of nonlinear dynamics through phase diagrams and time histories, and the critical condition for identifying the unstable region of excitation amplitude is obtained. On the other hand, the parameters are optimized based on the maximum voltage amplitude. Finally, multilayer feedforward neural networks are superior to predicting the results.

Introduction

In recent years, there has been a lot of interest in harnessing the energy wasted in the surrounding environment to power wireless devices or to develop self-powered technologies[1]. Based on the difference of working environment, various environment energy such as the wind energy[2], solar energy, and mechanical energy[3] is considered as the potential candidate. However, most of the research results focus on analyzing the dynamic characteristics from numerical simulation and related experimental analysis, and few people evaluate the dynamic characteristics and obtain critical conditions through theoretical analysis. And there are few researches of using the complexification-averaging method to study the performance of galloping energy harvesters. Therefore, this paper combines employs the complexification-averaging method to explore the theoretical solutions of energy harvesters with under both galloping and base excitations and meanwhile improve energy harvesting effectiveness efficiency by using the optimizing strategy.

Results and discussion

The original system equations with coupling terms are transformed into the following set of first-order differential equations by the complexification-averaging method, and then the relationship between the displacement amplitude and the parameters of the galloping energy harvester is deduced.

$$[\frac{g}{2}+\frac{\eta}{2}\frac{\omega^2 m_e c_e}{\omega^2 c_e^2+(\omega_e^2-\omega^2)^2}+\frac{3k}{8}|\phi_1|^2]^2\times|\phi_1|^2+[\frac{\omega_n^2-\omega^2}{2\omega}-\frac{\eta}{2}\frac{m_e\omega(\omega_e^2-\omega^2)}{\omega^2 c_e^2+(\omega_e^2-\omega^2)^2}]^2\times|\phi_1|^2=\frac{f^2}{4} \tag{1}$$

Furthermore, the voltage amplitude can be obtained:

$$|\phi_2|=\frac{\omega^2 m_e}{\sqrt{\omega^2 c_e^2+(\omega^2-\omega_e^2)^2}}\times|\phi_1| \tag{2}$$

The critical conditions for identifying unstable regions are derived according to the implicit function derivative theorem. And under different linear coefficients of the galloping energy harvester, the displacement amplitude and the voltage amplitude as a function of the excitation amplitude are plotted in Figure 1.

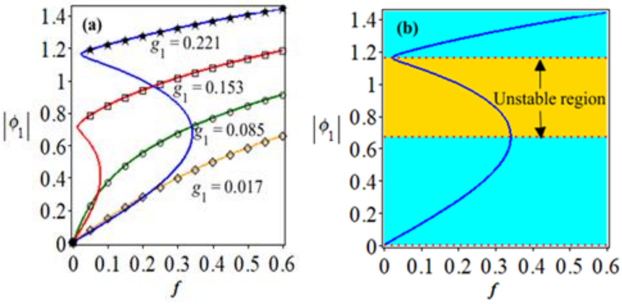

Figure 1: (a) The displacement amplitude with the variation of excitation amplitude under different linear coefficient of the galloping force ; (b) the unstable region for the displacement amplitude .

References

[1] Mannini C, Marra A M, Bartoli G. (2014) VIV–galloping instability of rectangular cylinders: Review and new experiments. *J. Wind Eng Ind Aerod***124**:124-109.

[2] Yang K, Wang J, Yurchenko D. (2019) A double-beam piezo-magneto-elastic wind energy harvester for improving the galloping-based energy harvesting. *J. Appl Phys Lett***115**.

[3] Zhou S, Lallart M, Erturk A. (2022) Multistable vibration energy harvesters: Principle, progress, and perspectives. *J. Sound Vib.*