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Determination of peak efficiency of galloping energy harvesters with various stiffness characteristics

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Abstract: In the work, through analytical considerations, the peak efficiency of three different variants of galloping energy harvester was defined. For this purpose, the authorial method based on elliptic harmonic balance was employed, consisting of comparison of impossible to analyze, accurate high order solutions, and simplified solutions of a linearized model. Research has shown that the peak efficiency of the hardening and bistable devices is greater by 17% and 30% respectively in regards to the linear device, while application of softening stiffness always leads to a loss of efficiency.

Keywords: energy harvesting, galloping, nonlinear vibration, elliptic functions

1. Introduction

In the era of the idea of the Internet of Things, the desire of scientists, engineers, medics, and even not-professionals is to continuously measure countless physical phenomena that occur both in our surroundings and at great distances beyond direct human reach. This increases the requirements for measuring devices and thus for their power supply – if access to the operating device is limited, it may not be possible to route the power cables or periodically exchange the batteries. The solution to this problem may be the application of autonomous devices - equipped with their generator harvesting ambient energy. An example of such a generator is the galloping energy harvester (GEH) - the device that allows to harvest the energy of vibrations induced by the flow.

In its simplest version, the GEH can be considered as a body (resonator) mounted on the elastic element, coupled to the piezoelectric (Fig. 1.). If an appropriately shaped body is used, at a certain flow velocity, called the critical velocity, negative damping will be induced in the system and thus stability of the system will be lost.

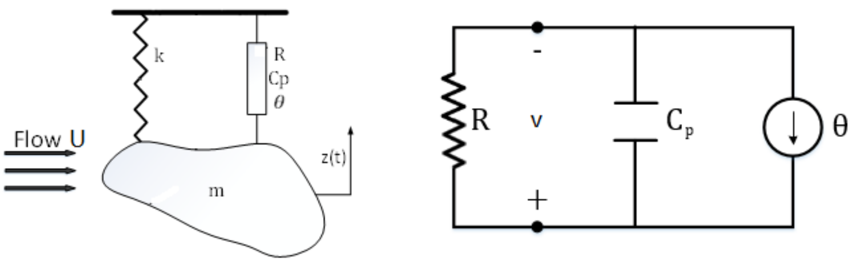

Fig. 1. Model of galloping energy harvester

One of the most important parameters describing energy generators is peak efficiency. In [1], the maximum efficiency was derived for the simplified linear GEH model, in which the harvested was defined as structural damping. In work [2], we confirm the validity of the obtained results also for the full electromechanical model. These results indicate that the peak efficiency of such a device depends only on the geometry of the resonator.

2. Results and Discussion

Employing the elliptic harmonics balance, the expressions describing the efficiency of various variants of devices were obtained as a function of the flow velocity in the form of $\eta_N = \eta_L \Psi$, where $\eta_L = \eta_L(U)$ is the efficiency of linear device and $\Psi = \Psi(m)$ (Fig. 2) is the coefficient that describes the impact of nonlinearity on the efficiency of the device in function of the modulus of elliptic function m. Depending on the nature of the nonlinearity, the value modulus is bounded in the following ranges: for hardening stiffness $0 < m < 0.5$, for softening stiffness $0 < m < 1$ and for bistable system $0.5 < m < 1$, it is therefore, possible to strictly determine the value of the Ψ coefficient at extreme its extreme values.

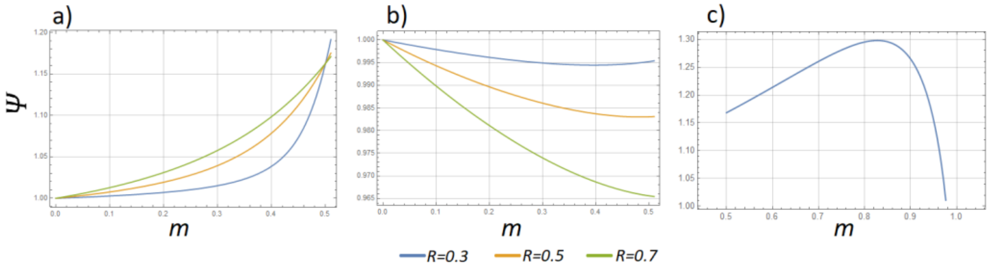

Fig. 1. Ψ values as a function of m for different R values and different stiffness variants: a) hardening, b) softening, c) bistable

Based on the above information, it can be concluded that: a) the function $\Psi(m)$ for the system with hardening stiffness depends on the values of the system parameters, but for the $m = 0.5$ it always has the same, maximum value $\Psi(0.5) \approx 1.17$, b) maximum value of $\Psi(m)$ for the system with softening stiffness is reached for $m = 0$ and $\Psi(0) = 1$ therefore, the softening stiffness will lead to a decrease in peak efficiency, c) regardless of the system parameters, the peak value of $\Psi(m)$ for the bistable system is $\Psi(0.83) \approx 1.30$.

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