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Enhancement of the performances of a quasi-periodic electromagnetic vibration energy harvester by energy localization

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INTRODUCTION

Developing techniques for vibration energy harvesting (VEH) based on various energy conversion mechanisms is being a focus of interest. In this context, a multimodal approach in a quasi-periodic system for vibration energy harvesting is investigated .
The basic idea to enhance the system performances consists in introducing imperfections. Thus, mistuning is achieved by varying the mass of few cells . These imperfections will lead to the vibration energy localization in regions close to the imperfections which will be exploited to maximize the harvested energy.

DESIGN AND MODEL OF THE VIBRATION ENERGY HARVESTER

The design and the equivalent model of the proposed harvester, made of two weakly coupled magnets guided by elastic beams, are shown in the figures 1 and 2, where the imperfection is tuned by the parameter α defined as the mass mistuning. The system is subjected to harmonic base excitation Y(t). The parameters k_{mec}, k_{mg} are respectively the equivalent mechanical and magnetic stiffness of the 2 degrees of freedom (dof) model.

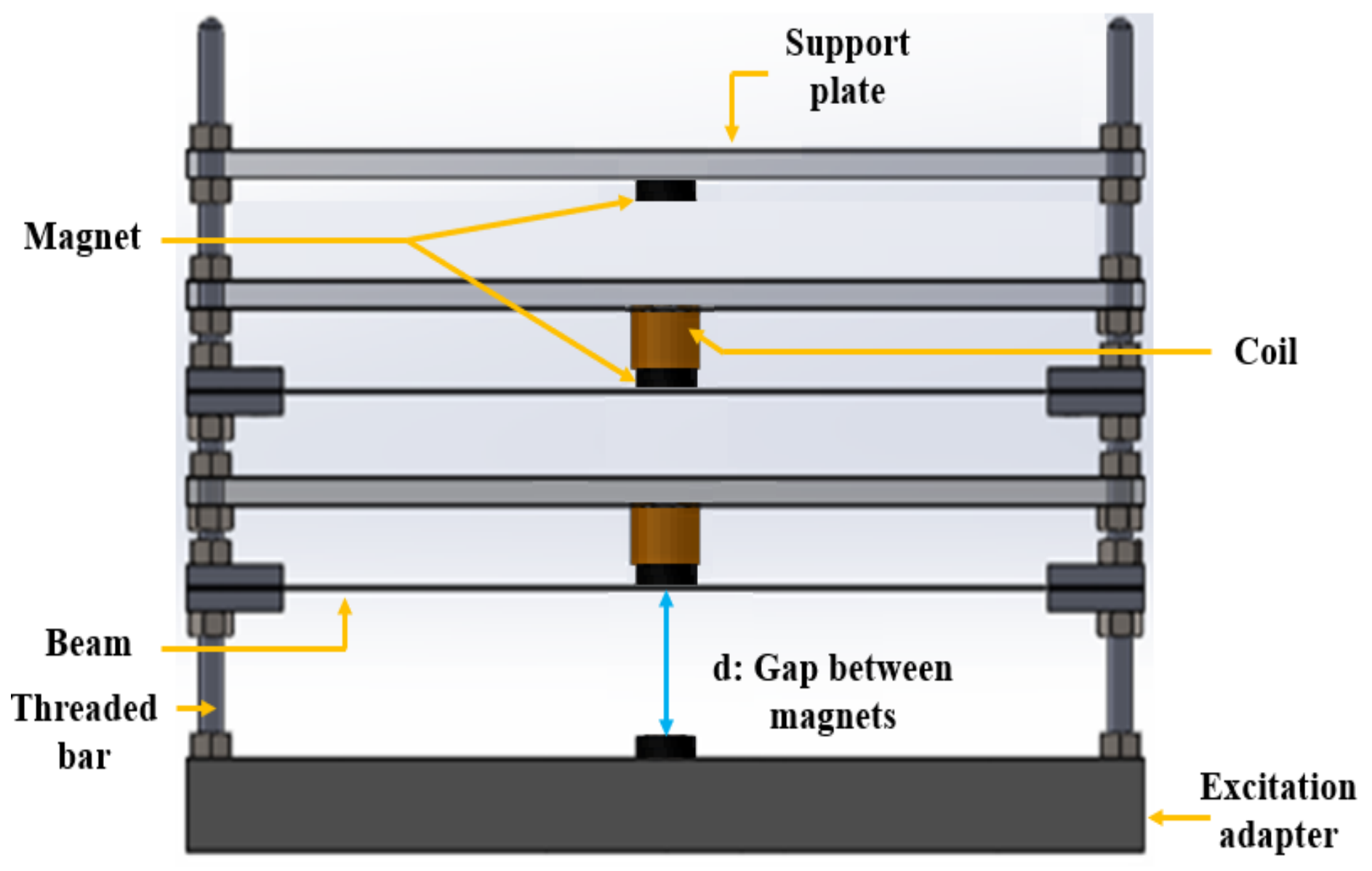

Figure 1. Linear VEH

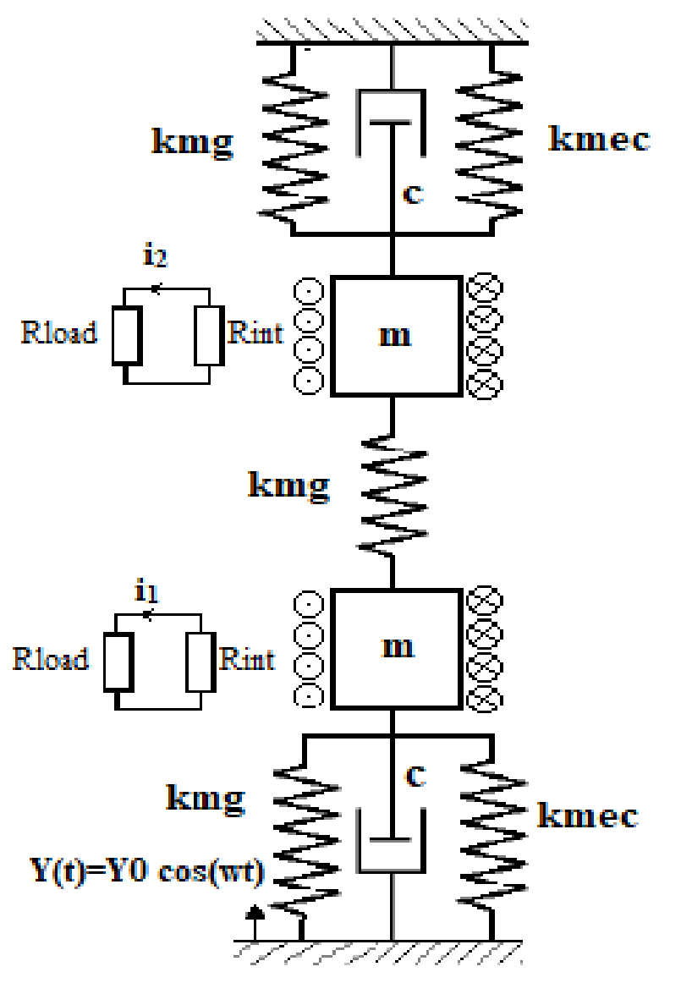

Figure 2. Equivalent model

The coupled multiphysics problem, for a 2-dof system, can be written in dimensionless form of modal amplitudes A_1, A_2 as:

$$\begin{cases} \begin{pmatrix} -\Omega^2 + i\Gamma\Omega + (1+2\beta) & -\beta \\ -\beta & -\alpha\Omega^2 + i\Gamma\Omega + (1+2\beta) \end{pmatrix} \begin{pmatrix} A_1 \\ A_2 \end{pmatrix} = \begin{pmatrix} (1+p) f \Omega^2 \\ (\alpha+p) f \Omega^2 \end{pmatrix} \\ i_k(t) = \dfrac{\Omega \delta d A_k}{(R_{load} + R_{\text{int}})T} \cos \Omega t \qquad k = 1,2 \end{cases}$$

Where p: mass ratio, β: coupling factor, Ω: frequency ratio, Γ: damping factor, f : dimensionless base excitation amplitude, δ: electromechanical coupling coefficient and T: time coefficient.

HARVESTED POWER AND MODAL LOCALIZATION

Two configurations to harvest the vibration energy were studied in order to highlight the benefits of localization:

1. From the vibrations of the two moving magnets (Figure 3).
2. From the vibrations of the mistuned magnet (Figure 4).

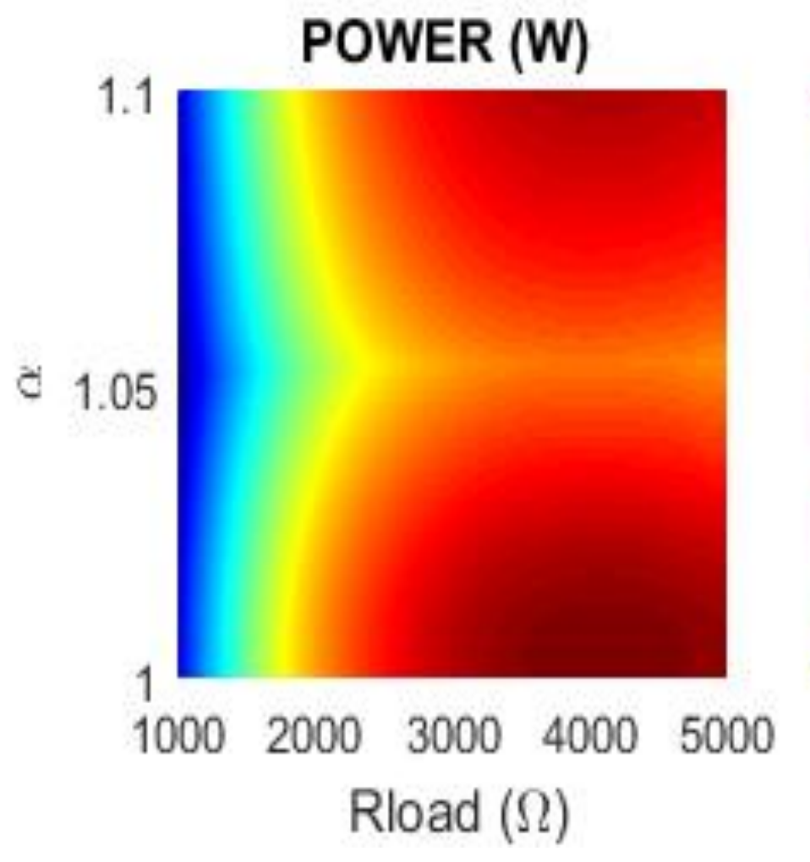

Figure 3. Harvested Power (config.1)

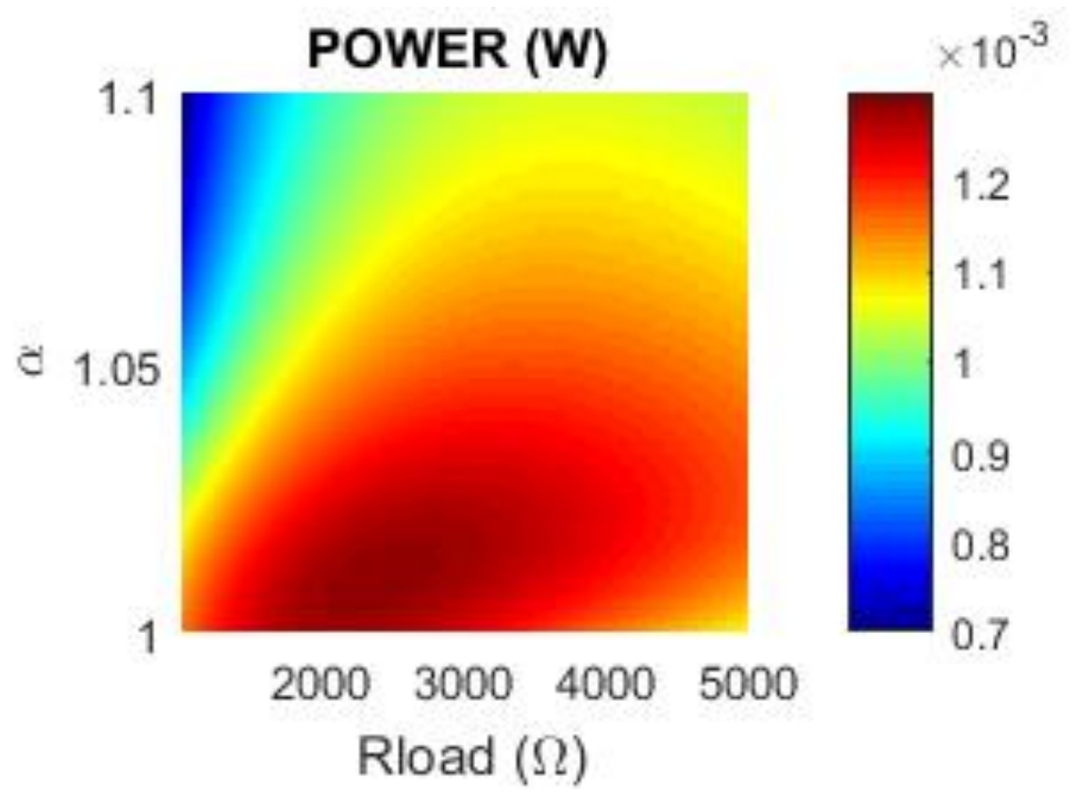

Figure 4. Harvested Power (config.2)

The harvested power from the two configurations are comparable. The 2nd configuration, more attractive in terms of technological constraints and cost, is adopted.

Therefore, the mean harvested power is given by :

$$\bar{P} = R_{load} \left[\frac{\delta d}{(R_{load} + R_{\text{int}})T} \right]^2 \left[\omega_2^2(\alpha, \beta) A_{2\max}^2 (\alpha, \beta, R_{load}) \right]$$

Modal localization is quantified by the following ratio :

$$\tau_L = \frac{|A_{2\max}| - |A_{1\max}|}{max(A_{1\max}, A_{2\max})}$$

The maximum localization ratio is about 41% as shown in figure 5.

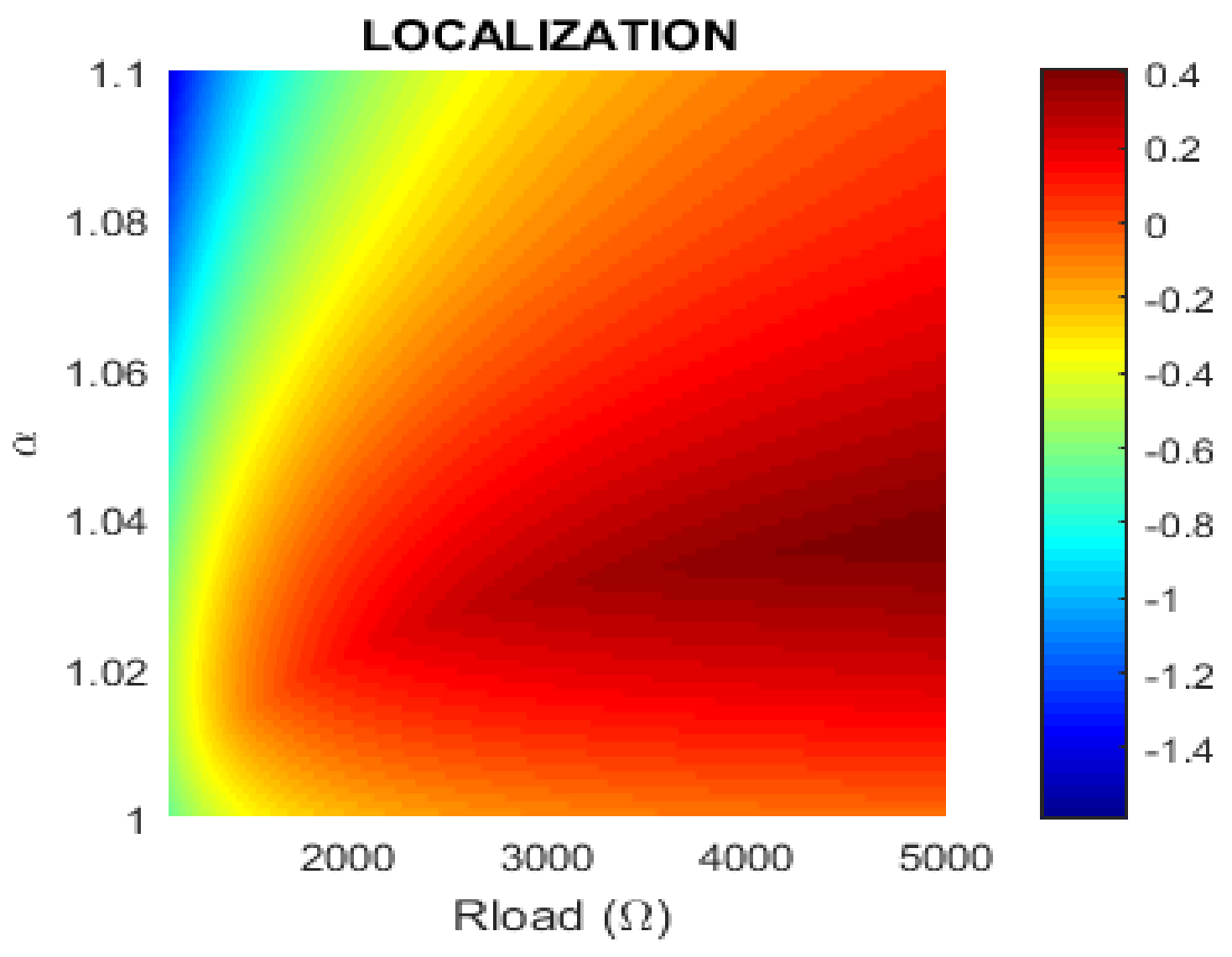

Figure 5. Modal localization

MULTIOBJECTIVE OPTIMIZATION

In order to improve the system performances, a multiobjective optimization procedure is proposed. The two objective functions are the mean harvested power $\bar{P}$ and the localization ratio τ_L. For this purpose, the Pareto Front is plotted as shown in figure 6.

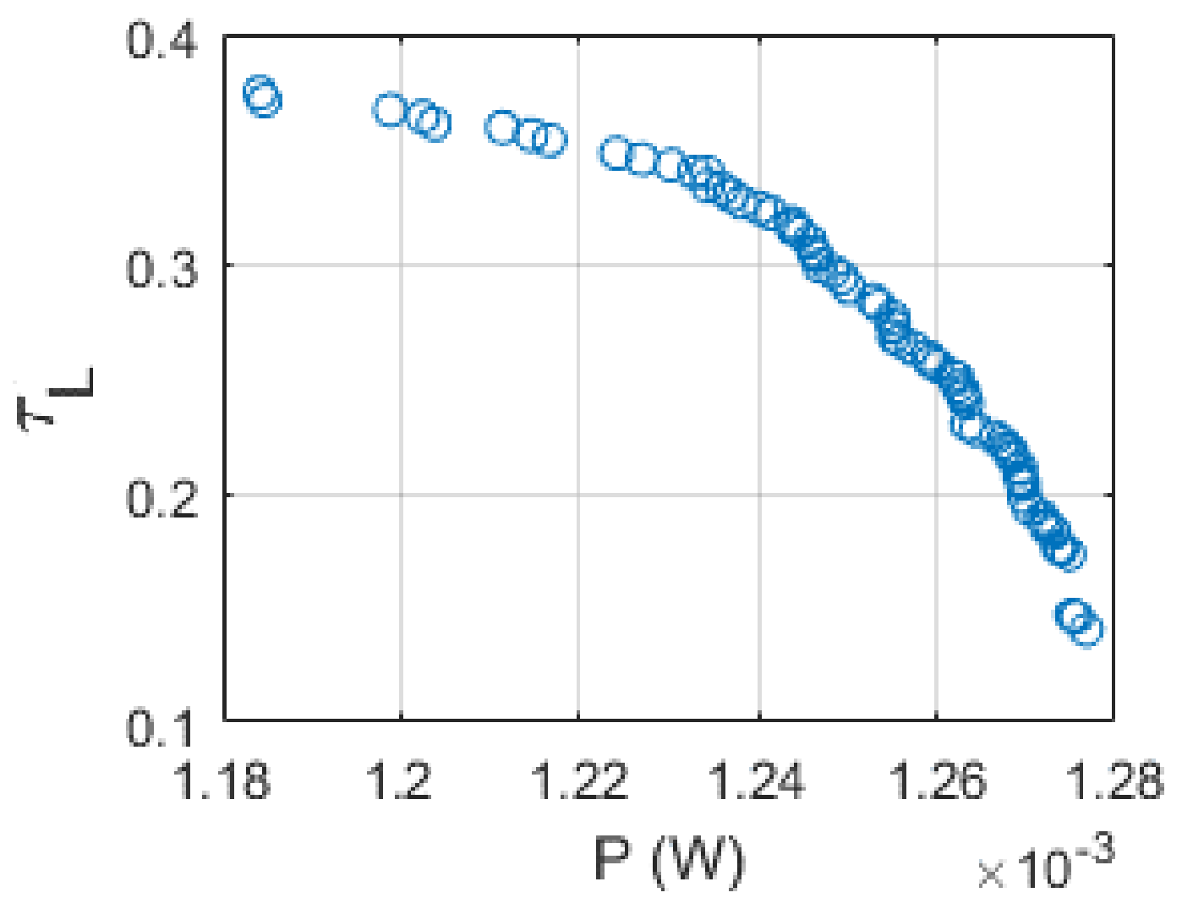

Figure 6. Pareto Front

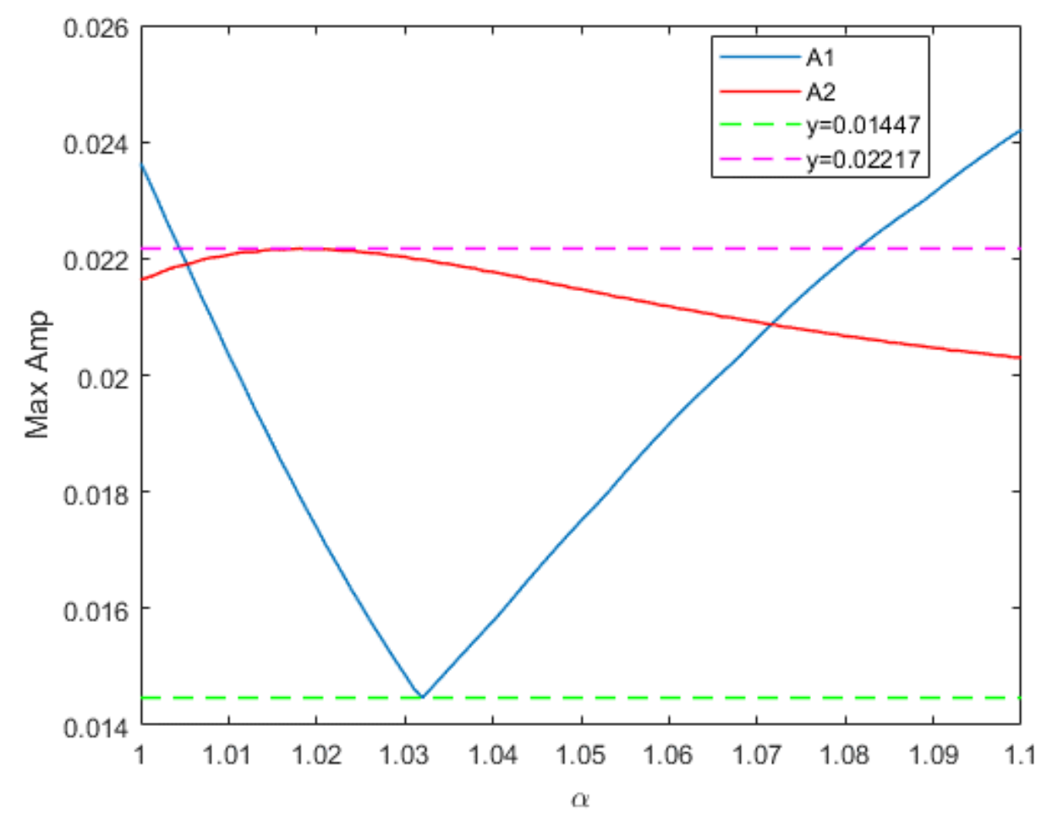

Figure 7. Maximum amplitudes

The compromise solution is to maximize simultaneously the two objective functions. The results of the multiobjective optimization are listed below for 3 design parameters:

$$\begin{cases} \underset{\alpha, \beta, R_{load}}{Max} \; (\bar{P}, \tau_L) = (1.24mW, 34\%) \\ \alpha \in [1.03, 1.033] \\ \beta \in [1.5\%, 2.2\%] \\ R_{load} \in [3k\Omega, 3.5k\Omega] \end{cases}$$

For these optimal values, the variation of the two maximum amplitudes is displayed in figure 7.

CONCLUSIONS

A vibration energy harvester based on modal localization is proposed. The concept consists in introducing a mistuning of mass in two weakly coupled magnets guided by elastic beams. A multiobjective optimization procedure was conducted in order to improve the performances of the proposed VEH with up to 1.24 mW of harvested power while maintaining a significant localization ratio of 34%.