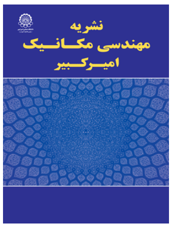

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Modeling and Optimization of Vibration Absorber Beam Combined with Magneto-Electro-Elastic Energy Harvester

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ABSTRACT: Mechanical structures are always exposed to unwanted vibrations and this can greatly affect system performance. The energy from this vibration can be used as a source to generate voltage. Therefore, the use of a vibration absorber that can minimize the vibrations of the structure and at the same time be used as an energy harvesting has been very important. In recent years, the use of intelligent materials capable of generating voltage has made significant progress in various fields. In the present study, a continuous beam with a layer of magnetoelectroelastic materials has been used as a dynamic absorber. This absorber helps to reduce the vibrations of the system by one degree of freedom and extracts energy from it. The best performance of this absorber will occur at the resonant frequency. The general absorber equations were extracted and the effect of different beam parameters on energy harvesting was investigated. Using the optimization method, appropriate values were obtained to achieve both goals. The studies were performed in the first three modes of the Bernoulli Euler beam. the highest energy harvesting occurred in the first mode and in the frequency range of 10 to 40 Hz. The vibrations of the main structure also decreased by about 65%.

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1- Introduction

The initial idea of a dynamic absorber, which consisted of a mass, a spring, and a damper, was invented by Farham in 1911 [1] to reduce the vibrations of the ship's cabin. Over time, energy harvesting from the dynamic absorber was also considered and many studies were conducted in the field of intelligent materials for energy harvesting from mechanical systems. Piezoelectric materials have the most development and study among intelligent materials. These materials deform in the presence of an electric field and conversely, produce an electric charge when they are deformed [2]. Recently, in the field of materials science, there has been a great deal of interest in intelligent materials with piezoelectric and piezomagnetic properties. A special feature of these materials, called Magneto-Electro-Elastic (MEE), is the relationship between electric polarization and magnetic field [3]. MEE materials possess a coupled field behavior between the elastic, electric, and magnetic field variables. This interaction provides new possibilities for electronic devices.

In energy harvesting research, this device has only been used to generate electrical energy or only piezoelectric materials have been used in the absorber. In this research, the mechanism of the energy harvesting device is combined with the dynamic absorber, and magneto-electro-elastic materials are used as the main material in energy harvesting. In this case, the energy harvester acts as a dynamic vibration absorber and in addition to generating electrical energy, the unwanted vibrations of the system can be reduced.

In the present study, by combining the energy harvesting device and the dynamic absorber in the form of a Bernoulli Euler beam containing a layer of magneto-electro-elastic material, a system has been designed to reduce the vibration of a single degree of freedom system under force excitation.

2- Configuration for MEE Energy Harvesting Systems And Mathematical Model

To begin this process, a mathematical model for generating voltage was provided by a cantilevered beam with MEE layers based on the assumptions of a Bernoulli Euler beam. This beam is connected to the main structure of a single degree of freedom consisting of a mass, spring, and damper which is excited by force, as schematically shown in Fig 1. The MEE material is used for energy harvesting in the 31 modes; meaning that the mechanical stress or strain acts in the 1 direction and the electrical and magnetic fields act in the 3 direction (i.e. the material is poled in the 3 direction).

The governing differential equation of motion for the transverse vibrations of a cantilever beam within the framework of the Euler- Bernoulli theory with tip mass is:

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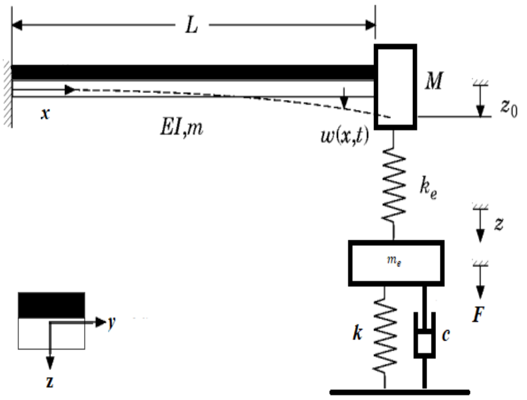

Fig. 1. The main structure with a vibration absorber.

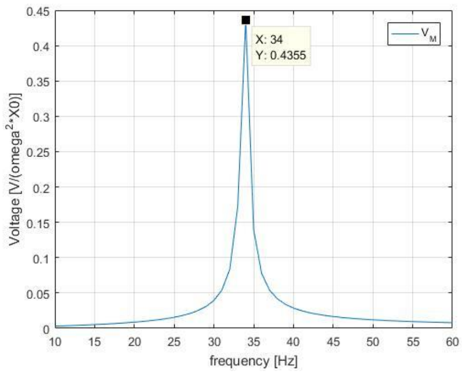

Fig. 2. The voltage generated in the magnetic field with optimized values.

$$EI\frac{\partial^4 w}{\partial x^4}+(m+M\delta(x-L))\frac{\partial^2 w}{\partial t^2}+ C_h\frac{\partial w}{\partial t}+\alpha_r^{EM}V_E(t)+\alpha_r^{MM}V_M(t)=0 \tag{1}$$

For an anisotropic and three-dimensional linear MEE solid, the MeM coupled constitutive equations can be written as [4]:

$$\sigma_i^M=C_{ik}^M\varepsilon_k^M-e_{ik}^M E_k^M-f_{ik}^M H_k^M \tag{2}$$

$$D_i^M=e_{ik}^M\varepsilon_k^M-h_{ik}^M E_k^M-g_{ik}^M H_k^M \tag{3}$$

$$B_i^M=f_{ik}^M\varepsilon_k^M-g_{ik}^M E_k^M-\mu_{ik}^M H_k^M \tag{4}$$

According to Eqs. (1) to (4), and Gauss and Faraday's law obtain the generated voltage.

The beam has a layer of magneto-electro-elastic so it will be affected by both electric and magnetic fields. Resistance R_1 is located in the electric field and resistance R_2 in the magnetic field. V_E is the amount of voltage generated in the electric field and V_M is the amount of voltage generated in the magnetic field. By changing the beam parameters, the amount of voltage generated in these two fields was investigated. Also, the effects of Beam Geometry Parameters on its natural frequency are investigated. The effect of these changes on the first natural frequency is considered because the highest displacement and output voltage is generated at this frequency.

Therefore, to optimize, we went to the genetic algorithm and used an appropriate cost function to achieve this goal. The two-objective cost function became a one-objective cost function. Thus, the problem became the minimization of the new objective function.

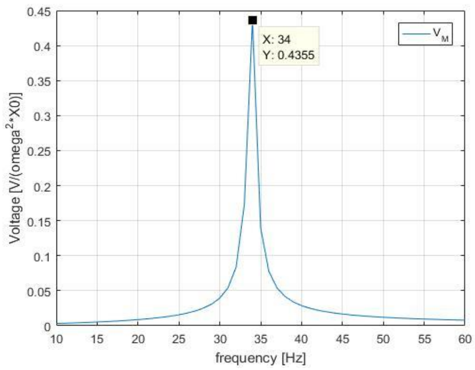

Fig. 3. The voltage generated in the electric field with optimized values.

The response surface methodology is used to design the experimental space and find the relationship between the variables and the objective functions. The type of RSM considered in this paper is Box-Behnken with 5 factors which generated 46 experiments.

3- Results and Discussion

In the sensitivity analysis, the effect of several different parameters on the output voltage was investigated and the five parameters that had the most impact were selected for optimization. The parameters considered for optimization are R_1, t_m, L, M, and b, and other beam parameters were considered fixed. The values of the output voltage in the first mode with the optimal parameters are shown in Figs. 2 and 3.

4- Conclusion

In the present study, a vibration absorber with the ability to harvest energy from motion was presented. This absorber is composed of intelligent materials with piezoelectric and piezomagnetic properties. First, the equations of motion of the primary system with the harmonic excitation force, connected to a two-layer Bernoulli Euler beam, with a layer of intelligent material and tip mass at the end were extracted. The Bernoulli Euler beam acts as an energy harvester, and if its resonant frequency is equal to the excitation frequency, the energy harvester will act as an absorber. the results showed that the maximum power is in the first mode. Therefore, the analysis of the beam energy harvesting system was performed in the first mode and the main frequency of the beam. Sensitivity analysis was performed for different beam parameters and the results showed that the length and thickness of the beam layers have the greatest effect on its natural frequency while the changes in beam width on the frequency are very imperceptible. Also, increasing the tip mass on the beam also reduced the frequency. The voltage and power generated were also evaluated by sensitivity analysis. Parameters whose increase was directly related to the increase in voltage and power included the length of the beam, the tip mass, the number of coil turns, the density of the layers, and the resistance of the electric field. However, by increasing the resistance of the electric field to the range of 10^5 ohms, the voltage also increased and then decreased. The highest voltage with a resistance of 10^5 ohms was recorded in the electric field equal to 71.41 Vs^2/m and in the magnetic field 1.2 Vs^2/m. Placing a mass at the free end of the beam significantly increases the amount of strain created, which in turn increases the output power. After examining the sensitivity analysis, to achieve the final goal, optimization was performed and the desired parameters were obtained based on the genetic algorithm.

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