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Modeling and design of magnetostrictive vibration-powered generator using finite element method

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ABSTRACT

This work investigates the design of a vibration-powered generator with one rod (unimorph) of iron–gallium (galfenol) and compares it with its two-rod (bimorph) counterpart. Galfenol is a promising magnetostrictive material that combines high magnetic susceptibility and desirable mechanical properties and therefore very suitable for harvesting the vibration energy that involves bending stresses. In this study, an energy-based magnetoelastic model, so-called Armstrong model, is employed to predict the behavior of galfenol under multiaxial stresses. The Armstrong model of galfenol is implemented into a static 3D finite element model of the energy harvester by which the performances of the devices are predicted and experimentally observed. Copyright © 2012 John Wiley & Sons, Ltd.

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KEY WORDS: Armstrong model, FEM, galfenol, vibration energy harvester

1. INTRODUCTION

Galfenol alloys are highly magnetostrictive with magnetically induced strains in the [100] direction as high as 280 ppm in highly textured polycrystals. Galfenol's high strength and high permeability have made it a popular option in transducer applications involving bending [1, 2].

The structure of the bimorph vibration energy harvester developed previously [3] is shown in Figure 1 in which two rods of galfenol are employed. In this paper, a unimorph type of the device is proposed as shown in Figures 2 and 3 in order to consume less galfenol and enhance the robustness of the device as one of the galfenol rods is replaced by a stainless rod.

Static magneto-mechanical coupling model based on FEM is used to study the behavior of the energy harvester. The Multiphysics finite element package COMSOL allows the magnetostrictive strain tensor to be implemented directly by using the actual properties of the materials involved within the system [4]. The Armstrong model is capable of predicting the multiaxial magnetoelastic behavior of magnetostrictive materials [5], and it could be incorporated in the finite element model of the whole system [6].

In the following sections, we first discuss the configuration of the proposed vibration energy harvester, and then we introduce the Armstrong model of galfenol as the active material of the device. Finally, the numerical results are discussed and compared with the experimental ones, including its energy extraction.

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Figure 1. Structure of the bimorph vibration energy harvester.

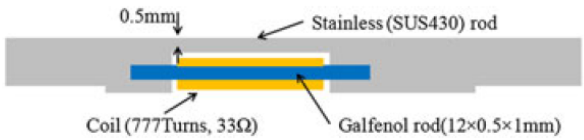

Figure 2. Structure of the unimorph vibration energy harvester.

Figure 3. Fabricated device.

2. CONFIGURATION AND PRINCIPLE OF OPERATION OF THE VIBRATION ENERGY HARVESTER

The energy harvester developed in [3] consists of two parallel square rods of galfenol ($Fe_{81.6}Ga_{18.4}$, 0.5 mm by 1 mm area and 10 mm length, magnetically easy axis in longitudinal direction), and as shown in Figure 1, on each galfenol rod, a coil of 312 turns is wound. In this paper, the galfenol unimorph energy harvester shown in Figures 2 and 3 is studied that a coil of 777 turns is wound only on the galfenol rod, and the other rod is made of stainless steel to improve the mechanical strength of the device as the Young's modulus of stainless is about 200 GPa whereas the one of galfenol is around 70 GPa. Figure 4 depicts the 3D FEM view of the device in which one end is bonded to a fixture and the other end makes use of free vibration. Two pieces of Nd–B–Fe permanent magnets (2 mm diameter and 2 mm length) are used to provide adequate bias flux for the rods, and the attached back iron yokes close the magnetic circuit.

The fundamental operation principle of the energy harvester is based on the inverse magnetostrictive effect that the magnetization changes with the stress. When a transverse load is applied to the mover as shown in Figure 4, one rod is compressed and the other one is stretched, leading to relative permeability change in the galfenol rod, which causes the magnetic flux density to vary. Therefore, voltages are induced in the coils around galfenol rod because of time-varying magnetic fields, and the vibration energy is harvested.

3. THE ARMSTRONG MODEL

The Armstrong model was originally constructed as the sum of the magnetic field, magnetocrystalline, and magnetoelastic energies [5]. The total free energy can be used to calculate the energy cost

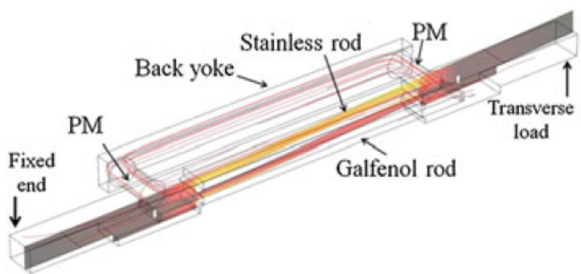

Figure 4. A 3D model of the galfenol unimorph vibration energy harvester.

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