Finite Element Analysis of Galfenol Unimorph Vibration Energy Harvester

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This paper develops a numerical model to examine the performance of the vibration energy harvester with one-rod (unimorph) of Iron-Gallium (Galfenol). The device's principle of operation is based on inverse magnetostrictive effect of the Galfenol rod. In order to take into consideration the anisotropy of the Galfenol, the Armstrong model is employed that is implemented into a static 3-D finite element model (FEM) of the energy harvester. The predicted results from the numerical model are compared to the measured ones.

***Index Terms*—Armstrong model, energy harvester, inverse magnetostrictive effect.**

I. Introduction

GALFENOL is a promising transducer material that combines high magnetic susceptibility and desirable mechanical properties and therefore very suitable for harvesting vibration energy that involves bending stresses [1], [2].

Previously, a bimorph vibration energy harvester has been developed [3] in which two rods of Galfenol are employed and capable of producing 10 $\mathrm{mW/cm^3}$. The advantages of this energy harvester over the conventional ones, such as those using piezoelectric materials, are smaller size, higher efficiency and it also has high robustness and low electrical impedance.

In this paper, a unimorph-type of the device is proposed 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 as shown in Fig. 1.

Static 3-D FEM is used to study the behavior of the energy harvester and the Multiphysics finite element package COMSOL allows the magnetostrictive strain tensor to be implemented directly 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 this paper, the Armstrong model is developed for Galfenol ($\mathrm{Fe_{81.6}Ga_{18.4}}$) and the numerical model is employed in the design of the device and also to predict the performance of the energy harvester, and finally the calculated results are compared to the measured ones. The results show improvement in power density of the proposed energy harvester, that can be used to feed wireless sensors without the use of primary battery or can be placed inside the embedded structures wherein the appropriate ambient vibration exists.

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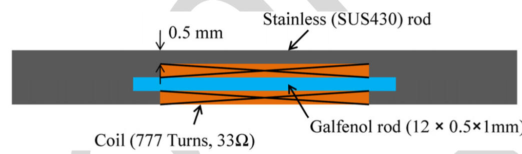

Fig. 1. Structure of the unimorph vibration energy harvester.

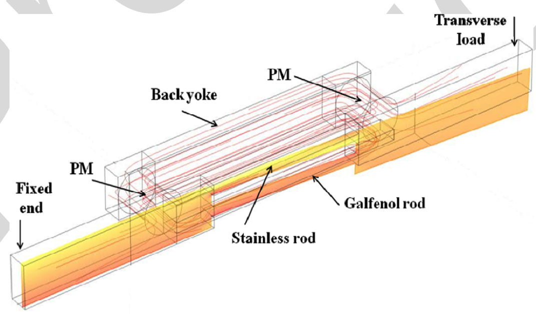

Fig. 2. 3-D model of the Galfenol unimorph vibration energy harvester.

II. Galfenol Unimorph Vibration Energy Harvester

The Galfenol unimorph energy harvester consists of two parallel rods of which one is made of Galfenol ($\mathrm{Fe_{81.6}Ga_{18.4}}$, 0.5 mm by 1 mm area and 10 mm length, magnetically easy axis in longitudinal direction) and a coil of 777 turns is wound only on the Galfenol rod, as shown in Fig. 1. 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 while the one of Galfenol is around 70 GPa. Fig. 2 depicts the 3-D 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 operating principle of the energy harvester is based on the inverse magnetostrictive effect that the magnetization changes with stress. when a transverse load is applied to the mover, one rod is compressed and the other one is stretched as shown in Fig. 2, 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