Finite element analysis of magnetostrictive vibration energy harvester

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Abstract

Purpose – The paper aims to analyze the behavior of the Galfenol rods under bending conditions that are employed in a vibration energy harvester by illustrating the spatial variations in stress and magnetic field.

Design/methodology/approach – This paper describes a 3-D static finite element model of magnetostrictive materials, considering magnetic and elastic boundary value problems that are bidirectionally coupled through stress and field dependent variables. The finite element method is applied to a small vibration-driven generator of magnetostrictive type employing Iron-Gallium alloy (Galfenol).

Findings – The 3-D static finite element modeling presented here highlights the spatial variations in magnetic field and relative permeability due to the corresponding stress distribution in the Galfenol rods subjected to transverse load. The numerical calculations show that about 1.1 T change in magnetic flux density is achieved which demonstrates the effectiveness of the inspected vibration-driven generator in voltage generation and energy harvesting. The model predictions agree with the experimental results and are coherent with the magnetostriction phenomenon.

Originality/value – This paper fulfils the behavior analysis of Galfenol rods under transverse load that includes both compression and tension. The compressive and tensile stresses contributions to change in magnetic flux densities in the Galfenol rods were calculated by which the effectiveness of the inspected vibration-driven generator in voltage generation and energy harvesting is demonstrated.

Keywords Magnetostrictive material, Vibration energy harvester, Finite element method, Vibration, Finite element analysis, Electric generators

Paper type Research paper

1. Introduction

Magnetostrictive materials are being employed in a host of applications ranging from active control and energy harvesting to torque and force sensing. The development of iron-gallium alloys (Galfenol) has improved the possibilities to build devices based on magnetostrictive phenomenon (Wun-Fogle *et al.*, 2006).

Recently, a micro energy harvester has been proposed using Galfenol to produce electricity from vibration energy (Ueno *et al.*, 2010; Ueno and Yamada, 2011). Contrary to Terfenol-D and piezoelectric materials, Galfenol's high strength and ductility have made it a popular option in applications involving bending (Wun-Fogle *et al.*, 2006).

Studies on Galfenol behavior involving bending mode have been performed using Galfenol unimorph sensors and laminated composites having Galfenol attached to other structural materials (Mudivarthi *et al.*, 2008; Datta, 2009). In this paper, we consider the vibration energy harvester (Ueno *et al.*, 2010; Ueno and Yamada, 2011) in order to investigate the behavior of Galfenol in bending conditions. A model for simulation of the vibration energy harvester, based on static finite element method,

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is developed and the multiaxial magneto-elastic behavior of Galfenol is included in the model using Armstrong model (Armstrong, 1997; Mudivarthi *et al.*, 2008, 2010; Datta, 2009). Contrary to the models previously developed and based on a strong coupling approach of magnetostrictive problem (Evans and Dapino, 2010), the approach employed in this paper is based on a so-called weak coupling approach to consider the bidirectional coupling between magnetic and mechanical problems (COMSOL, MULTIPHYSICS © (FEMLAB), www.comsol.com).

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. Finally, experimental results are presented which show the agreement between the numerical derivations and experimental results.

2. Configuration of the vibration energy harvester

The energy harvester consists of two parallel square rod of Galfenol ($Fe_{81.6}Ga_{18.4}$h, 0.5 mm by 1 mm area and 10 mm length, magnetically easy axis in longitudinal direction) is shown in Figures 1 and 2. On each Galfenol rod a coil of 312 turns is wound (0.05 mm diameter wire, 12 Ω). Before shaping to the rod, the Galfenol was stress-annealed under compressive stress to equip built-in uniaxial anisotropy such that flux variation is occurred under

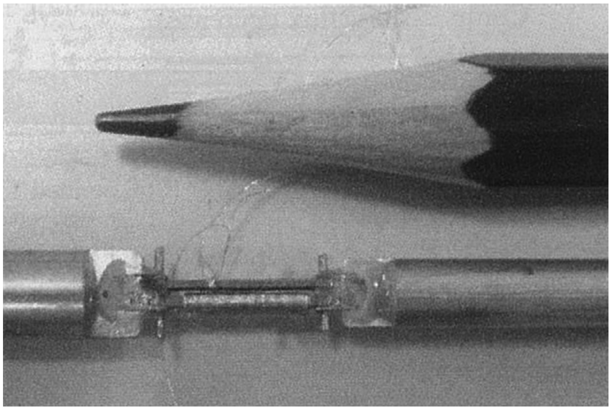

Figure 1.
The fabricated device

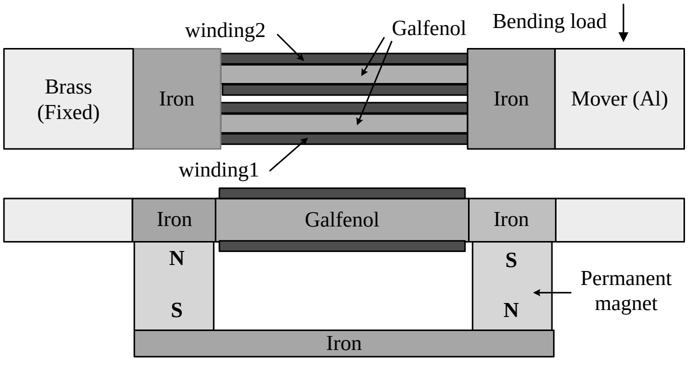

Figure 2.
Sectional view
of the device