Study of Giant Magnetostrictive Acceleration Sensors Considering Both Direct and Inverse Magnetostrictive Effect

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Abstract —Compared with other types of acceleration sensors, the rare-earth giant magnetostrictive acceleration sensors have obvious advantages. In this paper, a basic cell of the giant magnetostrictive acceleration sensor is designed. By the various combination of these basic cells, different test rang acceleration sensors can be obtained. In order to analyze performance of this acceleration sensor cell, this paper presents a magneto-mechanical strongly coupled model considering both direct magnetostictive effect and inverse magnetostrictive effect. Using the proposed model, the performance characteristic of the acceleration sensor cell is calculated by finite element method (FEM). In order to validate the presented model, an experiment has been done. A comparison between the calculated results and measured ones has been carried out to examine the validity of the proposed model and the FEM implementation. It is found that both of them are in an agreement. This indicates that the proposed FEM model can reflect response performance of the giant magnetostrictive acceleration sensors.

I. INTRODUCTION

Giant magnetotrictive materials have both direct magnetostictive effect and inverse magnetostrictive effect, which is a coupled magneto-mechanical phenomenon. On the one hand, giant magnetostrictive materials can show elongation and contraction in the magnetization direction, which is known as direct magnetostrictive effect. On the other hand, if a mechanical stress is applied to the giant magnetostrictive materials, a change in magnetic induction will occur, which is known as inverse magnetostrictive effect or the Villari effect [1-3]. Giant magnetostrictive materials present large magnetostriction, significant force, fast response, fine precision movement, high energy density and high coupling coefficient, which allows to develop electromagnetic devices such as sonar, actuator, transducer and magnetic sensor, and arouses more and more attention in high technology fields [3]-[6].

Due to interdependence of the magnetic and mechanical properties, the externally applied stress changes permeability of the medium as a consequence of inverse magnetostrictive effect and this change in the permeability of magnetostrictive material causes change in the stress as a consequence of direct magnetostriction effect. To account for this interdependence between magnetic and mechanical properties, coupled magnetomechanical analysis should be studied. However, previous work did not consider both direct magnetostrictive effect and inverse magnetostrictive effect at the same time.

This paper presents a method to extend the limits of application of the giant magnetostrictive acceleration sensor by the various combination of the basic cells. The performance characteristic of the basic acceleration sensor cell is calculated by finite element method (FEM) considering both direct magnetostictive effect and inverse magnetostrictive effect. In order to validate the presented model, an experiment has been done.

II. THE STRUCTURE AND PRINCIPLE OF THE BASIC GIANT MAGNETOSTRICTIVE ACCELERATION SENSOR CELL

Fig.1 shows the schematic diagram of the basic giant magnetostrictive acceleration sensor cell. It consists of two permanent magnets, two iron yokes, three giant magnetostrictive rods, and three inductance coils looped around the three giant magnetostrictive rods. The three giant magnetostrictive rods are located on the three vertices of an equilateral triangle, and the permanent magnets are placed on the center of the equilateral triangle. The permanent magnets are used to supply the bias magnetic field. When a static acceleration is exerted on the magnetostrictive rod, magnetic field in it will change. Magnetic flux density in the gap changes with respect to the applied acceleration. Using a Gaussmeter, the magnetic flux density in the gap between the two permanent magnets can be measured, and then we can obtain the applied acceleration on the magnetostrictive sensor. And when a dynamic acceleration exerted on the magnetostrictive rod, using an oscilloscope, an induced voltage in the inductance coil can be displayed, and then we can know the relation between the induced voltage and acceleration applied on the magnetostrictive rod. The three giant magnetostrictive rods receive the same pressure because of the symmetry of the structure, and the sensor has high measurement sensitivity and precision.

III. THE CHARACTERISTIC CALCULATION FOR THE BASIC GIANT MAGNETOSTRICTIVE ACCELERATION SENSOR CELL

According to the finite element method based on the minimization of energy functional, it is necessary to determine the functional of the acceleration sensor. When a static acceleration exerted on the giant magntostrictive rod, the total energy of the sensor includes pure elastic energy, the work done by external forces caused by acceleration, pure magnetic field energy, potential energy of magnetic field boundary and mutual magnetoelastic energy.

The mechanical field boundary should be the contour of the magntostrictive sensor. By neglecting the distortions of the rest parts of the sensor, the magntostrictive rod can be considered as the computed domain of the mechanical problem.

Considering both direct magnetostrictive effect and inverse magnetostrictive effect at the same time, the total energy functional of the sensor system can be expressed as follows:

$$I = \int_{\Omega_1} \frac{1}{2} \boldsymbol{\sigma} \cdot \varepsilon d\Omega - \int_{\Gamma_1} \boldsymbol{f}^{\Gamma} \cdot \boldsymbol{u} d\Gamma - \int_{\Omega_1} \boldsymbol{f}^{v} \cdot \boldsymbol{u} d\Omega \qquad (1)$$
$$+ \int_{\Omega_2} \frac{1}{2} \boldsymbol{B} \cdot \boldsymbol{H} d\Omega + \int_{\Omega_1} \boldsymbol{S} \cdot \boldsymbol{T} d\Omega + \int_{\Omega_1} \boldsymbol{B}' \cdot \boldsymbol{H}' d\Omega .$$

To minimize I for each and every unconstrained vertex potential, we can get the matrix equation

$$\boldsymbol{KX} = \boldsymbol{F} \qquad (2)$$

where K is the magnetic and mechanical stiffness matrix, X, the unknown column matrix including nodal magnetic potential and displacement vector, and F ,the known column matrix including the permanent magnet, external forces and magneto- mechanical coupled terms.

Equation (2) is nonlinear and can be solved by using Newton-Raphson method [7]. Solutions of (2) are the magnetic potential and displacement vector. Therefore, we can obtain the magnetic field intensity H and the magnetic flux density B in the gap of the giant magnetostrive acceleration sensor, and figure out the relation between magnetic flux density in the gap and the applied acceleration on the giant magnetostrictive rod.

IV. COMPUTED AND EXPERIMENTAL RESULTS

According to the above magneto-mechanical strongly coupled model and magneto-mechanical coupling characteristics of the giant magnetostrictive material, the relation between magnetic flux density in the gap and applied force caused by acceleration on the sensor is calculated. The result is shown in shown in Fig. 2. In order to validate the magneto-mechanical strongly coupled model, the experiment is carried out. The measured results are also shown in Fig.2. It can be seen that the presented model in this paper is valid.

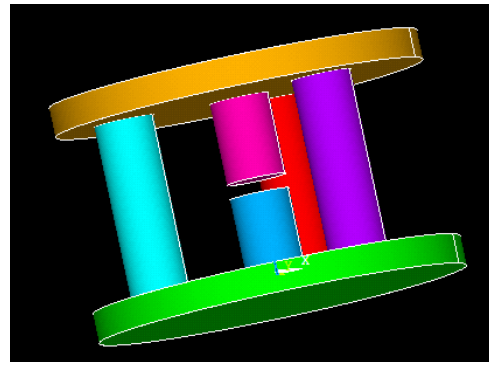

Fig. 1. The structure of the basic giant magnetostrictive acceleration sensor cell

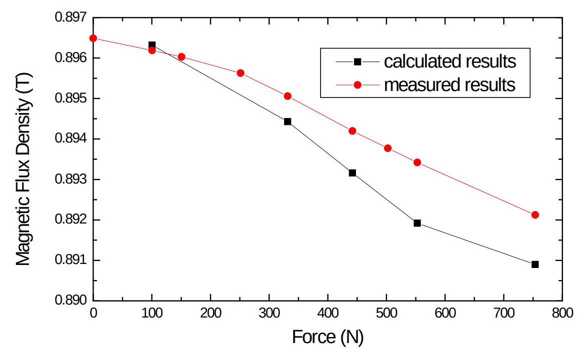

Fig. 2. The calculated and measured result for the giant magnetostrictive force sensor

V. REFERENCES

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