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DISPLACEMENT SENSORS USING MAGNETOSTRICTIVE DELAY LINES

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In this paper, we present further results in displacement sensors based on magnetostrictive delay lines using amorphous ribbons in the as cast form after stress relief and after stress current annealing. The elastic pulse generated due to pulsed current transmitted through an excitation coil is detected by means of a search coil as a pulsed voltage output. NdFeB permanent magnets in a form of pellet have been tested, having a magnetic anisotropy parallel to their axis. Experimental results obtained by displacing the magnets parallel and vertical to the delay line indicate monotonic response, thus allowing repeatable displacement sensing in three dimensions using proper arrangements. The MDL response was improved after stress relief and stress current annealing.

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1. Introduction

Numerous physical effects can be used for sensing a number of physical magnitudes. Mechanical sensors able to detect elongation, pressure, torque, etc. use several physical effects (semiconductor properties, changes of optic fibbers characteristics, etc.). A great effort is employed, in order to improve the technical characteristics and / or to decrease the cost of the devices. Among the most well known sensing techniques are the magnetic devices, that is, sensors using the change of magnetic properties of materials for sensing a mechanical input and especially displacement, force or torque [1]. One can distinguish well established old methods such as the linear variable differential transformer (LVDT) technique and new ones, using the magnetic properties of metallic glasses [2,3], or more complicated ones, which use a combination of magnetic effects.

A number of sensing devices has been presented in the past using the MDL technique [4], taking advantage of the high magnetomechanical coupling factor of Fe-rich amorphous ribbons and wires. These sensing devices are based on modification of the elastomagnetic waves due to a given input either at their point of origin or at the region of the receiving means or finally along the MDL itself, considered as an elastomagnetic waveguide [5-9].

Position sensors are always important in industrial applications. In many occasions large arrays of sensors are needed in order to measure the displacement of objects along a surface. There are also cases where the absolute steady-state position of an object or the dynamic change of the position of an object must be measured. In all these cases, one could use the principles of the measuring tape technique [4] concerning single-point output or array output response, where the dominating principle is the modification of the bias field around the excitation or the detecting point. Absolute sensors are able to detect the absolute distance between two points. These two points are usually the exciting and detecting means. Examples of absolute position sensors are the MDL sensors, the LVDT and a linear inductive sensor using closed magnetic paths.

Displacement sensors based on the MDL technique have been presented in the past with interesting results [10-13]. These devices present several advantages, such as ease of assembly, low manufacturing cost and therefore are interesting for several applications. Having some experience in positioning [14] we did research in this kind of sensors.

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2. Experimental results

The sensor arrangement is presented in Fig. 1. A FeSiB amorphous ribbon is used as the magnetostrictive delay line (MDL, 1). Two coils made of 48 SWG (0.3 mm) wire, 6 cm apart and 2 mm long are set around the ends of the MDL. The left one, having 300 turns, acts as the exciting coil (2) while the right one, having 800 turns, acts as the receiving coil (3).

Pulsed current is transmitted through the exciting coil, generating a pulsed magnetic field along the axis of the delay line which is also its easy axis of magnetization. Thus, at the area covered by the exciting coil, called hereinafter point of origin, rotation of magnetization occurs due to the magnetostriction effect. This rotation of the magnetization vector results in a reorientation of the magnetostrictive strain, which will propagate as a stress wave, i.e. as an acoustic pulse, towards both ends of the MDL.

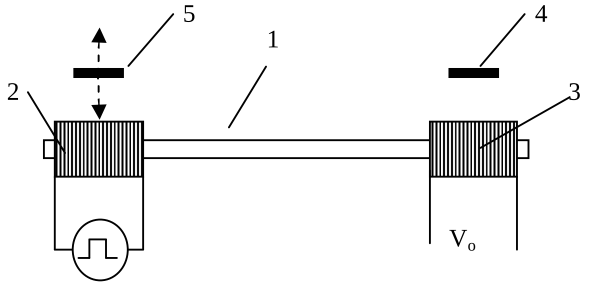

Fig. 1. Sensor arrangement: (1) MDL, (2) exciting coil, (3) search coil, (4) fixed NdFeB magnet (biasing magnet), (5) moving magnet (sensor core).

Two NdFeB permanent magnets [15] in a form of pellet having a magnetic anisotropy parallel to their axis are placed over the coils. The first one is fixed about 4 cm above the receiving coil in order to maximize its output (biasing magnet, 4). The other one is moving against the exciting coil, either vertically or parallel to the MDL (sensing core, 5). This movement causes magnetic flux changes in the exciting coil, proportional to the magnet displacement from this coil. These changes affect the biasing point of the $\lambda(H)$ function of the MDL at the acoustic pulse point of origin.

Therefore, transmitted pulsed current along the exciting coil results in a generated microstrain, the amplitude of which is dependent upon the above mentioned biasing field. Consequently, the amplitude of the corresponding propagating elastic wave and the detected pulsed voltage output depend on the mentioned biasing field, which in turn depends on the displacement of the moving permanent magnet from the exciting coil. Thus measuring the output of the search coil it is possible to determine the displacement of the moving magnet from the exciting coil.

Measurements were realized using the experimental setup described in detail in [10]. A micrometric driving device was used to move the sensor core. Both vertical and horizontal magnet movements are considered.

When the distance between the moving magnet (sensor core) and the exciting coil is minimum, the total magnetization of the MDL within this coil approaches saturation and therefore no microstrain can be caused; as a result no pulse can be detected along the search coil. When the sensor core is moving away from the exciting coil, the total biasing field inside this coil is reduced and a microstrain is appearing. This microstrain reaches a maximum value corresponding to the sharpest region of the $\lambda(H)$ function of the MDL and the corresponding pulse amplitude along the receiving coil is maximized.

3. Results, discussion and conclusions

Figs. 2, 3 and 4 present peak sensor output, V_o, as a function of the vertical magnet displacement from the search coil. Fig. 2 corresponds to the as cast form of the amorphous FeSiB ribbon used as the sensor core, while Figs. 3 and 4 present the results obtained after heat annealing the ribbon at 350 ^{0}C in Ar atmosphere for 10 min and after stress current annealing by passing 1A

DC current through the ribbon for 10 ms under 500 MPa tensile stress and allowing a 10s relaxation time. The same conditions stand for Figs. 5, 6 and 7, which present the results obtained in the case of horizontal magnet movement.

Vertical magnet movement

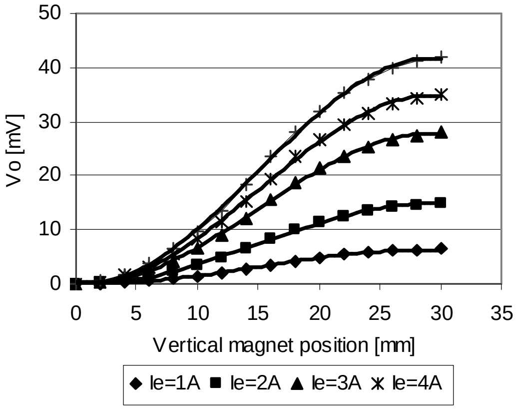

Fig. 2. Sensor output using as-cast amorphous ribbon.

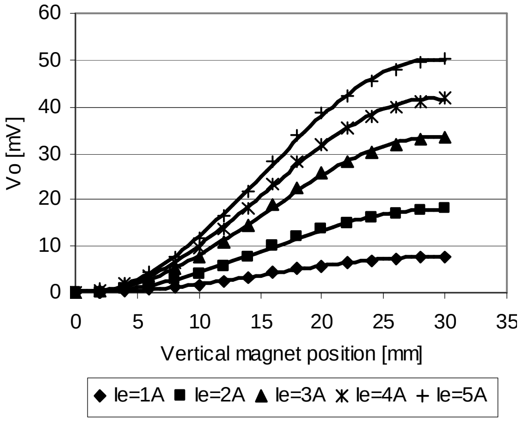

Fig. 3. Sensor output after heat annealing.

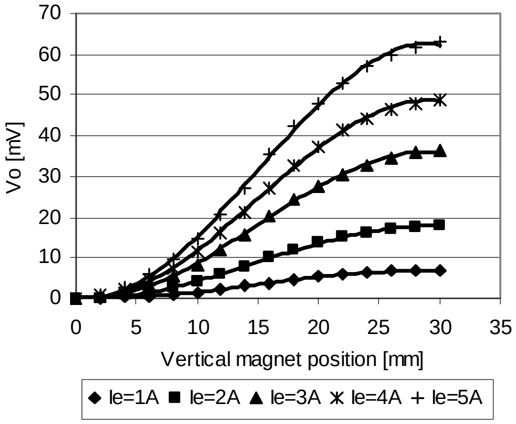

Fig. 4. Sensor output after flash stress current annealing.

Horizontal magnet movement

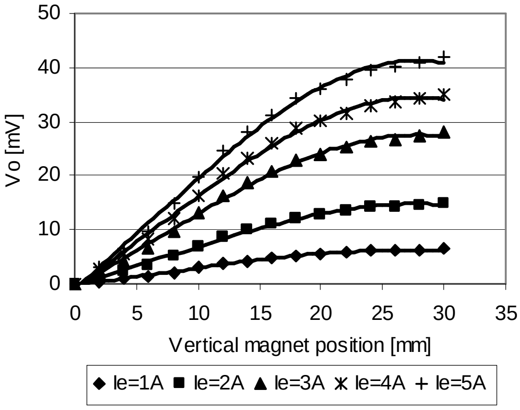

Fig. 5. Sensor output using as-cast amorphous ribbon.

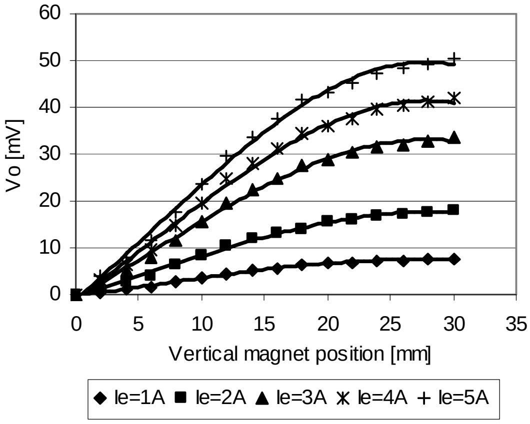

Fig 6. Sensor output after heat annealing.

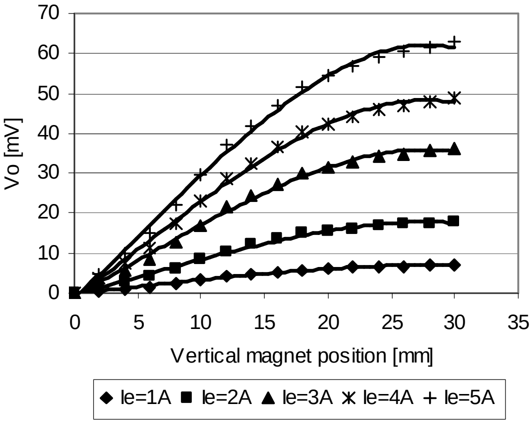

Fig. 7. Sensor output after flash stress current annealing.

Figs. 2 to 7 indicate that sensor output is monotonic in the range 10 – 20 mm concerning vertical magnet movement; the corresponding range for horizontal magnet movement is 6 – 12 mm.

Sensor uncertainty has been determined to be better than 0.1 mm for vertical magnet movement and 0.05 mm for horizontal magnet movement.

It has been reported that MDL non-uniformity response, determined as the fluctuation of amplitude of readings along the length of the line, is a non-standardized function [16, 17]. For the case of ribbon MDLs, it has been established that a first solution to this is the normalization process. Such a problem has been eliminated for the case of amorphous wires even in the as-cast form, while heat and magnetic annealing greatly improves their sensitivity and magneto-elastic uniformity.

Removing the excitation coil and shielding the search coil by using amorphous ribbons set around it, this sensor arrangement could be used as a self – excited accelerometer [18, 19], provided that the signals of the search coil are detected and integrated by a suitable electronic integrator [19].

Finally, it should be noted that using thin film technology this sensor arrangement could be miniaturized thus decreasing production cost of the device, probably improving sensitivity and uncertainty [20, 21].

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