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NEGATIVE MAGNETOSTRICTIVE DELAY LINES USED IN SENSING APPLICATIONS

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Sensor applications of magnetostrictive delay lines using sensing elements with negative magnetostriction are illustrated in this paper. The proposed sensors can be used for the measurement of applied tensile stress, pressure and force. The response of these sensors is presented and discussed in comparison with the more classic positive magnetostrictive delay lines.

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1. Introduction

Sensors have a great importance because of their penetration into a wide range of applications, like industrial, transport, automotive, medical, military, domestic, and environmental applications [1].

Magnetic effects are responsible for several sensing principles resulting in sensors that play a significant role in physical measurements used in all kinds of applications [2]. New sensors measuring mechanical sizes, like proximity, position, stress, torque and acceleration have been developed based on novel magnetic techniques [3-9]. One of the most often used magnetic effects in today's magnetic sensor technology is magnetostriction.

Magnetostriction is a property particular in magnetic materials and has been thoroughly investigated in terms of theory and modeling as well as in terms of experimental details and applications [10]. Its theory is based mainly on the principles of micromagnetics. One technique that utilizes the magnetostriction phenomenon in the design and development of sensors measuring displacement, stress and field is the magnetostrictive delay line (MDL) technique [11].

The motivation for realizing such an experiment was the need of repeatable and sensitive response, when using magnetostrictive elements either as MDLs or sensing cores. In this paper the response of sensors based on the MDL technique is presented using materials with negative magnetostriction. An evaluation of the response of the above-mentioned sensors is attempted with respect to the state of art. The sensors discussed concern two different arrangements for tensile stress measurement and two set-ups for measuring pressure or force arrangements.

2. Experiment and results

The materials used as MDLs in the above mentioned sensors belong in the general family of Fe-Co-Si-B alloys, while the results of this paper concern samples of the $(Fe_1Co_3)_{78}Si_7B_{15}$ composition. They were either in the as cast form, or after a stress relief process in 350 °C for 30 minutes or after flash current annealing using pulsed current of amplitude, duration and period equal to 1 A, 10 ms and 1 s respectively. Flash current annealing offered the optimum results in terms of

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maximum MDL amplitude. It is mentioned that all reported results in this paper concern magnetostrictive samples tested after flash current annealing. Wherever magnetic elements, besides the MDL, have been used, they are made of the same material as the MDL and followed the same treatment as the MDL.

The first type of sensor, illustrated in Fig. 1, is based on the electromagnetic properties of the magnetostrictive metallic glasses whose relative permeability is dependent on the tensile stress applied on their surface [12]. The active core is a soft magnetic material, called hereinafter core S, close to the MDL and placed at a fixed distance between the pulsed current conductor and the delay line. Transmitting pulsed current through the conductor generates a pulsed magnetic field in the MDL, with a certain amount of the magnetic flux trapped in the active core S because of its high magnetic permeability, which induces a voltage to the search coil.

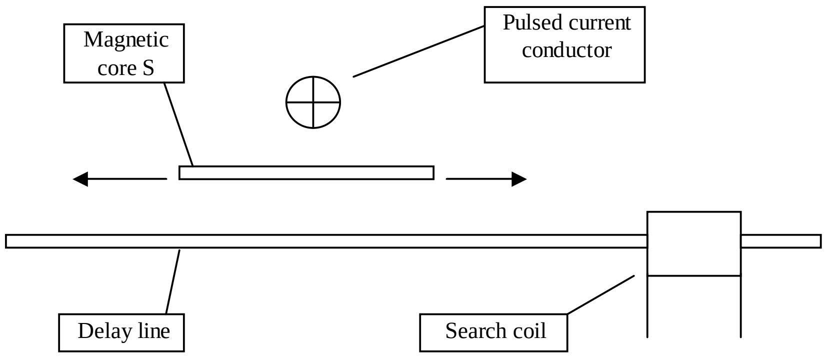

Fig. 1. Schematic of the basic concept of the tensile stress sensor.

The dependence of the peak amplitude, Vo, of the MDL output signal on the tensile stress applied on core S is illustrated in Fig. 2. The results concern a flash current annealed MDL. The sensor response decreases with the increase of the input, contrary to what is observed when sensing elements with positive magnetostriction are used. This is because in the case of positive magnetostriction the easy axis of magnetostrictive anisotropy tends to align parallel to the direction of the applied and internal stresses of the magnetostrictive element while in the case of negative magnetostriction, used in this work, it tends to align perpendicular to the stresses direction, thus resulting in a decrease in the induced signal.

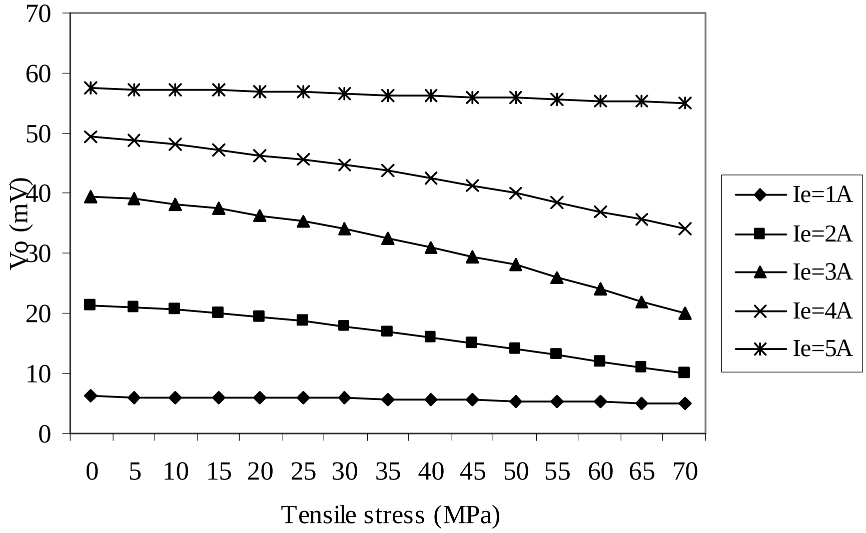

Fig. 2. Response of the stress sensor of Fig. 1 using a flash current annealed MDL.

The second type of the studied sensors is illustrated in Fig. 3. In this case, when pulsed current I_e is transmitted in the same direction in the two conductors, in the absence of core S, there is no magnetic flux in the delay line and consequently zero pulsed voltage output is detected [12]. Placing an unstressed soft magnetic core S close to the MDL causes a break in the balanced flux inside the MDL, inducing a pulsed voltage of peak value, Vo, which varies with the application of tensile stress on the core S.

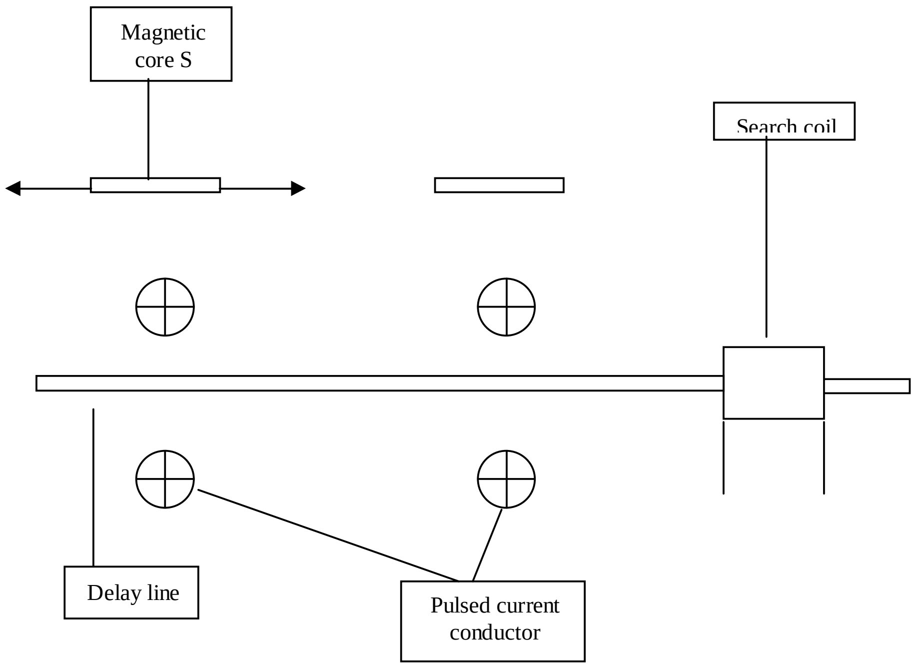

Fig. 3. Schematic of the balanced structured tensile stress sensor.

The dependence of Vo on the applied stress on the core S is illustrated in Fig. 4. The results concern a flash current annealed MDL. The magnitude of Vo increases with the applied stress, a result that, as expected and discussed in the case of the previous sensor, contradicts the results obtained when a positive magnetostrictive element is used in the MDL.

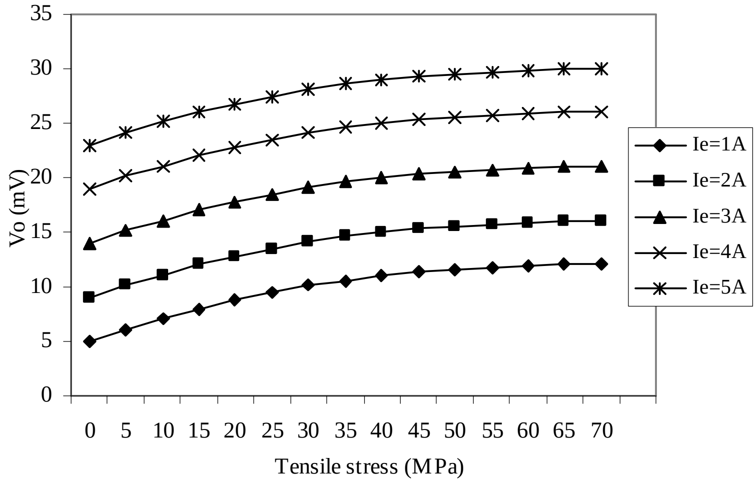

Fig. 4. Response of the balanced structured tensile stress sensor using a flash current annealed MDL.

Pressure sensors and force digitizers are presented hereinafter for comparison reasons with respect to the above described tensile stress sensors. The pressure sensor is illustrated in Fig. 5. Applying pressure or force on a part of the MDL between the excitation and the sensing points, distorts the propagating elastic signal. [13]. Such a response is illustrated in Fig. 6. This result is similar with the results obtained in positive magnetostrictive wires. This is expected, since the MDL, in this case, operates just as an acoustic waveguide.

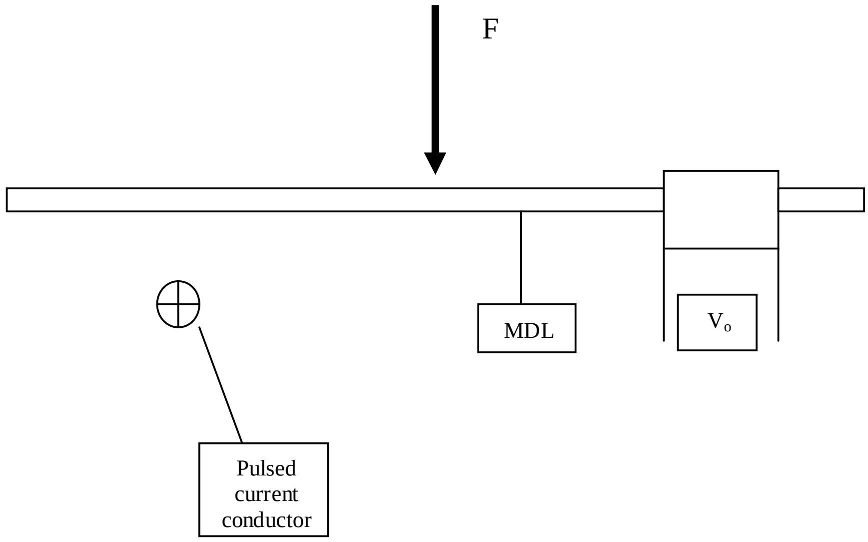

Fig. 5. A pressure gauge MDL set-up.

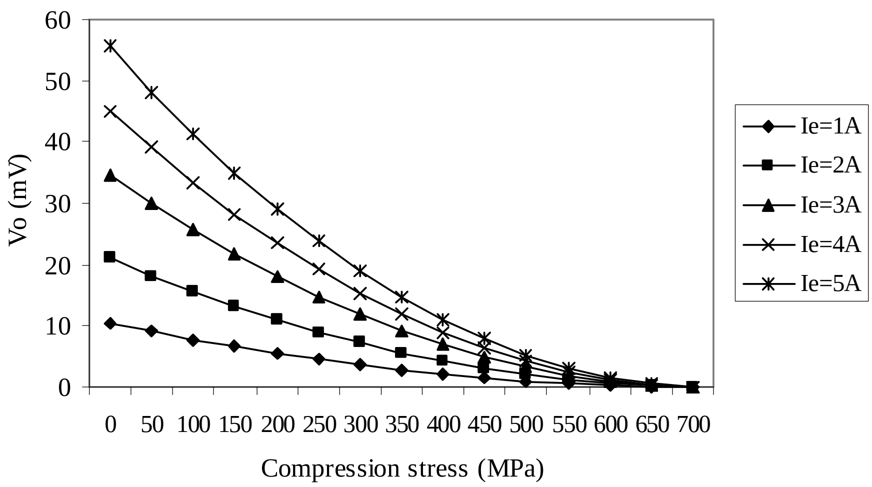

Fig. 6. Response of the pressure gauge MDL set-up using a flash current annealed MDL.

The force digitizer [14] is illustrated in Fig. 7, and its corresponding response in Fig. 8. These results are also well expected as in the sensor of Fig. 5.

3. Discussion

In all these measurements the noise level was significantly lower than in the case of positive magnetostrictive elements. The decrease in the sensitivity observed by increasing the excitation pulsed field is due to the magnetic and magnetoelastic saturation of both sensing core and MDL, in accordance to the λ(H) function of the under test elements. This sensitivity can be generally increased with appropriate treatment of the material and is usually optimized after flash current annealing.

The noise level of the negative magnetostrictive delay lines was measured to be significantly lower, compared to the positive magnetostrictive delay lines. This can be explained by the fact that Barkhausen jumps have a minor contribution to the magnetostriction and the corresponding generated and propagated elastic strains. This means that microstrains are generated mainly due to the rotation of magnetization rather than the sudden change of magnetization towards a closer easy anisotropy axis.

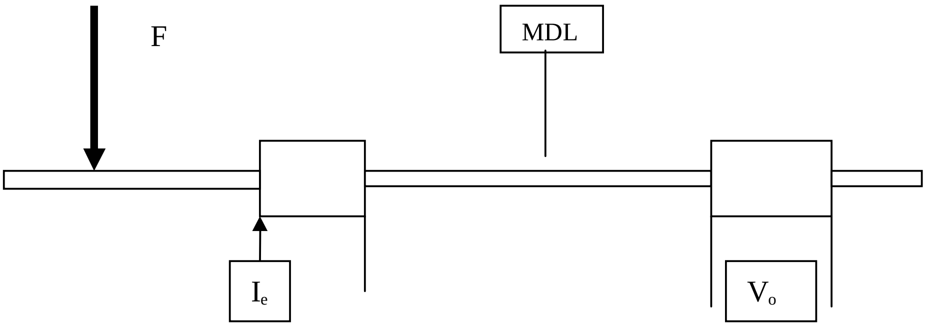

Fig. 7. A force digitizer MDL set-up.

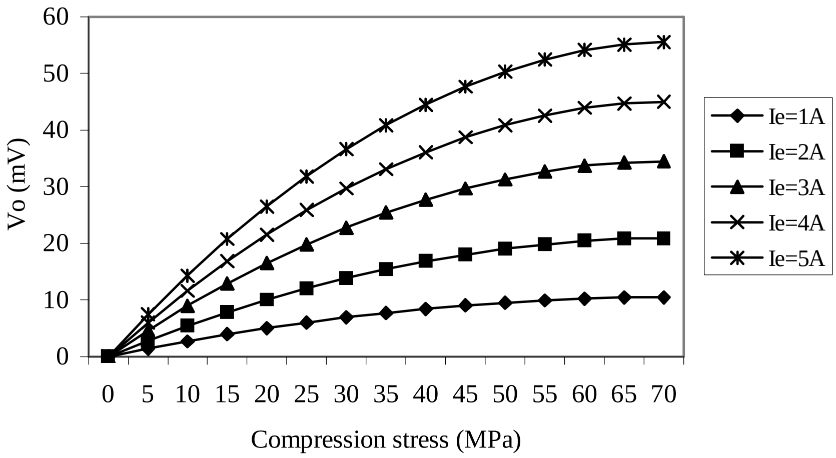

Fig. 8. Response of the force digitizer MDL set-up using a flash current annealed MDL.

Additionally, flash current annealing seems to offer an improvement of the magnetoelastic response in the negative magnetostrictive delay lines, compared not only to the as cast MDLs but also to the stress relieved ones. This may be explained due to the induced circumferential magnetic anisotropy caused by the flash current transmitted through the MDL. In fact, negative magnetostrictive ribbons and wires prefer to have such a normal or circumferential anisotropy respectively, which is aided or amplified by the flash current annealing through the sample.

Furthermore, it is observed that the first two kinds of stress sensors suffer from lack of sensitivity with respect to the same sensors using positive magnetostrictive elements. This drawback is overcome by the lower noise of the negative magnetostrictive elements, which in fact offer a similar level of uncertainty for the sensor.

In the contrary, the lower noise of negative magnetostrictive elements compared to the positive magnetostrictive ones together with their similar levels of sensitivity offer a significant advantage in pressure gauge and force digitizer applications.

From the above mentioned experiments, it can be seen that when tensile stress is applied along the anisotropy axis (length) of the MDLs or the sensing elements, the signal output increases instead of decreasing as measured in the case of positive magnetostrictive elements. This is in agreement with the fact that tensile stress causes rotation of magnetic dipoles towards the applied stress or orthogonal to it for the case of positive and negative magnetostrictive elements. This means that magnetic dipoles oppose the applied stress. Therefore, using negative magnetostrictive elements and fixing their ends in order to be used as acoustic waveguides or sensing cores, sudden or non-expectable stresses along their length cannot result in a large decrease of their magneto-elastic coupling factor and the MDL response respectively, as for the case of positive magnetostrictive elements.

4. Conclusions

Results are presented illustrating the response of MDL sensors using negative magnetostrictive alloy ribbons. From these results it was concluded that tensile stress sensors based on negative magnetostrictive elements offer less sensitivity but much better uncertainty, which is preferable for repeatable sensor applications. For pressure sensing applications, taking into account that both positive and negative magnetoelastic elements achieve comparable performance, negative magnetostrictive cores have the benefit of easier handling and housing, because they are fairly immune to random tensile stresses along their length.

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